Industry 4.0 Technology, Employee Skill Development and Performance of Construction Companies, Southwest Nigeria

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2024

Certification

This is to certify that this thesis **"Industry 4.0 Technology, Employee Skill Development and Performance of Construction Companies, Southwest Nigeria"** was carried out by **Oluyinka Soloman ADEKUNLE,** with Matriculation number **LCU/PG/003226,** in the Department of Management & Accounting under my thorough supervision in the Faculty of Management and Social Sciences, Lead City University, Ibadan, Nigeria and that this work had not been previously submitted.

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Dedication

This thesis is dedicated to Almighty God.

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I return all glory to Almighty God, whose grace has made this academic achievement possible. To Him belongs all the glory. I wish to express my profound gratitude to Lead City University, Ibadan, Nigeria for the opportunity given me to undergo this degree. I appreciate the Vice-Chancellor of the University, Professor K.A. Adeyemo, Provost, Postgraduate College, Prof. A.O. Oredein, Heads of Departments, Lecturers and other non-academic staff members of the University.

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“Even though the above institutions and persons have assisted in the process of this research work, I alone stand responsible for the errors, if any found in this work”.

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Abstract

This study examined the impact of Industry 4.0 technologies on organizational performance within the construction sector in Southwest Nigeria, particularly focusing on the Internet of Things (IoT), Building Information Modeling (BIM), Artificial Intelligence (AI), and 3D technology. Industry 4.0 offers solutions to long-standing construction challenges by enabling efficiency, cost management, quality, and timely project delivery. This research explored the moderating effect of employee skill development on the relationship between Industry 4.0 and organizational performance, proposing six hypotheses. Utilizing a mixed-method approach, data were gathered from 90 respondents across five major construction companies and analyzed with linear regression to test each hypothesis. Results indicate significant relationships for most hypotheses. Hypothesis One demonstrated that IoT significantly improves operational efficiency ($R = 0.663$, $R^2 = 0.440$; $F(3,184) = 47.403$, $p < 0.01$), explaining 44% of the variance, with a positive coefficient ($\beta = 0.230$, $t = 4.272$, $p < 0.01$). Hypothesis Two revealed that BIM positively affects project delivery time, though with moderate influence ($R = 0.250$, $R^2 = 0.063$; $F(3,184) = 4.035$, $p < 0.01$), accounting for 6.3% of variance and a coefficient ($\beta = 0.229$, $t = 2.459$, $p < 0.05$). Hypothesis Three shows AI as a substantial predictor of cost management ($R = 0.740$, $R^2 = 0.548$; $F(3,184) = 73.155$, $p < 0.01$), explaining 54.8% of variance, and an impactful coefficient ($\beta = 0.146$, $t = 3.118$, $p < 0.05$). For Hypothesis Four, results indicated that 3D technology significantly improves project quality ($R = 0.345$, $R^2 = 0.339$; $F(3,184) = 8.132$, $p < 0.01$), accounting for 33.9% of quality variation, underscoring its role in enhancing accuracy and reducing rework. Hypothesis Five analysis highlights that AI ($\beta = 0.677$, $t = 2.133$, $p < 0.05$) and 3D technology ($\beta = 1.374$, $t = 4.070$, $p < 0.05$) have a significant positive effect on organizational performance, whereas IoT and BIM are positively but insignificantly related. This model explains 54.3% of the variance in performance ($R = 0.751$, Adj. $R^2 = 0.543$; $F(4, 89) = 27.911$, $p < 0.05$), emphasizing the importance of AI and 3D technology as key contributors to performance. Hypothesis Six findings from hierarchical regression show that employee skill development significantly moderated the relationship between Industry 4.0 and organizational performance (R^2 change = 0.009, F-change = 5.665, $p < 0.01$). This moderation suggested that upskilling and reskilling amplify the beneficial effects of advanced technologies. In conclusion, Industry 4.0 technologies play a critical role in enhancing construction efficiency, cost management, quality, and timeliness. The study recommends that Nigerian construction firms invest in these technologies and employee training to maximize performance. Implementing IoT, BIM, AI, and 3D technology alongside workforce upskilling is essential for leveraging Industry 4.0's full potential. Future research should investigate the long-term impact of these technologies and explore emerging innovations like advanced AI applications and robotics.

Keywords: Artificial Intelligence (AI), Building Information Modeling (BIM), Construction Sector, Industry 4.0, Internet of Things (IoT)

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List of Acronyms

Abbreviation	Meaning
GDP	Gross Domestic Product
CAGR	Compound Annual Growth Rate
AAGR	Annual Average Growth Rate
IoT	Internet of Things
AI	Artificial Intelligence
4IR	Fourth Industrial Revolution
BIM	Building Information Modeling

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Chapter One

Introduction

1.1 Background of the Study

The construction industry constitutes a significant sector that promotes the economic development of any nation. This sector provides residential, commercial and infrastructure facilities in every nation. The construction industry significantly enhances people's and communities' overall well-being and living conditions by offering amenities such as residential accommodations, educational institutions, healthcare facilities, and communal areas.

The industry stands as a cornerstone of economic development globally, contributing significantly to GDP and providing essential infrastructure that supports other sectors. In essence, it is a driver of societal welfare and economic stability by creating residential, commercial, and infrastructural facilities that serve communities and economies likely, construction is one of the largest industries, with its value projected to grow from $8.2 trillion in 2022 to an estimated $17 trillion by 2029, reflecting a compound annual growth rate of 7.3%. This growth underscores the industry's role in driving employment and supporting a host of ancillary sectors, such as manufacturing, engineering, and real estate. For instance, United States, the industry’s contribution to the GDP is roughly USD 1.7 trillion, or 5–7% of the total economy, demonstrating its critical role in maintaining economic equilibrium and development[1,2].

Notably, the industry also plays a vital role in achieving Sustainable Development Goals (SDGs) through the adoption of green and sustainable construction practices, enhancing its global importance. However, despite this, the construction industry faces significant

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challenges. These include fluctuating costs, skill shortages, delayed project timelines, and, more recently, the impacts of global events like the COVID-19 pandemic that have disrupted supply chains and intensified labor shortages. Furthermore, the construction industry is experiencing a major transformation through the integration of Industry 4.0 technologies, including IoT, AI, Building Information Modeling (BIM), and 3D printing. These advancements hold the potential to fundamentally reshape traditional construction processes by boosting operational efficiency, cutting costs, and enhancing project coordination and accuracy. However, transitioning to these technologies presents challenges. High upfront costs, complex implementation demands, and the need for a skilled workforce capable of managing these advanced tools remain considerable obstacles[3,4].

In regions like Nigeria, where the construction mix of indigenous and international firms, these challenges are compounded by additional factors such as regulatory constraints, the need for infrastructure investments, and the rapidly expanding urban population. The Nigerian construction sector, valued at approximately $135.9 billion in 2022, continues to grow, driven by demand for housing and infrastructure development. However, the sector still contends with cost management issues, delays, and the complexities introduced by integrating new technologies[5,6,7].

Globally, the construction industry plays a significant role in the development of nations, but achieving sustainability and improving performance remains a common challenge across developed, emerging, and developing economies due to the dynamic business environment in which construction companies operate. The rapid pace of global urbanization, population growth, climate change, pandemics, and conflicts have put built environments under scrutiny. European countries like the UK, Germany, France, Belgium,

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and Switzerland have observed fluctuations in operational efficiency and project timelines, further strained by the impact of the COVID-19 pandemic[8,9].

The shift towards trends like digitalization and green building has greatly influenced the sector's workforce needs, impacting both skilled and unskilled labor. The industry has also faced setbacks due to the pandemic, with widespread consequences that affected project delays, material shortages, and reduced productivity. The construction sector was valued at $8.2 trillion in 2022 and is projected to reach $17 trillion by 2029, growing at a 7.3% compound annual growth rate (CAGR). However, construction firms face numerous challenges that could hinder this growth, including quality management issues, Industry 4.0 integration, economic uncertainties, safety concerns, and supply chain disruptions[10,11].

In the UK, factors such as pricing, lead time, sustainability practices, and strategic frameworks influence construction performance, while rising inflation and energy prices have escalated material costs and contributed to project delays. Similarly, in China, the construction industry faces challenges related to immature technical standards, limited cost-saving potential from technological innovation, and fragmented industry relationships. Additionally, issues such as declining energy productivity, a constrained innovation environment, and early-stage industrialization hinder sustainable development efforts. Addressing these challenges requires a focus on innovation, strategic planning, and optimized energy consumption to improve the industry's competitiveness and performance[12].

The construction industry in Nigeria is recognized as one of the largest and most vibrant in Africa, with a market composition of 78% indigenous enterprises and 22% international firms. In recent years, this industry has outpaced many other sectors in the Nigerian economy and is projected to maintain steady growth from 2020 to 2030. As of

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2022, the Nigerian construction market was valued at $135.9 billion and is expected to grow at an Annual Average Growth Rate (AAGR) exceeding 2% from 2024 to 2027[13,14]. This growth is driven by investments across key sectors, including transportation, energy, water and sewage, and housing projects.

The construction sector in Nigeria is known for its vibrancy and is considered one of the biggest in Africa. The composition of the construction market in Nigeria consists of 78% indigenous enterprises and 22% international firms[15]. In recent years, the Nigerian construction industry has seen substantial growth, surpassing the majority of other sectors within the local economy. It is anticipated that the industry will sustain a consistent development trajectory between the years 2020 and 2030. The construction market in Nigeria was assessed to be $135.9 billion in 2022. It is projected to experience an Annual Average Growth Rate (AAGR) of over 2% from 2024 to 2027[16]. This growth is anticipated due to investments in several sectors, such as transportation, energy, water and sewage, and housing projects. The construction industry in Nigeria holds immense significance for the nation's economic development and social progress[17]. The construction industry is a significant contributor to GDP and a catalyst for advancing infrastructure, generating employment opportunities, and stimulating economic expansion[18].

The construction sector in Nigeria is of immense importance to the nation’s economic and social development. It is a notable contributor to Nigeria's GDP and a catalyst for infrastructure advancement, job creation, and economic expansion. Factors such as urbanization and government initiatives further promote the growth of this industry, which plays a crucial role in meeting the demands of Nigeria's large and rapidly growing population. The industry also faces competitive pressures, tight schedules, complex

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projects, and challenges associated with Industry 4.0, including the need for technological adoption and skilled labor development to enhance efficiency, transparency, and sustainability in construction and infrastructure[19].

The performance of Nigeria's construction industry has been marked by significant growth and transformation in recent years, contributing substantially to the nation's economy and infrastructure development. As one of the largest and most dynamic sectors in Africa, the industry has played a pivotal role in driving GDP growth, employment, and urban development. Despite the challenges, it has shown resilience, reflecting the demands of Nigeria's rapidly expanding population and urbanization trends[20].

The Nigerian construction industry has undergone significant development and change, reflecting the nation's evolving economic and infrastructure requirements. As Africa's most populous nation, Nigeria's construction industry plays a vital role in fostering economic growth and meeting the needs of its rapidly expanding population[21]. Numerous factors, such as urbanization and government initiatives, have contributed to developing the Nigerian construction industry[51]. Despite this growth, the construction industry is characterized by competitive pressures, stringent schedules, complex projects, design errors, unfavourable site conditions, changing project cost and other project modifications[22]. These challenges have led the construction industry to engage in a substantial transformation with ongoing initiatives to enhance efficiency, transparency, and sustainability in construction and infrastructure development due to the Fourth Industrial Revolution[23].

The fourth industrial revolution as known as industry 4.0 adopts cutting-edge technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), 3D technology and Building Information Modelling are to fundamentally transform

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conventional construction procedures[24,25,26]. These technological advancements provide the potential for heightened operational effectiveness, decreased expenditures, improved project coordination, and the capacity to undertake intricate construction endeavours with heightened accuracy and swiftness[27,28]. The utilization of Industry 4.0 technologies holds considerable promise in terms of its potential to influence the operational outcomes of construction companies significantly. This influence extends to various aspects, including financial stability, efficiency in project delivery, safety records, and customer satisfaction. However, the rapid advancement of technology poses a significant challenge in preparing workers and enhancing their capacity to adapt to new technologies to achieve improved performance within the construction business[29].

Skill development is of utmost importance in the construction industry as it significantly impacts performance by increasing efficiency, safety, and the overall success of projects. A skilled workforce is essential in the construction industry, given its dynamic and intricate nature, to ensure compliance with rigorous safety regulations and complete intricate tasks. Well-trained professionals bring expertise to various construction tasks, ensuring that projects are executed with precision and meet industry standards. This not only enhances the overall structural integrity but also enhances the durability and security of structures. Also, skill development fosters adaptability and innovation. In an era of technological advancements and changing construction techniques, a workforce equipped with contemporary proficiencies can readily adopt novel technologies and methodologies, resulting in enhanced efficiency and reduced expenses. The maintenance of adaptability to industry advancements is a critical factor for construction professionals, as it empowers them to integrate sustainable practices and maintain a competitive edge over market trends[30,31,32].

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Multiple studies have shown that integrating Industry 4.0 technology is essential for the construction sector[33,34,35]. While there have been some studies regarding the impact of integrating Fourth Industrial Revolution (4IR) technologies on the overall performance of organizations within the context of the Nigerian construction industry the pivotal significance of employee skill development as a moderating variable remains inadequately explored. Examining the moderating impact of employee skill development may provide valuable insights into how worker skills influence the results of implementing Construction 4.0, bolstering competitiveness and sustainability within the construction sector.

The industry's performance can be assessed through key metrics such as operational efficiency, project quality, and timely project completion. Operational efficiency is critical for sustainable business growth, as it ensures continuity and cost-effectiveness. Quality is also a core performance metric, as it guarantees adherence to safety protocols and project durability, reducing the need for costly repairs and enhancing the sector's reputation. Project timelines further reflect industry credibility and facilitate faster returns on investment, supporting continuous economic activity[36].

Nigeria's construction industry has consistently outpaced several other sectors, growing at an average annual rate of 9% over recent years, fueled by large-scale government and private sector projects in infrastructure, housing, and energy. The sector's contribution to the GDP has grown steadily, with a market value of approximately $135.9 billion in 2022. Projections indicate a stable Annual Average Growth Rate (AAGR) of over 2% from 2024 to 2027, driven by increased investments in essential infrastructure, including transportation, water, sewage systems, and housing[37]. The construction industry is a significant source of employment in Nigeria, providing jobs across various skill levels. It

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supports both skilled and unskilled labor, creating opportunities for engineers, architects, surveyors, masons, carpenters, and laborers. This aspect is particularly critical in Nigeria, where unemployment rates remain high. By generating employment, the sector contributes not only to economic growth but also to social stability[38].

One of the main drivers of growth in Nigeria's construction industry is the demand for infrastructure to support urbanization and population growth. Projects in road networks, bridges, airports, and housing have bolstered the sector's performance. Investments in infrastructure enhance the quality of life for Nigerian citizens, providing essential services like transportation, healthcare facilities, and educational institutions. Such developments are aligned with Nigeria's broader goals of achieving Sustainable Development Goals (SDGs) and creating a more equitable and accessible living environment[39].

The construction industry in Nigeria, while pivotal to economic growth, faces a number of challenges that hinder its performance. The incorporation of emerging technologies such as Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Building Information Modeling (BIM), and 3D technology could significantly improve the sector's performance. However, there are several obstacles impeding their successful adoption and the overall development of the industry. The industry experiences significant competition both from indigenous and international firms. Projects are often complex, requiring coordination between various stakeholders, which can lead to inefficiencies, miscommunication, and delays in execution. Changes in project specifications, unforeseen site conditions, and fluctuating material costs lead to cost overruns[40]. Schedule delays are also common, resulting in a delayed return on investment and reduced project credibility. Errors in initial designs, coupled with inconsistent adherence to quality standards, impact the final output of projects. This undermines the durability and

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reliability of structures, leading to costly repairs and lower industry credibility. Bureaucratic inefficiencies, unclear regulations, and inadequate enforcement contribute to delays and increased costs in the industry. While the adoption of Industry 4.0 technologies has the potential to transform the Nigerian construction industry, several challenges prevent their full integration. The high cost of acquiring and implementing cutting-edge technologies such as AI, IoT, BIM, and 3D technologies is a major barrier for many construction firms, particularly smaller businesses that may lack the financial resources to invest in these innovations[41].

The Nigerian construction industry faces a significant skills gap, especially in relation to digital tools and modern construction methods. The workforce needs training in new technologies, and the lack of skilled labor is a significant challenge for the effective adoption of Industry 4.0 technologies. There is often resistance to adopting new technologies in established industries, especially among older generations of construction professionals who may be unfamiliar or uncomfortable with digital tools and automation. While IoT offers the potential to improve construction processes through real-time data collection and automation, the Nigerian construction industry faces issues such as insufficient infrastructure (e.g., unreliable internet connections) and limited awareness of how to fully utilize IoT devices for project management, asset tracking, and predictive maintenance. BIM is still in its infancy in the Nigerian construction industry[42]. The lack of skilled professionals capable of implementing BIM technologies, combined with insufficient knowledge about the full scope of BIM's benefits, impedes its widespread adoption. The technology also requires significant upfront investment, which is a challenge for firms with limited resources. AI has the potential to optimize construction project management, enhance design processes, and predict issues before they arise. However, the implementation of AI in Nigeria's construction sector is hindered by the

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high cost of AI technologies, as well as the limited availability of AI expertise in the country. There is also skepticism about the ability of AI to perform in complex, unpredictable environments, which is typical in construction projects. 3D printing in construction has the potential to reduce material waste, speed up construction processes, and lower costs. However, its adoption in Nigeria is limited by high capital costs, insufficient technological infrastructure, and the need for specialized training. Additionally, there are challenges in sourcing the appropriate materials for 3D printing in construction[43,44,45].

The Nigerian construction industry often faces shortages of construction materials, which can lead to project delays and cost overruns. The lack of a stable and reliable supply chain contributes to these shortages, especially in remote areas. Frequent power outages and unreliable utilities can disrupt construction activities, particularly when implementing technology that requires stable electricity or network connectivity. The integration of digital technologies in construction raises significant cybersecurity concerns[46]. The implementation of IoT devices, AI, and BIM introduces the risk of cyberattacks, data breaches, and unauthorized access to sensitive project data. Construction companies in Nigeria are yet to fully develop effective cybersecurity measures to safeguard their digital assets. Despite advancements in construction technology, the sector still faces significant safety issues, including accidents at construction sites[47]. The adoption of new technologies such as AI and IoT could improve safety monitoring, but implementing these technologies effectively requires skilled personnel and consistent training. The construction industry in Nigeria, like many others, struggles with sustainability issues. While technologies such as BIM and AI can contribute to more sustainable building practices, the industry is often more focused on short-term profitability than on long-term environmental impact. Additionally, the lack of policies promoting green building

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practices limits the industry's sustainability efforts. Inefficient waste management practices in the Nigerian construction industry contribute to environmental degradation. The adoption of 3D printing and other waste-reducing technologies could alleviate this, but these practices are still in the early stages of implementation[48,49,50].

The Nigerian construction industry faces several critical challenges that hinder its overall performance, ranging from cost and schedule overruns to inadequate technology adoption. While Industry 4.0 technologies such as IoT, AI, BIM, and 3D printing hold the potential to revolutionize the sector, their integration is impeded by high implementation costs, skill gaps, resistance to change, and infrastructure limitations. Addressing these challenges requires significant investments in workforce development, infrastructure improvement, and the adoption of supportive policies that facilitate the integration of modern technologies into the industry[51].

Against this background, this study will examine the impact of Industry 4.0 Technology components on the organizational performance of the selected construction enterprises in Southwest Nigeria.

1.2 Statement of the Problem

The construction industry in Southwest Nigeria is currently at a crucial stage in the face of the high expectation of its stakeholders which has cessecitated the need for adoption of Industry 4.0 technologies such as the Internet of Things (IoT), artificial intelligence (AI), 3D technology, and Building Information Modelling (BIM) to improve their outcomes . These technologies hold the potential to significantly enhance operational efficiency, reduce project delivery times, improve cost management, and ensure higher quality of work. However, the successful implementation of these technologies is heavily dependent on the skill set of the workforce, which currently exhibits a significant gap.

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Studies have indicated that the building process has the potential to be transformed by the technologies of three-dimensional printing (3D) and modelling, which have the ability to increase the precision of design and decrease the quantity of material waste[52,53]. Inefficiencies and increased expenses associated with project execution are the ultimate consequences of a lack of proficiency with 3D technology[54]. Building Information Modelling, or BIM, is an acronym for construction information modelling. Extant literature has shown that BIM is a technology that helps encourage comprehensive project visualisation and cooperation among stakeholders in the building industry all over the world[51,53,55]. However, the insufficient training in BIM technologies can have a detrimental influence not only on the quality of work but also on the coordination of projects[56].

These developments are hampered by the current skill gaps among the workforce, which results in suboptimal operational performance. However, the effective implementation of technologies related to Industry 4.0 has the potential to improve operational efficiency[57]. Technology that is at the cutting edge of development is painstakingly developed in order to speed up project schedules. However, workers without the skills to use these technologies face challenges. Successful implementation of Industry 4.0 technology has the potential to achieve significant cost savings. However, the disparity in skills leads to higher project costs because of inefficiencies and errors brought on by inefficient performance. One of the most important factors that determines the quality of building projects is the level of competence that staff has in the use of cutting-edge technology. However, insufficient skills lead to a decrease in the quality of work, and there is a risk that tasks will need to be at their best[58].

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The existing skill gap among employees significantly challenges the integration of Industry 4.0 technologies in the construction industry of Southwest Nigeria. To enhance the performance of construction companies, it is imperative to focus on comprehensive employee skill development programs that enable the effective use of IoT, AI, 3D technology, and BIM.

1.3 Aim and Objectives of the Study

This study aims to examine the effect of Industry 4.0 technology on the organizational performance of construction companies in Southwest Nigeria, with employee skill development as the moderating variable. The specific objectives include to:

i. assess the effect of the Internet of Things (IoT) and on Operational efficiency of selected construction companies in Southwest Nigeria

ii. investigate Building Information Modelling (BIM) influence on the Project Delivery Time of selected construction companies in Southwest Nigeria.

iii. examine the influence of Artificial Intelligence on Cost Management of selected construction companies in Southwest Nigeria

iv. examine how 3D technology affect the quality of work of selected construction companies in Southwest Nigeria.

v. Investigate the influence of industry 4.0 dimensions on organizational performance of the selected construction companies in Southwest Nigeria.

vi. establish the moderating effect of employee skill development on the relationship between industry 4.0 technologies and organizational performance of the selected construction companies in Southwest Nigeria.

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1.4 Research Questions

To achieve the overall aim and objectives of this research, the study raised the following research questions:

1 What is the effect of the Internet of Things (IoT) on efficiency of operations of the selected construction companies in Southwest Nigeria?

2 How does Building Information Modelling (BIM) influence on the Project Delivery Time of selected construction companies in Southwest Nigeria.

3 Does Artificial Intelligence (AI) Influence Cost Management of selected construction companies in Southwest Nigeria

4 What is the effect of 3D technology on the Project Quality of selected construction companies in Southwest, Nigeria.

5 How does Industry 4.0 affect organizational performance of the selected construction companies in Southwest, Nigeria

6 What is the moderating effect of employee skill development on the relationship between industry 4.0 technologies and organizational performance of the selected construction companies, Southwest, Nigeria.

1.5 Hypotheses

The following hypotheses were formulated upon which this study was anchored:

Ho1: There is no significant effect between Internet of Things (IoT) on Operational Efficiency Selected Construction Companies in Southwest Nigeria.

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Ho2: There is no significant effect between Building Information Modelling and Project Delivery Time of Selected Construction Companies, Southwest Nigeria.

Ho3: There is no significant relationship between Artificial Intelligence and Cost Management of Selected Construction Companies, Southwest Nigeria.

Ho4: There is no significant relationship between 3D technology and Quality of Work among Selected Construction Companies in Southwest Nigeria.

Ho5: There is significant effect between Industry 4.0 and organizational performance of the selected construction companies in Southwest Nigeria

Ho6: Employee Skill Development has no moderating effect on the interaction between Industry 4.0 Technology and Organizational Performance of Selected Construction Companies in Southwest Nigeria.

1.6 Significance of the Study

The persistent quest for the adoption of industry 4.0 by various stakeholders have made the need for this empirical research timely and significant. The pace of empirical studies on the effect of industry 4.0 technology, employee skill development, especially, in the performance of construction companies in Nigeria is still at a low ebb. Therefore, this study will be relevant to diverse stakeholders: the academic, policy makers, project managers, the industries and the society at large.

This study Industry 4.0 will be of significant importance for stakeholders across various sectors in to enhance efficiency, productivity, innovation, and competitiveness particularly among the construction companies in Nigerai. By embracing these technologies and adapting to the changing landscape, businesses, customers, employees,

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and governments can reap the benefits of the fourth industrial revolution. The stakeholders will also reap the gains of advanced technologies enable greater precision and control in construction processes, resulting in higher-quality products and reduced delivery time.

The findings will provide industry policymakers with insights, knowledge, and a deeper understanding of these technologies, fostering an environment that encourages innovation, boosts efficiency, and promotes sustainability within the construction sector. Moreover, the adoption of automation technologies has the potential to enhance construction workflows, lower labour expenses, and boost overall efficiency. Employing cutting-edge materials and construction techniques has the potential to expedite project schedules and minimise waste. Furthermore, the development of digital replicas of construction projects facilitates enhanced planning, coordination, and risk management, resulting in superior safety and quality outcomes.

The result of the empirical studies on Industry 4.0 technology, employee skill development and performance of construction companies**,** is still as at nascent stage in Nigeria. Therefore, this study will contribute immensely in advancing the academic and research framework on Industry 4.0 technology, employee skill development and performance of construction companies: in concept and model, the construct, its dimensions and domains, its antecedents. Equally, it will fill the identified gaps in literature especially in the area of the application of Industry 4.0 concepts to performance in the construction conpanies and models to specific research in the construction industries within Nigeria. Lastly, the study will be of benefit to academia as the study will contribute to extant literature and serve as reference point to further studies in the area of research and advancement of knowledge.

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The study's significance also resides in its ability to improve the skills and knowledge of the Nigerian workforce. Industry 4.0 technologies necessitate a proficient workforce adept at handling and maintaining sophisticated equipment. This research identified skill gaps and offer solutions to solve them, including education, training, and capacity building. This would enhance the quality of work in the construction sector and generate employment possibilities in technology-driven domains, hence fostering human capital development in Nigeria.

This study is essential in influencing the future direction of Nigeria's building industry during the global industrial revolution. As global firms embrace Industry 4.0 technology, Nigeria must implement these innovations to maintain competitiveness internationally. This study will provide a roadmap for the digital transformation of the construction industry in Nigeria by analysing the potential of these technologies to revolutionise construction processes. This will ensure that Nigeria's construction sector is equipped to address the needs of a swiftly changing technical environment, while also enhancing the nation's overall development and worldwide competitiveness.

This study concludes that the adoption of Industry 4.0 technologies by construction companies will have a significant positive significant impact on society in various ways. For instance, these technologies can streamline construction processes, resulting in faster project completion and fewer disruptions to communities. Construction companies can enhance the quality and safety of their projects, reduce the likelihood of accidents, and construct more durable infrastructure. By incorporating environmentally friendly materials and energy-efficient designs, construction practices are becoming more sustainable. The adoption of Industry 4.0 technologies is creating jobs in fields such as data analytics, software development, and robotics. The construction sector is a major driver of economic growth, and Industry 4.0 adoption can help this industry even more.

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High-quality infrastructure can enhance the quality of life for citizens by providing better access to transportation, housing, and essential services. Ultimately, the recommendations from this study will guide stakeholders in sustainable construction knowledge towards generating ideas that protect the natural environment, benefiting society as a whole.

1.7 Scope of the Study

This study is focused on the interaction between Industry 4.0, employee skill development, and organizational performance of construction companies in Southwest Nigeria. The study explored the concept that includes industry 4.0 (independent variable), measured using artificial intelligence, robotics, 3D Printing, augmented and virtual reality, machine learning, Internet of Things (IoT), and Building Information Modelling (BIM). On the other hand, the organization performance of construction companies (dependent variable) was measured using productivity, profitability, project quality, customer satisfaction and project completion time. The moderating variable of the study is the employee skill development measured by reskilling and upskilling.

This study was conducted in Southwest Nigeria. The Southwest region has six (6) States. However, Lagos, Ogun, Osun and Ekiti states was be central focus of this study. The choice of Lagos, Ogun, Osun, and Ekiti states for this study on Industry 4.0 and construction industry performance in Southwest Nigeria is strategic. Lagos, as Nigeria's commercial hub, is highly developed, showcasing advanced construction activities and significant Industry 4.0 integration. Ogun and Osun offer a blend of urban and semi-urban environments, providing insight into how Industry 4.0 technologies are adopted in varying infrastructure settings. Ekiti represents a more rural state, enabling the study to capture diverse regional experiences and challenges in adopting advanced technologies. Together, these four states provide a comprehensive overview of Industry 4.0's impact on

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construction in different socio-economic contexts, enhancing the generalizability and relevance of the study's findings. Five (5) construction firms; China Civil Engineering Construction Corporation, Reynolds Construction Company, Hitech Construction Company Limited, Setraco Nigeria Limited, and Kopek Construction Limited will be accessed as case studies for this study.

1.8 Limitation of the Study

This study on the impact of Industry 4.0 Technology, Employee Skill Development and Performance of Construction Companies, in Southwest Nigeria faces certain limitations. First, it focuses specifically on four states—Lagos, Ogun, Osun, and Ekiti—within the Southwest region. This geographical scope may limit the generalizability of the findings to other regions in Nigeria where construction industry dynamics may differ due to varied local factors.

The selection of companies is another limitation. The study focuses on a few large firms, such as China Civil Engineering Construction Corporation, Reynolds Construction Company, Hitech Construction Company Limited, Setraco Nigeria Limited, and Kopek Construction Limited, potentially excluding insights from smaller, local construction companies. These smaller firms may have unique experiences or face different challenges in implementing Industry 4.0 technologies, thus limiting the diversity of perspectives in the findings.

Additionally, this study examines specific dimensions of Industry 4.0—namely Artificial Intelligence (AI), the Internet of Things (IoT), Building Information Modelling (BIM), and 3D technology—which, while impactful, do not encompass all Industry 4.0 tools available to the construction industry. This narrow focus may overlook the broader

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implications of Industry 4.0 advancements, such as augmented and virtual reality or machine learning, that could also affect performance outcomes.

Despite these limitations, they do not detract from the credibility and authenticity of the study. The rigorous methodology, well-defined scope, and targeted data collection techniques ensure that the findings provide valuable and reliable insights into the effects of Industry 4.0 technologies on the performance of construction companies in the Southwest region. Future research could expand on these findings by including additional regions, companies of varying sizes, and a broader set of Industry 4.0 technologies to further enrich understanding in this field.

1.9 Operational Definition of Terms

3D Technology: This refers to a technological method of creating or viewing objects in a way that makes them appear to have depth, making them look more realistic and life-like, as if you could reach out and touch them.

Artificial Intelligence (AI): An area of computer science that concentrates on developing systems that through the use of algorithms and data analysis, are capable of conducting tasks that ordinarily require human intelligence, such as problem-solving, learning, and decision-making.

Building Information Modelling (BIM): A digital representation of the functional and physical characteristics of a building. By integrating data pertaining to design, construction, and operation, it enhances project management and maintenance and facilitates collaboration among stakeholders.

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Construction Industry: This encompasses the collective enterprises involved in constructing, modifying, and maintaining infrastructure, including companies, contractors, and firms that provide services in building, engineering, and industrial projects.

Construction: This refers to the process of planning, designing, and building infrastructure and facilities, including residential, commercial, and industrial structures.

Employee Skill Development: Enhancing the knowledge, skills, and competencies of employees through training, education, and professional development programmes. It seeks to enhance job efficacy and professional development.

Industry 4.0 Technologies: A collection of advanced technologies and concepts, such as IoT, A.I., robotics, and automation, implemented in manufacturing and industry to increase efficiency, connectivity, and productivity.

Industry 4.0: The fourth industrial revolution, characterized by the incorporation of digital technologies, automation, data exchange, and advanced manufacturing techniques across multiple industries.

Internet of Things (IoT): A network comprising interconnected physical objects or devices capable of communicating and exchanging data via the internet, facilitating automation and remote monitoring.

Off-the-job training refers to a form of education occurring outside an individual's standard work hours.

On-the-job training (OJT): refers to pragmatic, enabling employees to acquire practical experience in authentic environments while receiving guidance from seasoned mentors.

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Organizational Performance: The evaluation of a construction company's effectiveness, efficiency, and competitiveness via the analysis of key performance indicators (KPIs) including profit margin, project completion time, client satisfaction, and quality of work.

Productivity: A measure of efficacy and output in a particular context, typically represented as the ratio of output (goods or services produced) to input (resources, time, labour, etc.) within a specified timeframe.

Profitability: A measurement of a company's ability to generate profits from its operations, typically calculated as the ratio of net profit to revenue (revenue minus expenditures).

Project Completion Time: The amount of time required to finish a project from start time to end date.

Project Quality: The extent to which a project's deliverables meet established quality standards and satisfy customer or stakeholder needs.

Reskilling: refers teaching employee's new skills so they can transfer to different jobs within the same company.

Robotics: The design and construction of devices, or robots, capable of perceiving their surroundings, processing data, and performing tangible actions. Tasks can be executed autonomously or under human control.

Upskilling: focuses on enhancing existing skills to advance employees' careers or improve their performance in their current roles.

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Chapter Two

Literature Review

This section contains four sections. The first section explores conceptual clarification of key concept of the research, the second section traverse the theoretical review underlying the research concept, the third section reviewed empirical studies and the fourth section review summary of gaps in literature reviewed.

2.1 Conceptual Review

2.1.1 Construction Industry

The construction industry incorporates the whole construction process, starting with the production of raw and manufactured building materials, and extending to the provision of professional services including design, project management, and on-site physical work[1]. Infrastructure industry refers to the industrial sector that is involved in the construction, repair, renovation, and maintenance of infrastructures. The building sector has a substantial impact on a nation's technological and technical progress, frequently determining the evolution of its infrastructure, thereby making a valuable contribution to sustainability[2]. Construction, in this definition, defines the production process of the built environment, encompassing a range of activities from ideation to design to implementation. Infrastructure development is the economic sector that converts diverse resources into built facilities by means of planning, design, building, maintenance, repair, and operation. Hence, the construction industry includes all companies or entities that are professionally engaged in the construction process, including those that provide advisory services for planning, design, and supervision, as well as those that carry out on-site

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execution work, such as general contractors and builders[2]. These firms often retain strong professional connections with clients and financiers.

Nigeria achieved independence in 1960, which, together with the lucrative "oil boom" in the 1970s, resulted in a substantial surge in construction operations[3]. Prior to the conclusion of the second Republic in 1983, Nigeria's construction sector had a significant increase in construction contracts, predominantly controlled by international corporations, with only a negligible representation of local enterprises[4]. Unfortunately, this period also brought attention to the insufficient proficiency of the country's native enterprises in human resources, namely in fields such as project planning, design, construction, and maintenance. These skills were crucial for managing the increasing quantity and magnitude of government-planned projects. Nevertheless, enhancements have been noted in this aspect. Strengthened training institutions, increased participation of expatriates, partnerships between local and foreign entrepreneurs, political stability, and enhanced government policies have reduced the resource disparity necessary for the effective implementation of intricate projects between local firms and their foreign counterparts[4]. This transition represents a significant progress in comparison to the era preceding Nigeria's independence.

The construction business in Nigeria is a diverse enterprise that includes a wide range of operations, from the manufacturing of raw materials to the implementation of intricate building projects[5]. Construction is crucial in determining the physical structure of the built environment, making a substantial contribution to the economic growth and infrastructure of the country[6]. This essay thoroughly explores the many facets of the construction industry, providing a sophisticated comprehension of its intricacies.

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In Nigeria, the construction sector materializes in several forms, each making a distinct contribution to the country's development[7]. Preeminent categories include civil engineering construction, building construction, projects associated with the oil and gas industry, and the expansion of telecommunication infrastructure[8]. These categorizations highlight the industry's adaptability in effectively meeting various societal demands.

The construction sector in Nigeria functions within a dynamic environment, marked by the presence of public and private partnerships that enable concerted efforts between government bodies and private firms[9]. Moreover, the industry has a combination of local and international participation, with both providing crucial components to the overall vitality of the sector. The regulatory structure, overseen by authorities like the Federal Ministry of Works and Housing, guarantees compliance with standards and ecologically sound methods[10].

Essentially, the construction sector in Nigeria functions within a flexible conceptual framework, driven by fundamental ideas that go beyond the simple physical design of buildings[11]. The construction sector in Nigeria is not solely concerned with the physical construction of buildings; it is closely interconnected with the whole development of the country. This includes comprehensive economic expansion, generation of employment opportunities, and a steadfast dedication to enhancing quality of life[12]. Projects under this framework are considered not only as operational entities but also as actively contributing to the overall socio-economic progress of the nation. An inherent characteristic of the building industry in Nigeria is the growing incorporation of contemporary technology. From cutting-edge design methodologies to sophisticated building materials, the sector is utilising technical breakthroughs such as Building Information Modelling (BIM) and digital project management tools[13]. Through this integration, efficiency is improved,

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sustainability is promoted, and the industry is positioned at the front of technological advancement. The modern building sector in Nigeria attaches great importance to sustainability and environmental awareness[14]. Acknowledging the ecological consequences of construction operations, there is an increasing dedication to embracing environmentally friendly methods, reducing waste, and integrating green building concepts. This concept embodies a wider recognition of the industry's obligation to harmonize development with environmental conservation[15].

In comparison to the overall global construction industry, the Nigerian construction sector is somewhat diminutive in size[16]. The current valuation of the worldwide construction industry is approximately $4 trillion. The Nigerian construction sector, estimated to be worth around $3.15 billion in 2008, accounts for a mere 0.2% of the worldwide total[16]. Notwithstanding this, it is unquestionably the greatest among all other West African nations. In recent years, the Nigerian construction industry has rapidly expanded and surpassed most other sectors of the local economy[17]. In 2005, the industry experienced a remarkable growth rate of 12.1%, surpassing the average growth of the entire economy (5.6%) by more than double on the same year. With the economy anticipated to see more elevated growth rates in the foreseeable future, the construction sector is likewise predicted to maintain strong performance[18].

The construction sector is a dominant force in the global economy, making a substantial contribution to the Gross Domestic Product (GDP) of most countries. On a global scale, it accounts for roughly 9% of the world's Gross Domestic Product (GDP) and is a significant labour generator, offering employment to around 7% of the global population[19]. In 2004, the worldwide building expenditure amounted to more than $4 trillion[20]. Apart from its immense magnitude, the construction sector assumes a crucial function in the

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advancement of the economy. It establishes the required infrastructure and facilities for many human activities, linking them into an intricate network[20]. These facilities are indispensable for the production of commodities and services, encompassing materials needed by producers and those used by end-users. The construction sector is fiercely competitive and very responsive to economic fluctuations. As globalization has progressed, construction firms, especially those from industrialized countries, are increasingly expanding internationally to take advantage of global prospects[18]. For instance, American and European companies are moving their operations to the Middle East for cost effectiveness and better prospects.

The construction sector in the United States of America (USA) is considered one of the major marketplaces globally and provides support for investments, logistics, production, growth, output, and other associated building material sectors[21]. It employs a significant number of people, creating income opportunities and contributing to poverty reduction. The construction sector in the United Kingdom has a substantial impact of £117 billion on the national economy, representing around 6% of the total economic production[21]. The sector encompasses a substantial 2.4 million employment opportunities, or around 7% of the total workforce in the United Kingdom[22]. China is widely recognized as one of the leading construction output sectors globally. In 2020, the construction industry experienced a growth of 1.04 trillion U.S. dollars, making up 6.9% of China's gross domestic product[22].

The building sector demonstrates interdependencies with all 17 Sustainable Development Goals (SDGs). SDG2 (Zero Hunger), SDG3 (Good Health and Well-being), SDG4 (Quality Education), SDG6 (Clean Water and Sanitation), SDG7 (Affordable and Clean Energy), SDG8 (Decent Work and Economic Growth), SDG9 (Industry, Innovation and

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Infrastructure), SDG10 (Reduced Inequalities), SDG11 (Sustainable Cities and Communities), and SDG13 (Climate Action)[23]. The choice of building materials has a direct impact on the achievement of certain Sustainable Development Goals (SDGs), such as SDG 3, SDG 7, SDG 9, SDG 11, SDG 12, SDG 13, and SDG 15[23]. Moreover, these materials have an indirect impact on Achievement of SDG 2, SDG 5, SDG 10, and SDG 16.

2.1.1.1 Performance of Construction Industry

Since construction projects are large, complex, and have a significant impact on society and the economy, understanding and improving organizational performance in this sector requires looking at a number of factors, including efficiency, effectiveness, quality, safety, and sustainability[118]. These factors together determine the success of construction companies and their ability to deliver projects on time, within budget, and to the required standards[116].

The structure and operations of the construction industry are distinct, posing particular difficulties for organizational performance[119]. Construction projects, in contrast to many other industries, are usually one-time, large-scale endeavours involving a variety of stakeholders, including suppliers, clients, contractors, subcontractors, and regulatory bodies. Because of this complexity, there needs to be efficient coordination and communication between various teams and disciplines[120]. Therefore, a construction organization's performance is highly reliant on how well it manages these relationships and processes.

Project delivery is one of the main measures of organizational performance in the construction sector. Project completion on time is essential because delays can result in overspending, unhappy clients, and harm to one's reputation[121]. Studies have indicated

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that in order to guarantee on-time delivery, elements like project planning, resource distribution, and risk management are essential[121]. The application of sophisticated project scheduling methods and tools, such as Earned Value Management (EVM) and the Critical Path Method (CPM), can greatly improve an organization's capacity to meet deadlines and keep control over project timelines.

Another crucial component of organizational performance in the construction sector is cost management[123]. Cost overruns are a common occurrence in construction projects, which can negatively impact profit margins and the long-term viability of construction companies. To effectively manage project costs, financial forecasting, budget control, and accurate cost estimation are necessary[121]. Building information modelling (BIM), which provides comprehensive, real-time data on project costs, materials, and resources, has become a potent tool in recent years that improves cost management[56]. Building information modelling (BIM) enables construction companies to maximize resource utilization, cut waste, and enhance overall project efficiency, all of which improve financial performance.

In the construction sector, quality management is also a crucial element of organizational performance[122]. The built environment's functionality, longevity, and safety are directly impacted by the calibre of construction work. Defects, rework, and ultimately higher expenses and project delays can result from poor quality. Thus, in order to guarantee that the work satisfies the necessary standards, construction companies must put strong quality assurance and quality control (QA/QC) procedures in place[123]. This entails establishing precise quality standards, carrying out frequent inspections, and making certain that all parties involved follow the rules regarding quality. Adopting quality management systems,

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like ISO 9001, can improve organizational performance even more by encouraging an accountability and continuous improvement culture[124].

Another important component affecting organizational success in the construction sector is safety performance. Construction is by its very nature dangerous, exposing workers to risks like falls, equipment malfunctions, and toxic material exposure. Maintaining a strong safety culture is crucial to reducing these risks and safeguarding employees' health[67]. Prioritizing safety helps organizations not only lower the risk of accidents but also improve their reputation and save money on medical bills related to workplace injuries[124]. Using personal protective equipment (PPE), conducting frequent safety training, and putting safety management systems into place are all methods that can enhance safety performance. Furthermore, clients and stakeholders are requesting higher safety standards as part of project requirements, with safety performance being acknowledged as a critical indicator of overall organizational performance more and more[125].

In the construction sector, sustainability is a factor that matters more and more to organizational performance[78]. There is increasing pressure on construction companies to implement sustainable practices that reduce their ecological footprint, as concerns about climate change and its effects on the environment grow. This entails utilizing eco-friendly products, cutting back on energy use, and efficiently handling waste[126]. Businesses that practice sustainability can stand out from the competition, draw in eco-aware customers, and abide by legal requirements. Long-term cost savings are also facilitated by sustainable construction methods, since energy-efficient infrastructure and buildings typically have lower operating expenses. By showcasing a dedication to sustainability and

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drawing in new business, adopting green building certifications like LEED (Leadership in Energy and Environmental Design) can further improve organizational performance[127].

In the construction industry, achieving high organizational performance is not without its difficulties, though. The industry's fragmentation, where projects are frequently managed by several entities with different goals, cultures, and management styles, is one of the main challenges[128]. Performance may suffer as a result of inefficiencies, misunderstandings, and disputes brought on by this fragmentation. Construction companies need to concentrate on encouraging cooperation and developing trusting bonds with all project stakeholders in order to overcome these obstacles[129]. Building trust, having effective communication, and having the project team's goals aligned are all necessary for this. Approaches that encourage cooperation and enhance project outcomes include integrated project delivery (IPD) and collaborative contracting models like partnering agreements[129].

Performance in the construction sector is also greatly influenced by organizational culture and leadership. Establishing a clear vision, inspiring workers, and promoting organizational change all depend on strong leadership[130]. Executives who place a high value on innovation, ongoing development, and a dedication to quality have a big impact on how well their companies perform. Employee attitudes and behaviors, however, are shaped by the organizational culture[98]. An organisation that prioritises safety, quality, and teamwork is likely to exhibit superior performance. On the other hand, a culture that accepts short cuts, inadequate communication, or a lack of accountability can result in less-than-ideal performance and unfavourable project results[131].

In the construction sector, organizational performance is a broad term that includes a number of different elements, such as project delivery, cost management, quality, safety,

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and sustainability[132]. Achieving high performance is made more difficult by the particular qualities of the construction industry, like its complexity, fragmentation, and high-risk environment. Still, construction companies can improve project outcomes and performance by implementing best practices in project management, cost control, quality assurance, safety management, and sustainability[133]. Other important factors that affect performance are organizational culture and leadership. Successful organizations have higher levels of productivity, teamwork, and success when they have strong leadership and a positive culture.

Organizations that place a high priority on performance and consistently look to improve their methods will be better positioned to thrive in an environment that is becoming more demanding and competitive as the construction industry develops[134].

2.1.1.2 Operational Efficiency

In the construction industry, operational effectiveness plays a crucial role in determining a business's competitiveness and success[135]. It entails making the best use of all available resources, including time, labour, supplies, and machinery, in order to maximize output while lowering expenses, cutting waste, and raising productivity[22]. In an industry where intricate projects, stringent deadlines, and substantial financial risks are commonplace, achieving operational efficiency is not only an objective but also a precondition[12].

In the fast-paced world of construction, projects frequently entail a large number of stakeholders, complex planning, and a great deal of variation in the tasks and results. Because of this intricacy, attaining operational efficiency necessitates a strategic approach involving the following important domains: project management, workforce management, resource allocation, technology adoption, and process improvement[136].

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Effective project management is one of the cornerstones of operational efficiency in the construction industry. Large-scale, complex tasks requiring precise supervision and coordination are the norm for construction projects[137]. When a project is managed well, every step of the way—from planning to completion—is carried out as intended. To prevent delays and cost overruns, this calls for careful planning, scheduling, and monitoring of project operations. Construction companies frequently utilize tools like Gantt charts and the Critical Path Method (CPM) to organize work, identify dependencies, and distribute resources effectively. Additionally, the incorporation of real-time data and analytics-rich project management software enables construction managers to make well-informed decisions, make pre-emptive plan adjustments, and retain control over the project lifecycle[138].

Allocating resources effectively is another essential component of improving operational efficiency. The construction sector is highly dependent on people and material resources, and inefficient use of these resources can result in significant financial losses. Making sure that the proper quantity of labour and resources are accessible when and where they are needed, without excess or shortage, is a key component of efficient resource allocation[139]. To achieve this, precise forecasting, inventory control, and just-in-time delivery methods that cut waste and the expenses of keeping extra goods on hand are needed. Furthermore, ensuring that workers are assigned activities that align with their expertise and skill set through strategic labour deployment can greatly increase output and decrease idle time[140].

The construction sector has witnessed a notable increase in operational efficiency due in large part to the introduction of technology. The planning, carrying out, and monitoring of building projects are changing as a result of innovations like Building Information

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Modelling (BIM), robotics, and drones. Specifically, BIM makes it possible to create intricate digital models of infrastructure and structures that may be used to enhance stakeholder engagement, optimize design, and identify possible problems before construction ever starts. Construction inefficiencies can stem from errors and rework, which BIM lowers by offering a complete picture of the project[140].

Drones make it possible to collect data more quickly and accurately for site assessments, inspections, and progress tracking. By enabling remote inspections in dangerous locations, this technology not only saves time and labour for these jobs but also improves safety[34]. Similar to this, labour-intensive and repetitive operations are being revolutionized by the use of robotics in construction, including automated machines and robots for laying bricks. These innovations lower labour costs, increase speed and accuracy, and lessen the possibility of human error.

Another crucial component of operational efficiency in the construction industry is process improvement[141]. Lean Construction and Six Sigma are two examples of continuous improvement approaches that are being used more and more to improve value for clients, streamline operations, and get rid of waste. The goal of lean construction is to maximize value while eliminating waste—whether it comes from labour, resources, or time. It promotes a culture of continuous improvement, in which groups evaluate procedures on a regular basis, spot inefficiencies, and make adjustments to improve output. Contrarily, Six Sigma is a data-driven methodology that seeks to lower process variability in order to produce more consistent and predictable results[142]. Both approaches place a strong emphasis on the value of teamwork, communication, and a methodical approach to problem-solving, all of which are necessary to achieve operational efficiency in the intricate world of construction.

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Another crucial area where operational efficiency can be greatly increased is workforce management[143]. Because the construction industry relies heavily on labour, worker productivity has a direct impact on overall operational efficiency. Ensuring that employees have the skills, motivation, and resources they need to do their jobs well is a key component of effective workforce management[65]. This entails putting money into continuous training and development initiatives to keep staff members abreast of emerging methods and tools and putting in place performance management systems that incentivize output and excellence. Furthermore, creating a great work atmosphere where employees feel appreciated and involved can boost motivation, which in turn improves operational effectiveness.

Notwithstanding the evident advantages of operational efficiency, the construction sector encounters several obstacles in its Endeavor to achieve it. The industry's fragmentation, where projects frequently involve numerous suppliers, subcontractors, and other stakeholders with disparate goals and methods of operation, is one of the main challenges. Delays, inefficiencies, and poor communication can result from this fragmentation[146]. Construction companies need to concentrate on enhancing coordination and collaboration among all project participants in order to address this. This can be accomplished by using integrated project delivery techniques, in which all parties collaborate right away, exchanging data and coordinating their objectives[147].

The industry's reluctance to shift presents another difficulty. Historically, the construction industry has been hesitant to implement novel technology and procedures, partially because of the perceived hazards and expenses linked to change. However, construction companies need to embrace innovation and be prepared to invest in new tools and processes that can improve operational efficiency as the competitive landscape becomes

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more demanding. Strong leadership, a dedication to ongoing development, and a readiness to question the status quo are necessary for this.

The state of the economy has a big impact on how efficiently operations are run in the construction sector. Economic downturns may result in a decline in the demand for construction services, putting businesses under pressure to operate on narrower profit margins and face challenging resource allocation choices[148]. During these periods, companies need to discover ways to accomplish more with less, which makes operational efficiency even more important. This could entail contract renegotiation, supply chain optimization, or creative cost-cutting measures that don't sacrifice quality.

Operational effectiveness is a critical component of success in the building sector[149]. It entails the efficient use of resources, the adoption of cutting-edge technologies, ongoing process improvement, and effective personnel management. Even though the sector faces obstacles like resistance to change, fragmentation, and economic pressures, businesses that put an emphasis on operational efficiency are better positioned to complete projects on schedule, under budget, and with the highest possible quality[150]. Operating effectiveness will continue to be a crucial factor in the construction industry's evolution as long-term success and competitiveness are concerned.

2.1.1.3 Project Delivery Time

In the construction industry, project delivery time is a crucial element that directly affects a project's success as well as the overall performance of a construction company. It includes the whole period from the project's inception to the final handover of the completed structure[151]. Effectively managing project delivery time is necessary to guarantee that projects are finished on schedule, which prevents expensive delays, upholds client satisfaction, and maximizes resource utilization.

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It is impossible to exaggerate the significance of project delivery time in the construction sector. Construction projects are usually large-scale, intricate endeavours requiring substantial time, financial, and resource commitments. Wide-ranging repercussions may result from project delivery delays, such as higher expenses from labour and equipment utilization that is prolonged, penalties for late delivery, and possible harm to the contractor's image. Furthermore, delays might cause other projects' timetables to slip, which can have a cascading effect on a variety of stakeholders, such as suppliers, clients, and subcontractors[152].

The intrinsic complexity and unpredictability of construction projects is one of the main obstacles to managing project delivery time in the sector[3]. Construction projects are frequently one-of-a-kind, with each one posing its own unique set of risks and problems. This is in contrast to manufacturing, where production methods can be standardized and repeated. Delays may be caused by a number of variables, including the state of the weather, site accessibility, governmental permissions, and unanticipated ground conditions. Because of this, project management strategies used by construction organizations need to be proactive and heavily prioritize planning, scheduling, and risk management[154].

Project managers need to create a realistic timeline that includes all of the essential activities needed to finish the project, which includes breaking it down into manageable tasks, determining how tasks depend on one another, and allocating resources appropriately[155]. Project management tools, like Gantt charts and the Critical Path Method (CPM), can be used to visualize the timeline, spot potential bottlenecks, and make sure that everyone in the team is aware of their roles and deadlines.

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An additional crucial component of controlling project delivery time is scheduling. Carefully designed construction schedules guarantee that all tasks are carried out in the most effective way possible, including arranging for material delivery, labour deployment, and equipment use. Just-in-time material delivery, for instance, can minimize material deterioration risks and save storage costs; however, it also necessitates exact coordination with suppliers to guarantee that materials arrive precisely when needed[156]. Any interruption in the supply chain can cause delays, so backup plans must be in place to deal with such situations.

In order to ensure that a project is completed on schedule, risk management is just as important[155]. Construction projects are risky by nature, and there are many factors that can cause delays. Effective risk management includes identifying potential risks early in the project, evaluating their likelihood and impact, and developing mitigation strategies. For instance, if bad weather is a known risk, the project schedule may include buffer time to account for potential delays caused by weather[157]. Furthermore, keeping positive relationships with suppliers and subcontractors can help mitigate risks related to labour availability and material delivery.

In the construction sector, technology has also been a major factor in accelerating project delivery times. The use of Building Information Modelling (BIM) has had a significant influence. With the use of BIM, it is possible to create intricate digital models of infrastructure and structures, which facilitates greater stakeholder collaboration, project visualization, and the early identification of potential problems or design errors. BIM lowers the possibility of delays brought on by rework or design modifications during construction by locating and fixing problems in the virtual model prior to the start of

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construction. Furthermore, BIM makes scheduling and resource allocation more accurate, which improves project delivery efficiency[158].

Project management software that offers real-time data on project progress, resource utilization, and potential delays is also being used by construction companies more and more. With the use of these tools, project managers may maintain a close eye on the project timeline, make data-driven decisions, and modify the plan as necessary to stay on course[159]. The incorporation of this technology with mobile devices facilitates instantaneous communication and on-site updates, so augmenting the capacity to promptly address any potential concerns[86].

Sometimes it is impossible to avoid delays in project delivery, even with the greatest planning, scheduling, and risk management practices. When delays do happen, it's critical to handle them skilfully to reduce the damage they cause[160]. In these circumstances, open communication with the customer is essential for managing expectations and preserving confidence. One way to lessen the negative effects of delays is to give the client regular updates on the progress of the project, including any delays and the actions being taken to address them. Furthermore, looking into ways to expedite specific tasks or overlap them (a technique called "fast-tracking") might assist make up for lost time and get the project back on track[161].

The human element is crucial in project delivery time management, in addition to the technical aspects. The coordination and collaboration of several teams, including architects, engineers, contractors, and labourers, is crucial to the construction business[99]. A collaborative work culture, clear communication, and effective leadership are necessary to make sure that everyone in the team is working toward the same goals and adhering to

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the project deadline. To inspire people, settle disputes, and keep the project going forward in the face of obstacles, project managers need to be very capable leaders[162].

For construction companies, there can be dire repercussions if projects are not completed on schedule[162]. Apart from monetary fines and escalated expenses, tardiness might harm the organization's image and result in the forfeiture of prospective commercial prospects. Contractors with a track record of on-time delivery are more likely to be chosen by clients, and a history of delays can make a business less competitive. Delays can also sour ties with suppliers, subcontractors, and other stakeholders, which can undermine confidence and cooperation for subsequent projects[163].

The success of construction projects and the general performance of construction companies are significantly influenced by the project delivery time[162]. A comprehensive approach that incorporates careful planning, precise scheduling, proactive risk management, and the use of cutting-edge technology is necessary to manage project delivery time effectively[164]. Despite the fact that the complexity and unpredictability of construction projects create special obstacles, businesses who prioritize on-time delivery and consistently work to improve their project management techniques are more likely to succeed. Because delays have serious repercussions, construction businesses must concentrate on completing projects on schedule, every time, in order to preserve their competitiveness and good name in the sector[165].

2.1.1.4 Cost Management

In the construction sector, where there are typically limited tolerances for mistake and significant financial stakes, cost control is a critical component of project management. Planning, estimating, budgeting, funding, managing, and controlling the expenses related to a construction project are all necessary components of effective cost management. It

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guarantees that the project is finished within the authorized spending limit, increasing the construction company's profitability and providing the client with value[166].

The construction sector is intrinsically complicated due to its large-scale projects, numerous stakeholders, and high degree of project condition fluctuation[165,162]. These elements add to the difficulties in efficiently controlling expenses. Large expenditures in people, supplies, machinery, and technology are frequently made during construction projects, therefore going over budget can have a big financial impact. Therefore, to guarantee that projects are finished on schedule, within budget, and to the necessary quality standards, a methodical approach to cost management is crucial[167].

Cost estimation is the first step in the building cost management process and serves as the basis for financial planning and budgeting. Since it establishes the foundation for the financial management of the project as a whole, accurate cost estimation is essential[168]. To estimate the expenses of a project, estimators employ a range of techniques, such as parametric modelling, historical data analysis, and thorough quantity take-offs. These techniques account for labour, material, equipment, overhead, and contingency expenses. The accuracy of the cost estimate is contingent upon the availability of precise data as well as the experience and knowledge of the estimator. Cost estimation is a tricky balance because overestimating might render a bid uncompetitive, and underestimating can result in financial shortages during the project[169].

The approved cost estimates serve as the foundation for the project budget. The budget is a financial plan that allots resources in accordance with projected expenditures for the various project phases[170]. Throughout the course of the project, keeping track of and managing expenses requires a well-organized budget. It gives project managers a baseline to compare actual expenses to, making it easier to spot deviations and, if needed, take

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corrective action. In addition, budgeting entails allocating a contingency fund to cover unforeseen costs, which are frequent in construction projects because of unanticipated events like supply chain disruptions, weather delays, or design modifications[21].

In the construction sector, cost control is an essential part of cost management. It entails keeping an eye on real project expenses in comparison to the budget and addressing any discrepancies with remedial action[171]. A reliable real-time cost tracking system is essential for effective cost control because it helps project managers spot possible overruns before they become big problems. This entails updating cost reports on a regular basis, monitoring development in relation to goals, and determining the causes of any budgetary deviations. The tools that modern project management software offers for real-time cost tracking, variation analysis, and forecasting are essential to cost control[172]. Project managers can maintain the project's financial viability by using these tools to make well-informed decisions, modify resources, and allocate monies as efficiently as possible[43].

Cost overruns are one of the biggest obstacles to effective cost control in the construction industry. Cost overruns happen when a project's actual expenses surpass its projected expenses. Numerous things, such as imprecise cost estimation, scope modifications, delays, wasteful resource usage, and unforeseen site conditions, might contribute to them[173]. Cost overruns can have detrimental effects on the contractor as well as the client, resulting in monetary losses, disagreements, and in the worst situations, project abandonment[173]. Construction companies need to use strong cost management procedures, such as careful risk assessments, meticulous project planning, and tight adherence to budgetary constraints, to reduce the possibility of cost overruns.

In the construction sector, risk management and cost management go hand in hand. Risks associated with construction projects include labour shortages, market volatility, rising

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material prices, and regulatory changes, all of which can have an effect on project costs[174]. Early risk identification, evaluation of the risks' effect on costs, and development of mitigation plans are all necessary for effective risk management. This could entail negotiating fixed-price contracts with suppliers, locking in rates, or getting insurance to cover unanticipated costs. Construction companies may safeguard their finances and lower the chance of cost overruns by taking proactive risk management measures[175].

A further crucial component of cost control in the building sector is value engineering. Value engineering is an organized method for raising a project's worth by maximizing the trade-offs between price, usefulness, and quality[88]. It entails examining the building and design procedures to find areas where money can be saved without sacrificing effectiveness or quality. Common value engineering tactics include, for instance, replacing pricey materials with less costly alternatives that fulfill the same specifications or simplifying construction techniques to lower labour costs[176]. The objective is to complete the project as cheaply as feasible while still satisfying the client's needs and upholding strict quality standards.

In construction, procurement management is also essential to cost control. Getting the supplies, machinery, and services required to finish the project is part of the procurement process[177]. Effective procurement techniques guarantee that goods and services are acquired at the most competitive costs, which can result in large cost savings. Contract management, supplier negotiations, and meticulous planning are necessary for this. In order to prevent delays and cost escalation, procurement management also entails maintaining supplier relationships to guarantee on-time and reasonably priced delivery[178].

Another crucial component of cost control in the construction industry is contract management. Construction contracts specify the parameters within which the project will

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be carried out, including the work to be done, terms of payment, deadlines, and roles and responsibilities of all involved parties[92]. As they aid in preventing disagreements and miscommunications that may result in expensive delays or legal battles, precise and well-defined contracts are crucial for cost management. For example, because the contractor agrees to finish the project for a set price under a fixed-price contract, the client has more cost certainty. These contracts, however, can also shift more risk to the contractor, who has to control expenses carefully to prevent losing money.

The construction industry's cost management has greatly improved in recent years due to the widespread adoption of technology. Increasingly, cost estimation, budgeting, and cost control can be achieved with the help of building information modelling (BIM). More precise quantity take-offs and cost estimates are made possible by BIM's provision of comprehensive, three-dimensional digital representations of infrastructure and buildings. Improved coordination among project stakeholders also lessens the possibility of mistakes and rework, which are frequent causes of cost overruns. Furthermore, real-time cost tracking and forecasting are made possible by the integration of BIM with project management software, providing project managers more financial control.

Additionally, data analytics are being used more and more in building cost control. Large amounts of project data must be analysed for trends, patterns, and insights that can guide decision-making[179]. This process is known as data analytics. Analysing past project data, for instance, can assist in determining frequent reasons for cost overruns and creating plans to avoid them in subsequent projects. Project managers can take proactive steps to stay below budget by using predictive analytics to forecast possible cost difficulties based on real-time data.

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Effective cost management remains a difficulty for the construction sector, even with the development of technology and cost management techniques. The industry is prone to changes in labour costs, material prices, and economic conditions, all of which can have an effect on project costs[180]. Furthermore, cost management may be challenging due to the industry's fragmented structure, which involves numerous suppliers and subcontractors working on a single project. Construction companies need to invest in technology, consistently improve their cost-management procedures, and promote an accountable and disciplined financial culture in order to overcome these obstacles[176].

Cost control is an essential component of construction project management that has a direct bearing on the success and profitability of construction companies. It entails a thorough process for organizing, project cost estimation, budgeting, managing, and monitoring[23]. Construction companies may limit the risk of cost overruns, maximize resource utilization, and complete projects under budget by putting effective cost management techniques into place. The ability of construction companies to efficiently manage costs has been significantly increased by the deployment of technology, including BIM and data analytics[5]. Nonetheless, persistent obstacles including fluctuating markets and fragmented industries necessitate that construction companies maintain a state of alertness and initiative in their cost control endeavours. Cost management experts will be in a better position to prosper in the cutthroat and rigorous construction sector.

2.1.1.5 Quality of Work

Quality of work in the construction industry is a crucial factor that determines the success, safety, and sustainability of construction projects. It refers to the degree to which a construction project meets or exceeds the specified standards, requirements, and expectations in terms of materials, workmanship, and functionality[13]. Ensuring high-

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quality work in construction is essential not only for achieving client satisfaction but also for maintaining the structural integrity and longevity of buildings and infrastructure.

The importance of quality in construction cannot be overstated. Construction projects often involve significant investments of time, money, and resources, and the consequences of poor quality can be severe[24]. Deficiencies in construction quality can lead to safety hazards, costly repairs, project delays, legal disputes, and damage to the reputation of the construction firm. In extreme cases, poor quality can result in catastrophic failures, such as structural collapses, which can have devastating consequences for both human life and the built environment[28]. Therefore, quality management is a critical aspect of construction project management, aimed at ensuring that all aspects of the project meet the required standards and specifications.

Quality in construction is governed by a set of standards and regulations that vary by region and project type. These standards, often established by government agencies, industry bodies, and professional associations, provide guidelines for materials, workmanship, safety, and environmental impact[28]. Compliance with these standards is mandatory, and construction firms are required to follow them throughout the project lifecycle. However, meeting regulatory standards is only the baseline for quality. High-quality construction goes beyond mere compliance, striving to exceed client expectations and deliver projects that are not only safe and functional but also aesthetically pleasing and durable[51].

Achieving high-quality work in construction requires a comprehensive approach that involves careful planning, skilled labour, appropriate material selection, and rigorous quality control measures. The process begins with the design phase, where architects and engineers create detailed plans and specifications that outline the project's requirements.

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These plans must be precise and unambiguous, as any errors or omissions at this stage can lead to quality issues during construction[56]. Collaboration between designers, contractors, and clients is essential to ensure that the design meets the desired quality standards and is feasible to construct.

The selection of materials plays a significant role in determining the quality of the finished project. High-quality materials are essential for achieving durability, safety, and aesthetic appeal. However, the selection of materials must also consider factors such as cost, availability, and environmental impact[67]. Construction firms must source materials from reputable suppliers and ensure that they meet the required standards and specifications. The use of substandard or counterfeit materials is a common cause of quality issues in construction and can lead to serious problems, including structural failures and safety hazards[101].

Workmanship is another critical factor in construction quality. Even the best materials and designs can be compromised by poor workmanship. Skilled labour is essential for ensuring that construction tasks are performed correctly and to a high standard. This includes everything from the proper mixing and application of concrete to the precise installation of electrical and plumbing systems. Construction firms must invest in training and development programs to ensure that their workers have the necessary skills and knowledge to perform their tasks to the required standard[101]. Additionally, supervision and oversight by experienced project managers and foremen are crucial for maintaining high standards of workmanship on the job site.

Quality control is a key component of quality management in construction. It involves a series of checks and inspections at various stages of the project to ensure that the work meets the specified standards and requirements[180]. Quality control measures typically

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include the inspection of materials, verification of dimensions and tolerances, testing of structural components, and monitoring of workmanship. These inspections are usually conducted by qualified inspectors, engineers, or third-party consultants who are independent of the construction team. Any deviations from the specified standards are documented, and corrective actions are taken to address the issues[182]. Regular quality audits are also conducted to ensure that the project remains on track and that quality standards are consistently met.

Technology has played an increasingly important role in improving the quality of work in the construction industry[183]. Building Information Modelling (BIM) is one such technology that has revolutionized the way construction projects are designed, managed, and executed[183]. BIM allows for the creation of detailed digital models of buildings and infrastructure, which can be used to simulate construction processes, detect potential issues, and optimize designs before construction begins. This reduces the likelihood of errors and rework, which are common sources of quality issues in construction. Additionally, BIM facilitates better communication and collaboration among project stakeholders, ensuring that everyone is aligned with the project's quality objectives[185].

Quality assurance is another critical aspect of quality management in construction. While quality control focuses on identifying and addressing quality issues during construction, quality assurance is concerned with preventing those issues from occurring in the first place. It involves the implementation of processes and procedures that ensure that all aspects of the project are performed to the required standard[186]. Quality assurance typically includes the development of a quality management plan, which outlines the project's quality objectives, the roles and responsibilities of the project team, and the

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procedures for ensuring quality. This plan serves as a roadmap for achieving high-quality work throughout the project lifecycle.

One of the significant challenges in maintaining quality in construction is the coordination and management of multiple subcontractors and suppliers. Construction projects often involve numerous subcontractors, each responsible for different aspects of the work, such as plumbing, electrical, and HVAC systems. Ensuring that all subcontractors adhere to the same quality standards and that their work is properly integrated is crucial for the overall quality of the project[187]. This requires effective communication, coordination, and oversight by the project management team. Regular meetings, progress reports, and site inspections are essential for keeping all parties aligned and addressing any quality issues that arise.

The construction industry also faces challenges related to cost pressures and tight schedules, which can impact quality. To reduce costs and meet deadlines, some construction firms may be tempted to cut corners, use cheaper materials, or rush work. However, these shortcuts often lead to quality issues that can result in costly repairs, rework, and legal disputes. It is essential for construction firms to strike a balance between cost, time, and quality, ensuring that budget and schedule constraints do not compromise the quality of the finished project[11]. Clients and contractors must work together to establish realistic budgets and timelines that allow for high-quality work to be achieved.

Sustainability is an increasingly important consideration in construction quality. As the industry faces growing pressure to reduce its environmental impact, construction firms are incorporating sustainable practices and materials into their projects. High-quality construction today involves not only meeting the traditional standards of safety, durability,

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and functionality but also minimizing the project's environmental footprint. This includes using energy-efficient materials, reducing waste, and incorporating renewable energy sources. Sustainable construction practices contribute to the long-term quality and viability of buildings and infrastructure, ensuring that they remain safe, functional, and environmentally responsible for years to come.

The quality of work in the construction industry is a critical factor that determines the success, safety, and sustainability of construction projects[17]. Achieving high-quality work requires a comprehensive approach that includes careful planning, skilled labour, appropriate material selection, rigorous quality control, and effective quality assurance. Technology, such as BIM, plays a significant role in improving quality by enhancing design, communication, and collaboration. However, the construction industry also faces challenges related to cost pressures, tight schedules, and the coordination of multiple subcontractors. Overcoming these challenges requires a commitment to quality from all stakeholders, including clients, contractors, and subcontractors. By prioritizing quality, the construction industry can deliver projects that meet or exceed expectations, ensure safety and durability, and contribute to a sustainable built environment[188].

2.1.2 Industry 4.0 Technologies

Industry 4.0 also referred to as the Fourth Industrial Revolution, is a rapidly evolving phenomenon that is revolutionizing the manufacturing landscape through the seamless integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), robotics, and 3D printing[24]. This transformation is reshaping the way businesses operate and is paving the way for a more efficient and interconnected future. This new era of industrialization is characterized by the convergence of the physical, digital, and biological worlds, leading to the creation of smart factories and

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interconnected systems that optimize production processes and enable mass customization[24]. The concept of Industry 4.0, also known as the Fourth Industrial Revolution, marks a monumental transformation from the previous industrial revolutions that were primarily characterized by mechanization, mass production, and automation[25]. The Fourth Industrial Revolution builds upon these foundations, leveraging the power of data, connectivity, and intelligent systems to create a more agile, efficient, and responsive manufacturing ecosystem[26]. Key technologies driving Industry 4.0 include:

i. Industrial Internet of Things (IoT)

ii. Cloud computing and edge computing

iii. Big Data and analytics

iv. Artificial intelligence and machine learning

v. Robotics and automation

vi. Additive manufacturing (3D printing)

vii. Augmented reality and virtual reality

viii. Cybersecurity

In order to fully comprehend the significance of Industry 4.0, it is crucial to delve into the historical context of the previous industrial revolutions and how they have shaped the current state of technology and industry[26]. The Second Industrial Revolution, which is also commonly referred to as the Technological Revolution, occurred during the beginning of the 20th century and brought about significant advancements and innovations in various industries[27]. During this time, there was a significant shift towards

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the use of electricity, as well as the implementation of mass production methods, such as the famous assembly line. Additionally, there was a notable rise in the steel, chemical, and automobile industries, all of which were greatly impacted by groundbreaking innovations like the telephone, the lightbulb, and the internal combustion engine[28]. These advancements not only revolutionized industrial practices but also had a profound effect on society as a whole. The digital revolution, also known as the third industrial revolution, started in the middle of the 20th century with the advent of digital technologies like computers, the internet, and mobile devices[28]. This era was also characterized by automation, robotics, and the widespread use of electronic devices in manufacturing, which laid the groundwork for the creation of Industry 4.0[29].

The Fourth Industrial Revolution (ISR) is a technological shift that has significant implications for society, the economy, and the nature of work[30]. As it develops, companies, governments, and individuals must adapt and work together to ensure that the benefits of this transformation are widely shared and that potential risks are effectively managed. Industry 4.0 builds upon the advancements of the previous industrial revolutions by integrating cutting-edge technologies to create a more connected, intelligent, and efficient manufacturing landscape[31]. As industries adopt these technologies, they can expect to see improvements in productivity, flexibility, and customer satisfaction as well as face challenges related to workforce reskilling, cybersecurity, and the need for standardized frameworks.

Characteristics of Industry 4.0

The Fourth Industrial Revolution, or Industry 4.0, is bringing modern technologies like 3D printing, robots, artificial intelligence (AI), and the Internet of Things (IoT) together to change the manufacturing environment[32]. The integration of the physical, digital, and

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biological worlds has given rise to smart factories and networked systems that streamline manufacturing procedures and allow mass customisation, marking this new era of industrialization[33].

i. Smart Factories and Cyber-Physical Systems

The advent of smart factories, which use data and intelligent automation to optimize production processes, increase efficiency, and decrease downtime, is one of the key features of Industry 4.0. Cyber-physical systems (CPS) are these systems' means of monitoring and controlling physical processes; they are made up of interconnected machines, devices, and sensors that communicate with humans and each other in real-time[34]. Industry 4.0 relies on cyber-physical systems to seamlessly integrate the digital and physical worlds. These systems gather data from multiple sources, analyse it with sophisticated algorithms, and make decisions on their own based on the insights gathered[35]. This increases manufacturing processes' flexibility, adaptability, and responsiveness.

ii. Interconnectivity and Interoperability

The fundamental tenet of Industry 4.0 is interconnectivity and interoperability, which is the ability of machines, devices, and systems to be seamlessly connected and communicate with one another[35]. This is made possible by the use of common communication protocols, like OPC UA and MQTT, which facilitate data and information exchange across various platforms and systems. A smooth transition to smart manufacturing is made possible by interoperability, which also makes it easier for various stakeholders—suppliers, manufacturers, and customers—to collaborate, resulting in more transparent and efficient supply chains[36]. Overall, interoperability is essential to the successful implementation of Industry 4. 0.

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iii. Decentralized Decision Making

One of the main features of Industry 4.0 is decentralized decision making, which gives robots and systems the ability to act independently by using real-time data and insights. Advanced analytics, machine learning, and artificial intelligence technologies are used to enable systems to learn from past experiences and adapt to new situations, which makes this feasible[36]. Decentralized decision-making enhances production process efficiency, improves flexibility, and responds to requests more quickly. Additionally, it lessens the need for human interaction, allowing employees to concentrate on higher-value work and operate more productively with robots[36].

iv. Real-Time Data and Transparency

Real-time data availability and the capacity to derive insights from it are the driving forces behind Industry 4.0. Large volumes of data are gathered on a variety of production process factors, including machine performance, product quality, and energy usage, by sensors and other devices found in smart factories[36]. Advanced analytics technologies are then used to analyse this data in order to find trends, spot abnormalities, and streamline procedures. Better visibility and control over the whole supply chain are made possible by real-time data's increased transparency in manufacturing processes. Customers may follow the status of their orders and receive individualized products made to meet their unique requirements thanks to this transparency.

v. Predictive Maintenance and Self-Optimization

Predictive maintenance and manufacturing process self-optimization are made possible by Industry 4.0 technology[36]. Predictive maintenance algorithms can lower maintenance costs and downtime by identifying possible issues before they arise by analysing real-time

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data from sensors and machinery. This makes it possible to implement preventative maintenance plans that reduce production process interruptions. Industry 4.0 also includes self-optimization, whereby systems and machines continuously assess their own performance and modify parameters to maximize effectiveness and quality[37]. Continuous development of industrial processes is made possible by the application of machine learning algorithms, which learn from historical data and adjust to new circumstances.

Benefits and Opportunities

By combining cutting-edge technologies like the Internet of Things (IoT), artificial intelligence (AI), robotics, and 3D printing, Industry 4.0, sometimes referred to as the Fourth Industrial Revolution, is revolutionizing the industrial sector. Businesses can enhance their operations, goods, and services by taking use of the many advantages and opportunities presented by this new industrialized period[38].

i. Increased Productivity and Efficiency

A principal advantage of Industry 4.0 is the noteworthy enhancement in productivity and efficiency. Manufacturers may streamline their processes, decrease downtime, and boost output with the help of smart factories, which are outfitted with networked equipment and real-time data analytics. AI and machine learning-driven predictive maintenance reduces production interruptions and helps avoid equipment failures.

ii. Enhanced Customization and Product Quality

Manufacturers may now produce products with greater degrees of personalization and quality thanks to Industry 4.0 technologies. Modern sensors and real-time monitoring systems make it possible to identify and fix flaws early on, cutting down on waste and raising standards overall. Additionally, businesses may offer customized products and

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react swiftly to shifting client demands thanks to the flexibility and agility offered by smart production systems.

iii. Optimization of the Supply Chain

Supply chain processes can be optimized thanks to Industry 4.0's integration of IoT and real-time data analytics. Via digital platforms, businesses may link manufacturers, suppliers, and customers to increase cooperation, save lead times, and improve visibility. Logistics operations are streamlined, and inventory levels are optimized with the use of AI-driven demand forecasting and predictive analytics.

iv. Novel Business Strategies and Income Sources

Opportunities for new revenue streams and business models are presented by Industry 4.0. Manufacturers can provide value-added services like performance optimization and predictive maintenance because they have the capacity to gather and evaluate enormous volumes of data. Digital technology integration also makes it easier to develop cutting-edge goods and services, which boosts competitiveness and opens new revenue streams.

v. Efficiency in Resources and Sustainability

Industry 4.0 technologies enable firms to optimize energy consumption, decrease their environmental effect, and eliminate waste, so contributing to sustainability and resource efficiency. While advanced analytics assist find chances for process improvements and resource efficiency, smart factories can monitor and control energy usage in real-time.

Challenges and Considerations

By integrating cutting-edge technology like robotics, 3D printing, artificial intelligence (AI), and the Internet of Things (IoT), the Fourth Industrial Revolution is changing the

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production landscape. Although there are many advantages to this new industrial era, there are also many issues and concerns that businesses need to consider in order to successfully adopt and use these technologies[39].

i. Exorbitant Implementation Expenses

The high implementation costs of Industry 4.0 are one of its main problems. Investing in cutting-edge technology like robotics, artificial intelligence (AI), and Internet of Things devices is expensive. Furthermore, it may be expensive and difficult to integrate these technologies with the infrastructure and processes that are already in place. To justify the upfront costs, businesses need to carefully evaluate the return on investment and create a well-defined implementation strategy.

ii. Job displacement and reskilling of the workforce

Automation and artificial intelligence (AI) of Industry 4.0 technologies have the potential to replace some employment and necessitate worker reskilling. To run and maintain these sophisticated systems, workers will need to pick up new skills as machines replace manual and repetitive labour. To guarantee that their employees are ready for the demands of the modern workplace, businesses must fund their education and training initiatives. To close the skills gap and facilitate worker changes, cooperation between business, the government, and academic institutions is also necessary.

iii. Risks to Cybersecurity and Data Privacy

Industry 4.0's enhanced connection and data interchange give rise to worries about data privacy and cybersecurity. The likelihood of cyberattacks and data breaches rises with the number of systems and devices linked to the internet. To safeguard their systems and sensitive data, manufacturers need to have strong security measures in place, like network

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segmentation, access control, and encryption[40]. For the appropriate handling of personal data, compliance with data privacy rules, including the GDPR, is also essential.

iv. Regulatory frameworks and standardization

The broad adoption of Industry 4.0 technology is hampered by the absence of standards and legal frameworks. Data interchange and smooth integration between various systems and devices depend on their interoperability[41]. To guarantee compatibility and promote cooperation across sectors and boundaries, international standards and protocols must be developed. Additionally, legislative frameworks need to change to handle Industry 4.0's particular problems, like data ownership, liability, and intellectual property protection.

v. Management of Organizational Change

Organizational transformation is necessary for Industry 4.0 implementation, which might be difficult for businesses. A change in mindset and culture is frequently necessary for the acceptance of new technology and procedures[42]. Inadequate communication, a lack of support from the leadership, and resistance to change can all impede the successful execution of Industry 4.0 activities[43]. To promote the required organizational transformation, businesses must create a culture of innovation, involve people at all levels, and build effective change management practices[43].

By combining cutting-edge technology like robotics, artificial intelligence (AI), big data analytics, and the Internet of Things (IoT), the Fourth Industrial Revolution is revolutionizing several industries[44]. These technologies are making it possible to build intelligent, networked systems that stimulate creativity, increase efficiency, and optimize procedures. Let's examine a few of the most important Industry 4.0 use cases and applications.

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2.1.2.1 Internet of Things

The term "Internet of Things" (IoT) describes real-world items that have sensors integrated into them and can connect to computers[45]. The Internet of Things makes it possible to monitor and control the physical world digitally. IoT connects the digital and physical worlds via a range of technologies[45]. It is possible to integrate sensors and actuators into physical objects. Sensors keep an eye on motion, temperature, and really any alteration in the surrounding conditions. Sensors send signals to actuators, which subsequently respond to the changes they detect[46]. Sensors and actuators are in communication with computing systems over wired (like Ethernet) or wireless (like Wi-Fi or cellular) networks; these computers are able to keep an eye on or control the activities and health of linked devices and objects[47].

When paired with data and analytics, the ubiquitous connectivity that IoT offers opens up new avenues for product and service innovation and operational efficiency improvements for businesses. In fact, one of the most important developments in the digital transformation of economies and businesses today is the Internet of Things[48].

Any object having inbuilt sensors and actuators that can connect with an external network is considered an Internet of Things device[49]. IoT devices are generally utilized in the following nine fields:

i. Human bodies. The human body can have devices implanted or attached to it, such as the pervasive connectivity that IoT enables, when combined with data and analytics, opens up new possibilities for product and service innovation as well as gains in operational efficiency for organizations[50]. The Internet of Things is, in reality, one of the most significant advancements in the digital transformation of

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economies and enterprises in existence today. Wearable or edible gadgets that help manage conditions like diabetes, track or preserve health and fitness, and more.

ii. Homes. Devices like automatic vacuum cleaners, home voice assistants, and security systems can be installed by homeowners.

iii. Retail environments. Stores, banks, restaurants, and arenas can install devices to improve inventory management, enable self-checkout, and expand in-store services.

iv. Offices. Applications of IoT in offices could include building security or energy management.

v. Standardized production environments. IoT applications are typically used in these environments—manufacturing facilities, hospitals, or farms—with the goal of maximizing equipment utilization or raising operating efficiencies.

vi. Custom production environments. IoT applications may be utilized for health and safety initiatives or predictive maintenance in specific environments, such as those in mining, construction, or oil and gas exploration and production

vii. Vehicles. IoT can support usage-based design, condition-based maintenance, and presales analytics for automobiles, trucks, ships, aircraft, and trains.

viii. Cities. Applications for the Internet of Things include resource management, smart meters, adaptive traffic control, and environmental monitoring.

ix. Outside. IoT applications could include real-time routing, connected navigation, or shipment tracking in urban settings or other outdoor settings like train tracks, autonomous cars, or flight navigation.

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There are many more real-world instances. IoT solutions are being utilized in many different contexts, such as workplaces to monitor the number and frequency of meeting room usage, fields and farms to manage animals, refrigerators to assist restaurants in streamlining their food compliance procedures, and more[51].

Economic Potential of IoT?

IoT has enormous potential and is only getting bigger. It is projected to reach up to $12.5 trillion globally by 2030[51]. This encompasses the value reaped by users and clients of Internet of Things goods and services.

IoT has varying potential economic value depending on usage context. Large portions of this total are accounted for by IoT applications in the contexts of human health and factories. By 2030, the value potential of IoT in factories alone could reach up to $3.3 trillion, or slightly more than 25% of the total[52]. In human health settings, the economic impact of IoT could account for roughly one-sixth of the total estimated value.

Having a platform to run analytics, store and secure your data, and develop and manage applications is helpful if you want to reap the benefits of IoT[53]. In essence, these platforms perform numerous tasks in the background to simplify and lower the cost of life for developers, managers, and users[54]. They deal with problems like connecting to and extracting data from numerous end points, some of which may be in awkward places with sporadic connectivity.

A few things to think about when assessing IoT platforms are as follows:

1. environment for applications: Here, industries might look into things like: Is it possible for the platform to create, test, and support multiple applications? Is it easy to connect to the apps that my company already uses?

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2. administration of data: For example, knowing whether the platform can join and organize several unidentified data sets is useful[55].

3. possession of cloud computing infrastructure: Does the infrastructure provider use its own public cloud provider or does it own and run its own data centers? For additional information on this subject, see "What is cloud computing?"

4. safety: What unique commercial-grade encryption, authentication, and monitoring features does the platform offer?

5. Processing and control at the edge: Here, industry could look at the platform's ability to perform edge analytics without transferring data to the cloud or check how simple it is to set up for local asset control without the need for human intervention[55].

The following six requirements, which cover both enterprise and consumer use cases, are met by a seamless IoT experience:

i. Hyperconnected: Many devices and sensors that share data are seamlessly connected.

ii. Integrated: Easily integrated within and between device networks, it makes use of several platforms, back-end systems, and connectivity standards at the same time.

iii. Secure and trusted: A high level of trust in managing the multilayered complexity of both new and legacy solutions is made possible by dynamic cybersecurity.

iv. Intelligent: Thanks to AI and machine learning, devices and systems are intelligent enough to make decisions in real time based on data analysis. This makes the transition from monitored to automated implementation possible.

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v. Mobile: friendly experiences are made possible by low maintenance, battery-efficient devices and networks with a personality.

vi. Hyper personalized.: Experiences are customized for various platforms and situations.

The Industrial Internet of Things, or IIoT, is among the advanced manufacturing technologies collectively referred to as Industry 4.0, or the Fourth Industrial Revolution[57]. There are both positive and negative factors that can impact IoT adoption in terms of maximizing its value.

IoT solution adoption and impact could be accelerated by three factors:

i. The proposition of perceived value. Consumers find value in IoT and its ability to support sustainability initiatives and digital transformation[58].

ii. Technical advancements. For the vast majority of IoT applications, there is affordable technology that makes large-scale IoT deployments possible[58]. Advances in analytics, artificial intelligence, and machine learning can be combined with hardware advancements to provide more precise insights and expedited decision-making.

iii. Networks. These form the core of the Internet of Things, and more people now have access to faster 4G and 5G networks[58].

On the other hand, a number of variables may limit adoption. These include the requirement for new channels for cross-functional collaboration, problems with interoperability, installation difficulties, and worries about privacy and cybersecurity[59].

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When an organization is just getting started, it can be beneficial to think about the things that could make enterprise IoT journeys more rapid.

Organizations should adopt the technology at scale rather than focusing on isolated projects if they want to truly benefit from the Internet of Things[60]. When implementing IoT, the company should do the following helpful steps to scale IoT: Invest in technical talent. Change the entire organization, not just the IT function. Decide who owns IoT in the organization. Design for scale from the beginning[61]. Don't dip your toe in the water—deploying multiple use cases can be a forcing mechanism in transforming operating models, workflows, and processes. Push for interoperability. Proactively shape your environment by creating and managing IoT ecosystems.

2.1.2.2 Building Information Modelling

Building Information Modelling, or BIM, is a process that is required globally to guarantee that building planning, design, and construction are highly collaborative and efficient[62].

Building Information Modelling, also known as Building Information Management, is abbreviated as BIM. Architects, engineers, contractors, manufacturers, real estate developers, and other construction professionals can plan, design, and build a structure or building within a single 3D model thanks to this highly collaborative process[62]. Building information management refers to the use of data that building or structure owners have access to for the operation and management of buildings. Even after the building is constructed, this data enables governments, municipalities, and property managers to make well-informed decisions based on information derived from the model[63].

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Drawings and blueprints were once utilized to provide details about a specific building layout. Dimensions and requirements were quite difficult to visualize with this 2D method. Then came CAD (Computer Aided Design), which made plans more useful in a digital setting for drafters. Later, CAD became 3D, giving plans more lifelike images[64]. Building information modelling, or BIM, is the norm these days, but it goes much beyond simple 3D modelling.

The elements that comprise a BIM model, known as BIM objects, contain geometry, intelligence, and data storage capabilities. BIM software refreshes the model to reflect any changes made to any element. In order to foster greater collaboration among structural engineers, architects, MEP engineers, designers, project managers, and contractors, this enables the model to stay coordinated and consistent throughout the whole process[65].

BIM encompasses the collaborative process of data sharing and teamwork among all stakeholders involved in the construction and lifecycle management of built assets. Nonetheless, information, or the "I," is where BIM's real power resides[66]. From the beginning to the end, every piece of information obtained is not only saved but also useful. The information can be utilized to increase precision, communicate design intent from the office to the field, enhance knowledge transfer between stakeholders, lessen the need for change orders and coordination issues in the field, and offer information about current structures for future refurbishment projects[66].

An "information model" is the term used to describe the data that is gathered and exchanged in a BIM model through a freely accessible online space called a common data environment (CDE)[67]. Information models can be applied to a building's design, construction, operation, and even restoration and renewal phases. For different kinds of

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projects, different BIM levels can be attained[68]. Every level denotes a distinct set of requirements that show a certain degree of "maturity." Levels of BIM range from 0 to 4D, 5D, and even 6D. These levels are meant to serve as a gauge for how well—or how much—information is shared and handled during the entire process[69].

BIM has specific goals and objectives that are advantageous to everyone advancing through the stages because of the obvious advantages[70]. Without a doubt, building will become even more digital and highly collaborative in the future. With the growing sophistication of BIM, 4D, 5D, and even 6D BIM will begin to be used in the process.

Moreover, efforts are being made globally to minimize waste in the construction industry. Conflicts, reworking, and inefficiencies in the supply chain are largely to blame for this[71]. All of this is significantly less likely when team members collaborate in a BIM environment, paving the way for a brighter tomorrow.

2.1.2.3 Artificial Intelligence

Artificial intelligence (AI) is the technology that makes it possible for computers and other devices to mimic human autonomy, creativity, problem-solving, learning, and comprehension[71]. The ability of a machine to carry out a task that would have previously required human intelligence is known as artificial intelligence (AI). Its definition has changed over decades of research and technological advancements since it was first proposed in the 1950s[72]. AI-enabled apps and gadgets are able to see and recognize objects. They are able to comprehend and react to human language. They are able to pick up new skills and knowledge. Both users and experts can receive detailed recommendations from them. They are capable of acting on their own, negating the need for human intelligence or involvement (a self-driving car is a classic example)[73].

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The notion behind the term artificial intelligence (AI) is that, even if intelligence is innate in organic life, its presence elsewhere renders it artificial. Alan Turing, a computer scientist, was among the first to investigate the notion that machines could use data and reasoning to make decisions in the same way as humans[74]. The Turing test, which he invented, measures whether people can tell a machine's performance is artificial (convincing deepfakes are an example of AI passing the Turing test). Programmers write code for basic computing systems that allows them to perform certain tasks. However, AI can only exist in computers that have the capacity to store data, including previous commands, in a manner akin to how the human brain stores memories and skills in order to learn. Because of this feature, artificial intelligence (AI) systems can learn new skills and adapt to tasks for which they were not specifically designed.

According to some experts, intelligence is the capacity to learn new things, adapt, solve issues, plan, and improvise in novel circumstances[75]. Modern AI systems exhibit certain characteristics of human intelligence, such as learning, problem-solving, pattern-finding, perception, and even a restricted range of creativity and social awareness, even though they cannot replace human intelligence or social interaction. There is a plethora of potential uses for AI, many of which are currently commonplace in daily life. This potential extends to wearables, vacuums, and even the recently redesigned Google Search at the consumer level. Another excellent example of artificial intelligence is the built-in Google or Alexa voice assistant in your smart speakers. Personalization is a key use of AI in consumer products, whether it be for biometric security or targeted advertising[75]. This explains how your phone can recognize your face from someone else's when you use Face ID, for example. It has learned your face's characteristics by comparing specific data points to the faces of billions of other people. AI can be used on a larger scale by content

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and marketing teams to expedite production, and by developers to write and run code. The speed and effectiveness of medical research can also be greatly increased by AI.

Narrow AI, general AI, and super AI are the three subcategories of artificial intelligence[76].

Artificial narrow intelligence (ANI) is the term for intelligent systems that have been specifically trained or engineered to accomplish particular tasks or resolve particular issues without explicit design. Voice assistants such as Google Assistant, Alexa, and Siri depend on this kind of AI. ANI is sometimes referred to as weak AI because it lacks general intelligence. However, that does not negate its inherent power. ANI includes tools that flag inappropriate content on the internet, image recognition systems, voice assistants, and technologies that reply to basic customer service inquiries[76].

Strong AI, also known as artificial general intelligence (AGI), is still purely theoretical since it entails a machine that can comprehend and carry out a wide range of tasks on its own thanks to its experience[76]. Given that AGI systems would be able to reason and think more like people do, this sort of intelligence would be more comparable to human intellect. Similar to a human, an artificial general intelligence (AGI) might be able to comprehend any intellectual task, think abstractly, gain experience, and apply that experience to solve new problems. We're essentially talking about a machine or system that is capable of common sense, which is currently impossible with any AI that is available[77].

A machine intelligence that surpasses all human intelligence and performs better than humans in every way is called artificial superintelligence (ASI). Such a system has the potential to wipe out humanity in addition to upending it completely[76]. That sounds a lot like something you'd read in a science fiction book, and for good reason. It is still only a theoretical idea to create an intelligent system that is capable of self-improvement through

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learning. But if used wisely and morally, the system might produce amazing advancements in technology, medicine, and other fields[77].

Innovation in the construction sector is being propelled by artificial intelligence (AI), as evidenced by the latest patents that highlight improvements in accuracy, efficiency, and safety. These technologies provide ways to improve transportation systems, guarantee good hygiene, and identify and prevent accidents[78]. Although strategic AI deals are still stable, job postings show a notable increase, especially in computer and mathematical occupations, suggesting a growing need for AI knowledge in the construction industry. AI is having an impact on a number of industries besides construction.

Artificial intelligence (AI) technologies are being used by construction companies to innovate and enhance their operations[77]. Systems for detecting people in hoist ways, utilizing contamination sensors to verify hand washing, goods transportation cableways, artificial intelligence (AI) for telemetry data identification, and trajectory and intent prediction are among the recent patents in this field. Benefits from these technologies include increased accuracy, efficiency, and safety during construction. AI, for instance, can assist with accident detection and prevention, hand hygiene, transportation system optimization, and access control device user intent prediction[78]. By obtaining these patents, construction companies can use cutting-edge AI applications customized to meet their unique needs to improve operations, lower risks, and streamline procedures.

Machine Learning (ML) is another term that comes up when talking about AI. Machine learning (ML) is a branch of artificial intelligence (AI) that lets computers learn from data without explicit programming[79]. As the machine is exposed to more data, it gains knowledge and produces more accurate insights. Construction sites can become safer, more efficient, and waste-free by utilizing AI's remarkable qualities. Artificial Intelligence

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(AI) presents significant advantages for the construction sector, making it a worthwhile area of study.

Information requests, order changes, and other problems are commonplace in construction projects[78]. When examining the vast amount of data, machine learning can be a wise assistant. It can notify project managers of important problems that require their quick attention.

Artificial intelligence (AI) has been used in many applications for both simple tasks like spam email filtering and sophisticated safety monitoring systems. The services include everything from monitoring construction sites to improving workplace safety to scheduling work schedules optimally. AI has a lot more to offer and is already proving its worth.

Applications of AI in Construction

i. Generative Design

The term "generative design" refers to AI's capacity to investigate multiple model iterations until the optimal solution is identified[79]. To facilitate communication between the various construction teams, the architecture, engineering, mechanical, electrical, and plumbing (MEP) plans should be included in the building's 3D models as they are developed. Making sure that the various models from the sub-teams don't conflict with one another is the difficult part, though. In this scenario, artificial intelligence (AI) could utilize generative design to take a BIM model and analyse a number of small and big design adjustments to make a system more reliable, safer, or just easier and faster to build. A human could take months to investigate all of these options, but an AI engineering program could do so in a matter of hours[80].

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ii. Project Management

Projects involving construction are typically prone to delays and cost overruns. However, AI is able to forecast future events and make realistic timeline predictions by analysing past data, including scheduled start and end dates[81].

The likelihood of project delays can be determined using AI-enhanced project planning and management (PPM) software, which may help with project revision and resource and time management improvements[82]. Drone technology is also being integrated with AI to offer fresh viewpoints on ongoing projects. Drones with AI capabilities can monitor productivity levels and identify potentially dangerous activity, improving site safety, efficiency, and productivity.

iii. Increased Productivity

Autonomous vehicles are being used on construction sites to carry out a variety of tasks over the course of the project. A few businesses have already created self-contained excavators and bulldozers that can be given tasks and operate on their own[83].

Concrete pouring, bricklaying, welding, and demolition are examples of repetitive tasks performed by self-driving construction equipment. Because these machines are more productive than human workers, construction time can be decreased while personnel can focus on more important tasks.

For example, remote diggers could work around the clock on a project that is located far away, guaranteeing much faster completion of the work.

iv. Improved Safety

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Artificial intelligence (AI) has been used in many applications for both simple tasks like spam email filtering and sophisticated safety monitoring systems[84]. Compared to workers in other industries, construction workers have a five-fold higher chance of encountering potentially fatal situations.

To monitor various aspects of construction operations, job sites can be outfitted with sensors, cameras, and Internet of Things devices. Artificial intelligence (AI) systems can identify risky behavior and alert the construction crew to possible dangers with the use of facial and object recognition technologies[85].

Artificial intelligence is also being developed to evaluate site photos, check them for possible safety risks, and compare them to accident histories. Additionally, the technology can be used to keep an eye on tools, supplies, and equipment by sounding an alarm in the event that theft attempts are made at the location[86].

v. Building Management

The benefits of AI extend beyond the building phase; even after a project is finished, it can demonstrate remarkable potential. Building managers can use the structural data contained in BIM to keep an eye on emerging problems and provide solutions to stop them from happening[87].

AI can optimize and automate facility management, lowering operating expenses in the process. These encompass energy efficiency, proactive maintenance and malfunction identification, and augmenting the overall occupant experience.

vi. Project Estimation

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Construction blueprints could be analysed by AI-driven estimating software, which would then generate automated take-off solutions. By generating accurate estimates in a matter of seconds, the software can spare construction professionals from laborious and costly estimation procedures[87]. Building Estimators can focus on higher-value services for their clients, like value engineering and scoping, thanks to AI engines. All it takes to upload blueprints in any format or file type is[88].

2.1.2.4 Robotics

The application of robotics to the construction industry is transforming the way that infrastructure is designed, built, and maintained. This technological advancement is not just a small step toward improvement; rather, it is a fundamental shift that has the potential to greatly increase efficiency, safety, and sustainability[89]. Historically, the construction industry has been a labour-intensive one, with manual processes that are frequently dangerous, time-consuming, and prone to human error. By automating tasks that were previously done by hand, robotics has helped to overcome these challenges[90]. Robots are capable of more accuracy and consistency than humans when it comes to performing physically taxing, hazardous, and repetitive tasks.

The increase in productivity is one of robotics' most important contributions to the construction industry[91]. The amount of time needed to perform jobs like material handling, welding, and bricklaying can be significantly decreased by using robots[92]. Bricklaying robots, such as the SAM (Semi-Automated Mason) system, can lay bricks substantially faster than human labour, which can save a significant amount of time on large-scale projects. The construction process can be optimized by these robots because they have artificial intelligence (AI) systems and sensors that enable them to work alongside human workers and adapt to their surroundings[93].

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Robotics in construction not only increases productivity but also dramatically improves safety. Building sites are frequently dangerous places where employees run the risk of suffering injuries from exposure to dangerous materials, heavy machinery mishaps, and height falls. In these hazardous environments, robots can be used to carry out tasks that would otherwise endanger human workers[94]. Drones, for instance, are being utilized more often for site inspections, particularly in hazardous or difficult-to-reach locations. These drones can give site managers high-resolution imagery and real-time data, allowing them to monitor progress and spot possible dangers without endangering workers.

Furthermore, the accuracy and precision that robotics provides can result in better-quality construction. Robots ensure precise construction of structures by performing tasks with minimal error[95]. In complex construction projects, like high-rise buildings or intricate architectural designs, where even a small deviation from the plan can have significant consequences, this level of precision is especially valuable. For instance, the use of 3D printing robots reduces waste and raises the overall quality of the final product by enabling the creation of complex components with a high degree of accuracy[96].

Another important area that robotics is influencing in the building sector is sustainability. One of the biggest users of raw resources and a major cause of environmental deterioration is the construction industry. Robotics can lessen these effects by cutting waste and increasing resource efficiency[97]. By ensuring that just the required number of resources is used, automated systems can optimize material consumption and reduce waste. Furthermore, robots can be used in building deconstruction, where they can meticulously disassemble buildings and separate materials for recycling, assisting the construction sector in implementing a circular economy[98].

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Robotics integration in the construction industry is not without difficulties, though. The expense of robotic systems is one of the main challenges. Even though robotic technology has obvious long-term benefits in terms of quality, safety, and productivity, the initial investment required might be prohibitive, particularly for small to medium-sized construction enterprises[98]. Skilled labourers who can manage and maintain these cutting-edge devices are also required. This calls for a change in the labour force, since there is an increasing need for programmers, engineers, and technicians with experience in robotics.

The industry's reluctance to shift presents another difficulty. The construction industry has long been associated with conservatism and deeply embedded established norms[99]. It can be challenging to bring about a cultural shift and a desire to accept new technology in order to deploy robotics. Concerns have also been raised over the possible effects on employment, as job displacement may result from the automation of jobs that were previously completed by humans[100]. Robotics advocates counter that rather than eradicating jobs, their field will see a shift in the nature of work, opening up new career options in fields like AI system administration and robotics maintenance.

In spite of these obstacles, robotics in construction has a bright future[101]. We should anticipate seeing increasingly advanced robots that can do a greater variety of jobs as technology develops. The exciting potential to further alter the construction sector lies in the development of autonomous robots that can navigate construction sites, make judgments, and carry out complex activities without human interference[102]. Furthermore, usage of robotic technology is anticipated to rise as its costs fall down and its advantages are acknowledged by more people.

In summary, the construction industry is expected to significantly benefit from robotics. It is a vital instrument for tackling the problems the industry faces because of its capacity to

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raise production, boost safety, and advance sustainability. Robotics in construction has obvious long-term benefits, but there are challenges along the way, such as high costs and opposition to change. As the construction industry develops further, robotics will probably play a major role in the building process, fostering efficiency and innovation in the creation of the future.

2.1.2.5 3D Technology

The way we create, manufacture, and interact with the world around us has been revolutionized by 3D technology, which has emerged as a revolutionary force across numerous sectors. Since its early uses in design and prototyping, 3D technology has spread to a wide range of industries, including healthcare, architecture, entertainment, and education, presenting previously unheard-of opportunities for efficiency and creativity[103].

Fundamentally, 3D technology comprises many essential procedures, such as 3D modelling, 3D scanning, and 3D printing. Using specialist software, 3D modelling entails producing a three-dimensional representation of an item. It is possible to improve, adjust, and work with this digital model before translating it into physical form[103]. Conversely, 3D scanning turns an actual object or environment into a digital 3D model by capturing its physical measurements. This is especially helpful in fields where precise reproductions of real items are needed, including manufacturing and archaeology[104]. Lastly, the process of turning a computer model into a physical product by layering on material is known as additive manufacturing, or 3D printing. Complex geometries that would be challenging or impossible to produce using conventional manufacturing processes may now be produced because to this approach.

The manufacturing industry has seen one of the biggest effects of 3D printing technology. In the past, subtractive techniques were used in manufacturing, which entailed taking

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material out of a solid block to form it into the required shape[104]. The intricacy of forms that could be created with this method was constrained, and it frequently caused substantial material waste[105]. However, because material is injected just where needed in 3D printing, it is possible to create complicated structures with little waste. As a result, there is a growing interest in additive manufacturing to produce prototypes, finished goods, and even customized parts. Because 3D printing may lower manufacturing costs, shorten time-to-market, and make it easier to create highly personalized items, industries including consumer electronics, automotive, and aerospace have welcomed the technology[106].

Another field in which 3D technology has had a significant impact is healthcare. 3D printing has been used to create prosthetics, medical implants, and even scaffolds for tissue engineering. Additionally, 3D printing has made it possible to produce prototypes for surgical planning quickly, allowing surgeons to practice intricate procedures on precise models of a patient's anatomy before performing the actual surgery[106]. This lowers the risk of complications and improves surgical precision. Finally, researchers are investigating the possibility of using 3D bioprinting, a process that involves printing with bioinks made of living cells, to create functional tissues and organs. Although 3D bioprinting is still in its infancy, technology has the potential to alleviate the severe organ scarcity in the future.

3D technology has also been quickly embraced by the building and architectural sectors. To design structures and infrastructure, engineers and architects employ 3D modelling software, which makes project visualization and analysis more precise[107]. Designers may investigate intricate geometries and maximize their designs for energy efficiency and structural integrity thanks to this technology. Moreover, complete buildings and even

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individual building components are being created using 3D printing. This method, called 3D printing for building, has the potential to cut down on labour expenses, material waste, and construction time. The completion of a 3D-printed office building in Dubai in 2017 serves as an example of how this technology might be used for major construction projects[108]. The capacity to print buildings on location has ramifications for cheap housing and disaster aid as well, as quick structural deployment is essential.

The creation and consumption of material has been completely revolutionized in the media and entertainment sectors by 3D technology[109]. Cinema today would not be the same without 3D animation and visual effects, which allow filmmakers to create realistic, immersive worlds that entice viewers. The development of 3D modelling and rendering has also benefitted video games, making them more realistic and captivating to play[110]. With their reliance on 3D material, virtual reality (VR) and augmented reality (AR) technologies are pushing the frontiers of entertainment by enabling users to engage with digital worlds in novel and captivating ways. Beyond only entertainment, these technologies may also be used in training, education, and simulation, where immersive 3D environments can improve skill development and learning[111].

Another area where 3D technology is becoming widely used is education. In order to encourage students' creativity and invention, curricula are increasingly including 3D printing and modelling technologies. With the use of these technologies, students may bring their ideas to life and get practical experience that can help them comprehend difficult ideas more fully[112]. Students majoring in engineering or architecture, for instance, can create and print prototypes of their projects using 3D modelling software, giving them real-world experience with design thinking and problem-solving. Students can better

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learn complex intricacies in the sciences by using 3D printed replicas of molecules, organs, or other biological structures instead of typical 2D representations.

3D technology has drawbacks in addition to its numerous benefits. The consequences of 3D printing for intellectual property are a major worry as technology makes object replication simple and poses issues with copyright and patent infringement[113]. Furthermore, worries regarding the possibility of producing illicit or hazardous goods, such weapons, have arisen as a result of the widespread availability of 3D printing technology. To guarantee that 3D technology is utilized properly, addressing these issues calls for a mix of technological protections, regulatory frameworks, and ethical standards.

Furthermore, there are still obstacles standing in the way of the widespread adoption of 3D technology across various industries[114]. These include the high price of sophisticated 3D printers, the requirement for specific knowledge to run and maintain these machines, and the restrictions on the kinds of materials that can be printed using 3D technology[115]. But as the technology develops and matures, it's anticipated that these obstacles will disappear, resulting in increased adoption and new uses.

3D technology is an incredibly potent instrument that is changing entire industries and creating new avenues for creativity and innovation[116]. 3D technology has the potential to decrease costs, increase efficiency, and improve the quality of goods and services in a variety of industries, including manufacturing, healthcare, architecture, and entertainment. Even though there are obstacles to overcome, 3D technology's continuous advancements promise to increase its impact and establish it as a crucial component of our technological environment[117].

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2.1.3 Skill Development

Skill development is a crucial function that enables organizations to maintain a competitive edge in today's dynamic business environment. Companies that invest in employee development see higher retention rates, as employees are more likely to stay with employers who invest in their growth[212]. Managers play a crucial role in employee development because they identify the specific needs of their team members and create a conducive environment for learning[213]. It was suggested that managers should be actively involved in the training process, from identifying needs to implementing training programs[212]. Recent studies emphasize the shift toward employee-driven development, where employees proactively take on roles in enhancing their skills. Studies such as [215,215] proposed a broader conceptualization of employee development, characterizing it as a partnership between the employer and employee. They suggest that incorporating proactivity, updating learning contexts, and rethinking the value of human capital are essential for aligning development practices with current workplace trends[214]. However, a scholar emphasizes the importance of integrating learning into a daily workflow. This approach ensures that employees can apply new skills immediately, enhancing retention and practical application[216].

Building successful upskilling programs involves identifying valuable skills and competencies that align with organizational goals. The COVID-19 pandemic has accelerated the need for reskilling, making it a short-term survival strategy for many companies[217]. A systematic review by a scholar examined how ongoing job education influences employee retention and found that CPD programs are vital for maintaining and enhancing employee skills over time. Consequently, organizations need to adopt dynamic approaches to teaching new skills, especially in the context of hybrid workplaces and

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emerging technologies. This requires continuously adapting and updating training programs to meet the evolving needs of businesses[219].

In this study, the researcher recognizes reskilling and upskilling which is used by employee at any given stages of the work life either by way of navigating to another job or improving on the already acquired skills. On-the-job training (OJT) and off-the-job training (Off-JT) are two essential methodologies for employee skill development, each possessing distinct attributes, advantages, and obstacles, particularly in sectors such as construction[189]. Comprehending these training methodologies is crucial for enhancing employee performance and guaranteeing safety and efficiency in high-risk settings like construction sites.

2.1.3.1 Method of Skill Development

1. **On-the-Job Training (OJT):**

OJT is hands-on, workplace learning under the supervision of experienced workers. Training workers as they perform their daily activities lets them learn by doing. This usually means construction workers learn by operating heavy machinery, establishing electrical systems, or handling building supplies. This training method provides instant feedback from supervisors or proficient colleagues, allowing trainees to rectify errors and enhance their talents in actual time[189]. A novice operator of a crane or other heavy machinery will gain from immediate guidance on appropriate handling methods, safety protocols, and task performance. The prompt feedback loop is essential for averting expensive errors and maintaining compliance with safety standards on active construction sites. Another significant advantage of OJT is its cost-effectiveness. Since the training takes place within the normal workflow, there are fewer additional expenses for training infrastructure or off-site training sessions[190]. However, OJT is not without its challenges.

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Since training occurs in real-time within the workplace, it often lacks the structure needed for in-depth theoretical understanding or reflection[191]. In high-risk environments such as construction, inadequate supervision or insufficient training time can lead to workplace accidents or safety violations, which poses a significant risk to both the trainees and their colleagues. Therefore, OJT must be carefully structured and closely monitored to ensure safety and efficacy[192].

2. Off-the-Job Training (Off-JT)

Off-the-job training occurs outside the immediate workplace, usually in classes, workshops, or training facilities. In the construction industry, Off-JT may encompass technical training on blueprint interpretation, building rules, safety measures, or the utilisation of specialised software such as Computer-Aided Design (CAD)[193]. Off-JT offers a more secure educational setting, especially for the operation of intricate instruments or machinery. Another advantage of Off-JT is the potential for extensive learning. Trainees can thoroughly explore building rules, safety regulations, and other critical ideas that may be challenging to comprehend in a rapid work setting[194]. It also allows for learning soft skills, such as leadership, communication, and project management, which are crucial for advancing into supervisory roles. However, Off-JT tends to be more expensive than OJT. Training facilities, equipment, and instructors often come at a high cost, and workers need to spend time away from their regular duties to participate in the training[192]. Additionally, there can be a gap between learning and application. Skills acquired in off-the-job training may not be immediately relevant to the construction site, and there can be a delay in applying theoretical knowledge to real-world situations[195].

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A hybrid methodology integrating on-the-job training and off-the-job training is frequently the most efficacious in the construction sector[196]. Trainees acquire theoretical knowledge during off-the-job training, including construction safety principles and sophisticated machinery operation, and subsequently implement those skills in practical environments under meticulous supervision. This integrated approach guarantees that employees are both proficient and self-assured in their positions, as they acquire hands-on experience while comprehending the overarching theoretical principles that regulate construction procedures. It also assists employees in obtaining essential qualifications while equipping them for the practical problems encountered on-site.

Professional development of employees in the construction sector is an essential element for sustaining competitiveness, guaranteeing safety, and achieving projects of superior quality. The construction sector, known for its dynamic and intricate characteristics, places significant reliance on the knowledge and skills of its personnel[188]. With the increasing complexity of projects and the ongoing evolution of technology, the demand for a highly proficient workforce has never been more urgent. Enhancing the abilities of employees not only boosts individual performance but also promotes the holistic success of construction companies by increasing productivity, minimizing mistakes, and promoting innovation[121].

The construction sector includes a broad spectrum of operations, ranging from home construction to massive infrastructure projects, each necessitating a varied array of compétences. The breadth of abilities encompasses numerous manual crafts, including carpentry, masonry, and plumbing, as well as more specialised fields such as project management, engineering, and the application of advanced building technology[21]. The inherent characteristics of construction work, characterized by its significant variability

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and the importance of accuracy, make the sector especially responsive to the proficiency levels of its personnel. An adequately trained and skilled staff is crucial for guaranteeing the safe, timely, and competent completion of projects according to the necessary requirements[189].

The rapid progress of technology is a key catalyst for the enhancement of staff skills in the construction sector. The implementation of Building Information Modelling (BIM), prefabrication methods, drones, and other digital technologies has revolutionised the architectural design, management, and execution of building projects. These technologies necessitate the acquisition of novel talents that were not conventionally included in the skill set of the construction worker[190]. For example, BIM specifically requires expertise in 3D modeling software, whereas the operation of drones necessitates understanding of aerial surveying methodologies. With the increasing integration of these technologies in the building process, it is imperative for the industry to allocate resources towards training programs that provide the workforce with the essential skills to use them proficiently.

Furthermore, alongside technical progress, the increasing focus on sustainability in the building industry has also underscored the importance of enhancing skills. A comprehensive understanding of green building materials, energy-efficient design, and environmentally friendly construction procedures is essential for the implementation of sustainable construction practices[189]. Given the growing emphasis on sustainability in regulations and client expectations, it is imperative for construction companies to guarantee that their personnel receive training in these domains. Employing this approach not only enables companies to adhere to regulatory obligations but also establishes them as frontrunners in the expanding sustainable construction industry.

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The construction sector is currently experiencing a substantial deficiency in skills, mostly caused by an aging workforce and a scarcity of new graduates entering the business. A significant number of seasoned construction workers are approaching retirement, raising concerns about the availability of sufficient qualified talent to fill their positions. The existence of this skills gap presents a significant obstacle to the sector, as it has the potential to result in production delays, higher expenses, and a deterioration in the standard of work. In order to tackle this issue, construction companies should prioritize the recruitment, training, and retention of young professionals. Essential approaches for cultivating the future construction workforce include apprenticeship programs, vocational training, and collaborations with educational institutions.

The construction industry has traditionally relied on apprenticeships as a fundamental means of enhancing skill development. These curricula integrate practical training with classroom instruction, enabling apprentices to acquire the necessary abilities for their trade while also developing a theoretical comprehension of construction concepts. The effectiveness of apprenticeships lies in their provision of practical experience under the supervision of seasoned mentors, a highly significant asset in an industry that places great importance on practical abilities. By allocating resources to apprenticeship programs, construction companies may guarantee a consistent supply of highly trained personnel who are well equipped to fulfill the requirements of the sector.

Furthermore, with apprenticeships, ongoing professional development (CPD) is crucial for ensuring that the current staff remains current with the most recent industry trends, technology, and optimal methods[191]. Continuing Professional Development (CPD) refers to the continuous training and education that an individual undergoes throughout their career to ensure the continuous improvement of their skills and knowledge. This holds

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significant importance in the construction sector, as advancements in technology, changes in legislation, and evolving client expectations can quickly make incumbent capabilities outdated. Continuing Professional Development (CPD) encompasses a range of formats such as workshops, seminars, online courses, and certification programs. By cultivating a culture that promotes ongoing education, construction companies may guarantee that their personnel maintain a leading position in the industry[192].

Proficient development of leadership and management skills is an essential aspect of skill enhancement within the construction sector. Effective leadership is crucial for the effective implementation of construction projects, which frequently require the coordination of several teams, the management of intricate logistics, and the making of crucial choices under stressful conditions. Proficient leadership, effective communication, and adept problem-solving abilities are essential for construction managers and supervisors to successfully negotiate the complexities of the sector. Training programmes that specifically target these areas can facilitate the development of the next generation of construction leaders who possess the ability to propel projects with enhanced efficiency and effectiveness.

Another crucial component of employee skill development in the construction sector is safety training. Construction sites are intrinsically dangerous settings, where workers are directly exposed to hazards such as falls, equipment malfunctions, and contact with dangerous substances. It is imperative to ensure that all employees possess comprehensive knowledge of safety procedures in order to prevent accidents and safeguard the welfare of the workforce. Comprehensive safety training programs should encompass a broad spectrum of subjects, such as the utilization of personal protective equipment (PPE), identification of hazards, emergency response, and the safe operation of

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equipment. Regular safety training serves the dual purpose of safeguarding personnel and minimising the probability of expensive accidents and project delays.

Furthermore, the government and industry associations play a crucial role in fostering skill development in the construction sector. A number of governments acknowledge the significance of a proficient construction labour force and have enacted legislation and financial initiatives to bolster training and education in the industry. Specifically, construction companies that allocate resources towards staff training programs may be eligible for grants and subsidies[191]. The development of training standards, provision of certification programs, and provision of resources for continuing education are all essential functions performed by industry bodies, including trade associations and professional organizations. Effective collaboration among construction companies, government agencies, and industry organizations is crucial for establishing a strong foundation for enhancing skills in the sector.

Furthermore, the process of globalization in the construction sector has brought up novel requirements and prospects for the enhancement of skills. Given the growing presence of construction companies in global markets, it is imperative for them to possess the ability to adjust to diverse legal frameworks, cultural settings, and construction methodologies. This necessitates a personnel that possesses not only extensive technical expertise but also cultural proficiency and the ability to collaborate efficiently in heterogeneous teams[193]. The implementation of training programs that prioritize global best practices, cross-cultural communication, and international standards can effectively equip personnel to tackle the complexities of operating in a globalized industry.

There exists a strong correlation between the enhancement of employee skills and both career advancement and job satisfaction within the construction sector. The provision of

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skill development opportunities serves to incentivize employees, enhance job satisfaction, and mitigate turnover. Organizational loyalty and commitment among employees are more likely to be maintained when they see that their employer is actively engaged in fostering their professional development. This, in turn, benefits the construction company by lowering the expenses linked to hiring and training new staff. To cultivate a competent and driven staff capable of tackling industry difficulties, construction companies can establish well-defined career trajectories and offer access to training and development opportunities[192].

Professional development of employees in the construction sector is crucial for sustaining competitiveness, guaranteeing safety, and executing projects of superior quality. Given the industry's dependence on a highly trained staff, the fast progress of technology, increasing focus on sustainability, and the difficulties posed by an aging workforce, it is crucial to invest in training and development. Essential elements of a complete skill development strategy include apprenticeships, ongoing professional development, leadership training, and safety initiatives[193]. Furthermore, the endorsement of governmental and industrial organizations, together with an emphasis on superior international standards, can guarantee that the construction labor force is adequately equipped to fulfill the requirements of the sector. By placing skill development as a top priority, construction companies can cultivate a staff that is more competent, flexible, and driven, so resulting in improved project results and sustained success in the long run.

2.2 Theoretical Framework

2.2.1 Socio-Technical Systems Theory

The Socio-Technical Systems (STS) has become a significant paradigm for comprehending the complex interaction between social and technical elements in

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organizational settings[189]. The concept is based on the understanding that work systems must be effectively and satisfactorily created by integrating both human and technological elements in a harmonious manner.

Eric Trist, a British psychologist affiliated with the Tavistock Institute of Human Relations in London, stands as a fundamental player in the advancement of STS Theory[190]. The pioneering study undertaken by Trist and his colleagues during the 1940s and 1950s focused specifically on the British coal mining sector. Their research revealed that work systems optimized to harmonize social elements, such as collaboration and communication, with technical elements, such as machinery and processes, led to increased productivity and enhanced employee happiness. The foundational principles of STS Theory were significantly shaped by Trist's profound findings.

Fred Emery, an Australian social scientist, significantly contributed to the progressive development and widespread dissemination of STS Theory. Working in close collaboration with Trist at the Tavistock Institute, Emery broadened the scope of the theory by exploring the concept of "open systems" thinking[191]. He stressed the importance of perceiving companies as open systems that engage in ongoing interactions with their external surroundings. Emery also expressed support for participative work design, which entails the active involvement of employees in defining the work processes they participate in. This approach aims to improve both the effectiveness of the company and the well-being of the employees.

Renowned British academic Enid Mumford made a substantial contribution to STS Theory[192]. She gained recognition specifically for her contributions to the design and execution of information systems in industrial settings. Mumford's research underscored the need of taking into account the social ramifications of emerging technologies and

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promoted the participation of users in both the design and execution phases. The methodology she developed, called ETHICS (Effective Technical and Human Implementation of Computer-based Systems), aimed to optimize the design of technological systems to align with both organizational objectives and the welfare of personnel[193].

The notable contributions made by Trist, Emery, and Mumford, among other scholars, played a crucial role in establishing Socio-Technical Systems Theory as an essential framework for comprehending and enhancing the intricate interactions between individuals and technology inside professional environments. Their groundbreaking contributions persistently shape modern methodologies in organizational design, namely in domains such as information systems, management, and human resources.

Although widely influential, Socio-Technical Systems (STS) Theory has been subject to criticism from many viewpoints. A prevalent criticism of the theory is that it may be excessively idealistic, particularly in its presumption that the social and technical aspects may always be ideally harmonized within an organization. In fact, critics contend that attaining this equilibrium is frequently difficult because of the intricate and unpredictable nature of both human behavior and technological progress. The theory's emphasis on participatory design and worker engagement, although theoretically valid, might pose challenges in hierarchical organisations characterised by a concentration of decision-making authority at the CEO level. Consequently, this can result in opposition from the management or difficulties in harmonizing the interests of all parties involved[190].

One further critique of STS Theory is its apparent lack of clarity in implementing its concepts. Although the theory has a strong conceptual framework, there are many who contend that it does not include explicit and practical protocols for practitioners to adhere

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to[195]. This might pose challenges for businesses in converting the theoretical concepts into practical approaches for system design and deployment. Moreover, the focus on customizing systems to suit the particular requirements of an organization might lead to solutions that are heavily influenced by the individual circumstances, therefore restricting the wider utility of the idea.

Furthermore, the theory has been criticism for its incomplete consideration of power relations and organizational politics[196]. Despite its focus on collaboration and worker empowerment, STS Theory may not sufficiently address the impact of power dynamics and conflicts inside an organization on the effectiveness of socio-technical designs. The failure to consider this aspect can result in a neglect of the possibility for technical systems to strengthen preexisting disparities or power imbalances within an organization.

Ultimately, several detractors argue that STS Theory may encounter difficulties in keeping up with the swift technical progress of the contemporary age. The hypothesis emerged at a period characterized by rather sluggish technical advancements in contrast to the current digital era, wherein advancements such as artificial intelligence, automation, and big data are revolutionizing work environments at an unparalleled pace. This prompts inquiries on the applicability of the theory in tackling the limitations presented by these developing technologies, which may necessitate the development of novel frameworks and methodologies. To summarise, although Socio-Technical Systems Theory has made substantial contributions to comprehending the interaction between social and technical aspects in organisations, it has faced criticism for its idealistic, ambiguous, and occasionally inadequate consideration of power dynamics and the rapid rate of technological growth.

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The Socio-Technical Systems (STS) Theory is highly relevant for the implementation of Industry 4.0 technologies in the construction sector. It provides a comprehensive framework that combines social and technical elements to fully maximize results. In light of the construction industry's growing adoption of digital transformation via Industry 4.0 technologies, including automation, robotics, artificial intelligence, and the Internet of Things (IoT), the concepts of STS Theory offer significant insights into the successful integration of these technologies into intricate organizational systems[195].

Innovations in Industry 4.0 hold the potential to transform the construction sector by increasing productivity, decreasing expenses, and enhancing safety. Nevertheless, the effectiveness of these technologies relies not only on their technical capacities but also on their integration into the current social frameworks of construction firms. The significance of taking into account the human factor in this process is underscored by STS Theory[195]. This implies that in order to effectively implement Industry 4.0 technologies, it is necessary to ensure a meticulous synchronization between technological systems and the social systems in which they function. This entails comprehending the requirements, abilities, and apprehensions of the employees, and guaranteeing that novel technologies are implemented in manners that facilitate rather than disturb existing work methodology.

Furthermore, STS Theory emphasizes the key need of including workers in the process of designing and implementing new technologies. Within the framework of Industry 4.0 in the construction sector, this may entail including construction workers, engineers, and managers in the deliberate selection and tailoring of technologies to meet the particular requirements of construction projects. The use of this participatory strategy can effectively mitigate opposition to change, cultivate a feeling of ownership among

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personnel, and guarantee the alignment of the technology with the pragmatic parameters of construction activity[197].

One further facet of STS Theory that is pertinent to the implementation of Industry 4.0 is its emphasis on the interconnectedness of social and technical components. Within the construction industry, it is important to acknowledge that the effective incorporation of cutting-edge technology depends not just on the technology itself, but also on the organizational culture, communication, and collaboration across teams[198]. For instance, the implementation of collaborative robots or automated machines on building sites necessitates the adoption of novel methods of coordination and communication among people. Science and Technology Studies Theory promotes a comprehensive approach to these issues, arguing for the development of systems that facilitate smooth interaction between human workers and technical tools.

Moreover, the application of STS Theory can effectively mitigate the possible hazards and unforeseen outcomes associated with the implementation of Industry 4.0 in the building industry. Although automation has the potential to increase productivity, it can also result in job displacement or alterations in job responsibilities that could affect worker happiness and safety. Through the use of STS concepts, construction firms can proactively anticipate these issues and devise solutions to alleviate them, such as implementing reskilling programs or redefining work positions to align with emerging technologies[198].

Socio-Technical Systems Theory is profoundly applicable to the implementation of Industry 4.0 technologies in the construction sector. The aforementioned framework offers a thorough approach to incorporating emerging technologies, taking into account

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both the technical and social aspects[199]. Consequently, this results in enhanced and enduring acceptance of technology.

2.2.2 Experiential Learning Theory (ELT)

Experiential Learning Theory (ELT) was centrally formulated by David A. Kolb, a prominent educational theorist, throughout the 1970s[200]. Kolb's work was deeply shaped by the insights of many preceding intellectuals, such as John Dewey, Kurt Lewin, and Jean Piaget. John Dewey, an American philosopher and educator, is widely recognized as a fundamental figure in the field of experiential learning. Dewey underscored the significance of acquiring knowledge via direct experience and active involvement with the surroundings. He was of the opinion that education should be based on practical experiences and that thoughtful inquiry is essential for significant acquisition of knowledge. The concepts proposed by Dewey on the dynamic relationship between the learner and their surroundings had a substantial influence on the development of Kolb's learning methodology[200].

Kurt Lewin, a psychologist of German-American descent, also exerted a substantial influence on Kolb's formulation of English Language Teaching for adults[201]. By virtue of his action research and field theory, Lewin's contributions to social psychology established the notion of experiential learning as a cyclical process. He underscored the need of actively participating in experiences, contemplating them, and employing these contemplations to direct future endeavors. Based on his research on cognitive development, Swiss developmental psychologist Jean Piaget made significant contributions to the theoretical foundations of English Language Teaching (ELT)[202]. The work of Piaget emphasized the process by which humans generate knowledge through their interactions with the environment and how novel experiences are integrated into

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preexisting cognitive frameworks. The ELT theory, developed by Kolb, combines these elements to propose that successful learning takes place through an ongoing process of real experience, reflective observation, abstract conceptualization, and active experimentation.

The Experiential Learning Theory (ELT) has attained considerable influence; however, it has also seen substantial criticism from many viewpoints. An often-voiced criticism is that the theory excessively simplifies the learning process by imposing an inflexible, four-stage cycle that may not precisely mirror the actual learning phenomenon. Detractors contend that the process of learning is frequently non-linear and that individuals may not unequivocally advance through Kolb's phases in a consecutive fashion. Individual learners may choose to bypass certain phases, participate in many stages concurrently, or pursue alternative routes based on the specific circumstances. Such inflexibility can restrict the usefulness of English Language Teaching (ELT) un many learning settings when the intricacy of human thinking and behavior does not easily conform to a predetermined pattern[203].

One other critique of ELT is its insufficient attention to cultural and individual variations in learning preferences. Kolb's conceptual framework presupposes a broad applicability of the learning cycle, therefore potentially disregarding the impact of cultural background, personal experiences, and cognitive styles on individual learning processes[204]. Some cultures, for instance, may prioritise collaborative learning or oral traditions, which may not readily correspond with Kolb's paradigm. Moreover, the theory has faced criticism due to its insufficient empirical evidence, as some scholars have raised doubts about the accuracy of the learning styles inventory devised by Kolb. The assessment, intended to classify individuals into distinct learning styles according to their preferences for

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particular phases of the learning process, has been criticism for its psychometric limitations and its inconsistent ability to predict successful learning results. Consequently, although ELT has offered useful understanding of experiential learning, its assumptions and generalizations have been questioned, necessitating more sophisticated and adaptable methods to comprehend how individuals acquire knowledge from experience.

The use of Experiential Learning Theory is very pertinent to the integration of Industry 4.0 technologies in the construction sector, as it provides a structured approach that seamlessly corresponds to the dynamic and practical aspects of construction work. In the context of the ongoing transformation of construction processes by Industry 4.0 technologies, including robotics, artificial intelligence, and digital twin technology, the Experiential Learning Theory offers a significant framework for comprehending the effective learning and adaptation of workers to these developments. The theory places great importance on experiential learning, a critical aspect in the construction sector since the adoption of new technology typically necessitates hands-on, vocational learning. The emphasis of Experiential Learning Theory on the ongoing process of experience, reflection, conceptualization, and experimentation facilitates the incorporation of new technological applications into workers' current habits, therefore enhancing their ability to quickly adjust to changes in the work environment.

Furthermore, the application of Experiential Learning Theory proves to be highly advantageous in tackling the obstacles associated with enhancing and adopting new skills in the construction sector, which are crucial for the effective integration of Industry 4.0 technologies. The technique of experiential learning promotes the direct involvement of workers with novel technology, analysis of their experiences, and acquisition of new skills through active experimentation. This methodology not only serves to facilitate the

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development of technical abilities, but also fosters a more profound comprehension of how these technologies might augment construction processes. By promoting a culture of ongoing learning and adjustment, Experiential Learning Theory assists the construction industry in effectively managing the challenges of Industry 4.0. This ensures that workers are not only skilled in using new technologies but also capable of creating and enhancing them as they accumulate more experience.

2.2.3 Organizational Learning Theory

Numerous influential intellectuals have contributed to the development of Organizational Learning Theory, which investigates the process of organizational learning and adaptation. Leading this field is Chris Argyris, a distinguished academic whose research has played a crucial role in advancing the knowledge of organisational learning[204]. Argyris, in conjunction with his colleague Donald Schön, pioneered the notions of "single-loop" and "double-loop" learning. Single-loop learning is the act of modifying current patterns to enhance efficiency within established frameworks, whereas double-loop learning is the act of challenging and changing fundamental assumptions and norms. Their research emphasized the need of contemplating and questioning organizational processes in order to promote more profound and innovative learning.

Another notable figure in the field of Organizational Learning Theory is Peter Senge, whose famous publication "The Fifth Discipline" popularized the concept of the "learning organization." Senge's theory expanded upon the ideas proposed by Argyris and Schön, highlighting the need of organisations cultivating systems thinking and establishing conducive settings that facilitate ongoing learning and adaptability[205]. The framework developed by Senge emphasizes the cultivation of a culture that promotes learning, collaboration, and innovation among personnel at every level of the organization. This, in

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turn, enhances the organization's overall ability to adapt and prosper in a dynamic environment[205].

These academics have established the fundamental principles for comprehending how businesses can methodically acquire knowledge from their experiences, adjust their plans, and develop skill sets that allow them to successfully negotiate intricate and changing business environments. Their contributions have been crucial in supporting the notion of organisational learning as an essential element of sustained success and adaptability.

The Organizational Learning Theory, although highly influential, has had numerous critics. An important criticism of the theory is its tendency to presuppose a very idealized and logical process of learning and adaptation inside organisations. However, critics contend that this assumption fails to consider the intricacies and paradoxes that are present in actual organizational environments. For example, the proposed theory may not comprehensively consider the impact of power dynamics, political conflicts, and divergent interests that could hinder or distort the process of learning. Within numerous businesses, these elements can give rise to obstacles to efficient learning, resulting in opposition to change and an inability to successfully apply new information.

One further critique of Organizational Learning Theory is its inclination to prioritize formal learning processes while potentially neglecting the significance of informal learning and the social environment in which learning takes place. The idea frequently emphasizes systematic methods for learning and managing knowledge, which may not sufficiently encompass the informal, experiential, and often implicit types of knowledge that are essential in many operational settings. This constraint can lead to an inadequate comprehension of the specific mechanisms by which learning occurs inside organizations, particularly in dynamic settings where informal networks and on-the-job experiences

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have a substantial impact[204]. Moreover, the theory's emphasis on internal learning processes may overlook the significance of external factors, such as market fluctuations and technical progress, which can equally greatly affect an organization's capacity to acquire knowledge and adjust to new circumstances[205].

The application of Organizational Learning Theory is highly relevant to the implementation of Industry 4.0 technologies in the construction sector. It offers significant perspectives on how companies can successfully incorporate these sophisticated technologies into their operations. The implementation of Industry 4.0 technologies, such as automation, artificial intelligence, and digital modeling, signifies a substantial departure from conventional methods[123]. Consequently, construction companies must acquire knowledge and adjust their strategies to effectively respond to the swift-paced technological advancements. The Organizational Learning Theory provides a structured approach to comprehend how construction firms may methodically assimilate new information, adjust their strategy, and integrate new technology into their operations.

The framework highlights the significance of both individual and group learning processes in organizational contexts. For construction companies embracing Industry 4.0 technology, this entails cultivating a culture that promotes ongoing learning and the exchange of knowledge. Through the use of concepts from Organisational Learning Theory, construction firms can establish systems to acquire and distribute information acquired from new technical implementations, so enabling a seamless transition and more efficient integration[206]. This entails establishing conducive settings where employees are motivated to engage in experimentation, deliberate on their experiences, and exchange knowledge among different teams. Implementing such a strategy not only improves the

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technical skills of the employees but also guarantees that the company can adjust and create new solutions in direct response to changing technological requirements, ultimately promoting more effective and long-lasting integration of Industry 4.0 technologies in the construction sector.

2.3 Review of Empirical Studies

The empirical review section considered the review of both the research methods and findings of previous empirical works around industry 4.0 components (Internet of Things (IoT), Building Information Modeling, 3D technology and artificial intelligence) and organisational performance (operational efficiency, project time delivery, cost management and quality of work). The findings review systematically compared the empirical results of the scholars on objective-by-objective basis.

2.3.1 Industry 4.0 technologies and Organizational Performance

A study examines the strategic reaction of the Chinese automobile sector to Industry 4.0 and identifies the essential elements required for its effective execution[201,12,34,87]. The results of the study indicated that variables such as the size and profile of the organization did not have a substantial impact on the use of sophisticated manufacturing technology. Significantly, implementing a strategic approach to Industry 4.0 not only improves the competitiveness of a business but also has significant social and economic consequences. Another study examined the influence of Industry 4.0 technological elements on the operational effectiveness of enterprises in Kayseri, Turkey, within the framework of the countrywide endeavour to digitalize the sector. The findings demonstrated a favourable impact of the technological elements of Industry 4.0 on several indicators of organizational performance, including profitability, sales, production volume, quality, and substantial decreases in production costs. The objective of another study was to enhance

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comprehension of the implementation activities necessary in the German manufacturing sector[23]. The research identifies key and focused elements for the implementation of Industry 4.0: the cultivation of specialized knowledge related to Industry 4.0, obtaining financial resources, including employees in the implementation process, and fostering a collaborative and adaptable corporate culture. This study provides managers with the necessary tools to successfully integrate Industry 4.0 into their businesses, therefore enabling them to avail themselves of the benefits of Industry 4.0.

The objective of this study is to investigate the level of readiness of Nigerian construction consultants to use Fourth Industrial Revolution (4IR) technology in both pre- and post-construction operations[27]. Among the 10 obstacles identified, the high-ranked variables impeding construction consultants from implementing 4IR technologies are the expense of adopting the technologies, the unwillingness of stakeholders to accept, insufficient standards and reference architectures, and lack of knowledge. The present study assesses the deployment of cloud computing and its Critical Success Factors (CSFs) in the context of promoting sustainable construction projects in Nigeria[33]. The findings revealed that the four most important CSFs for cloud computing applications were trusted data storage, performance, and cost of accessibility and availability. The present research study aimed to examine the influence of talent management methods on the sustainable organizational performance within real estate enterprises in the United Arab Emirates (UAE) [67]. The research findings indicated that the retention and attraction of talent did not have a substantial impact on the sustainable performance of the company. In contrast, the study revealed that learning and growth, as well as career management, are associated with substantial and favourable effects.

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The objective of this study is to conceptualize the framework of training and development as a causal factor for the performance of municipal council employees in South Africa[32]. The research findings indicated that training and development indeed exerted an impact on the performance of employees. This study assessed the influence of training and development on organisational performance[34]. The primary results of the study indicate that Training and Development effectively enhances the performance of the personnel within the department. The department offers training and development programs that lack contextual relevance to the employees' job responsibilities. The present study examined the impact of human capital development in North-Kivu Hospitals in the Democratic Republic of Congo[67]. The findings indicated a high level of human capital and a statistically significant positive correlation between the growth of human capital and managerial performance in healthcare organizations.

The objective of this study was to investigate the relationship between training and the perceived actual or projected performance of small and medium-sized firms (SMEs) in the United Kingdom[70]. Differentiating training based on its type reveals that on-the-job and off-the-job training have a positive and significant correlation with performance. However, when both types of training are received concurrently, the combined relationship becomes more pronounced than their individual effects.

2.3.2 Internet of Things (IoT) on Operational Efficiency

Following an analysis of the advantages and disadvantages of digital transformation, another research conducts an empirical investigation on the influence of digital transformation on the operational and financial performance of firms[63]. Analysis indicates that there is a positive relationship between the level of digital transformation and the process-based operating performance. Additionally, there is a U-shaped relationship

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between the intensity of digital transformation and the profit-oriented financial performance. An investigation on the current level of adoption of Industry 4.0 technologies in the construction sector and assess their influence on the development of the construction 4.0 concept[45]. The findings indicate that Industry 4.0 has the most significant influence on the increase of productivity in the construction sector. Furthermore, there is a consistent annual growth in the interest for digital technologies. However, the integration of these technologies into the construction industry is sluggish and restricted. The objective of this study was to use both exploratory and empirical research methods to determine and confirm performance indicators that are important for assessing investments in Smart Manufacturing Systems (SMS) in Indian small and medium-sized enterprises (SMMEs) in the auto-component machining industry[13]. The results suggested that SMS enabled by Industry 4.0 provide different competitive benefits compared to conventional manufacturing systems.

The manufacturing and automotive sectors have much benefited from the significant applications of digital technologies, particularly the digital twin (DT)[14]. The result indicated digital technologies positively enhance delivery time and minimizes cost. An exhaustive investigation was undertaken to pinpoint the primary obstacles that hinder the adoption of IR 4.0 technologies in the construction sector and the potential benefits achieved in the future[19]. The evidence of this study indicates that the social and technical aspects are the major determinants of successful implementation. The objective of this study is to evaluate the effects of integrating virtual reality technology in the construction sector of Egypt[46]. The conclusion was reached that virtual reality has the potential to improve the construction process in several areas, including design evaluation and progress monitoring. This paper investigates the research efforts in industry 4.0 and the Internet of Things in the context of construction[90]. The data revealed that smart

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construction emerged as the prevailing industry 4.0 technology in the construction sector of Ghana. The present study investigated the criteria and interconnections associated with the formation of prevailing professional skills, namely social skills that exert an impact on organizational learning, company sustainability, and the improvement of operational efficiency[67]. The study revealed that professional and social skills, including as communication, leadership, problem-solving, and teamwork, had a significant impact on the organizational performance of hotel enterprises in Phuket.

An analysis was conducted to assess the influence of training on employee performance, considering that the combined performance of individuals will ultimately drive organizational performance[9]. The study demonstrated that the training acquired by employees by enhancing their skills, knowledge, and abilities had a substantial impact on production. Recent research indicates that training significantly influences employee commitment to the organization. The present study investigated the correlation between employee training and the overall performance of deposit money banks operating in Abia State, Nigeria[56]. The study revealed a strong and statistically significant correlation between staff training and organisational success. A study evaluated the influence of training on the performance of employees in the technology-oriented instructional institution[36]. Evidence indicates that the design of training, assessment of training needs, style of training delivery, and evaluation of training have a notable and beneficial impact on the performance of employees.

The objective of this study is to conceptualize the framework of training and development as a causal factor for the performance of municipal council employees in South Africa[32]. The research findings indicated that training and development indeed exerted an impact on the performance of employees. The primary objective of this study is to examine the

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correlations between the practices of human resource development and organizational management effectiveness within the framework of Iraqi public universities[33]. The present study reveals that human resource development (HRD) methods, including talent development, training and development, organizational development, and career development, exert a favourable and substantial influence on the effectiveness of organizations. The objective of this study is to examine the impact of organizational learning capability on the innovative performance and strategic performance of small and medium-sized firms[63]. The results indicate that the adaptability of an organization to learn affects the innovative performance of small and medium-sized firms.

2.3.3 Building Information Modelling and Project Delivery Time

At present, the industry's primary emphasis is on adopting building information modelling (BIM), sometimes to the detriment of investigating other cutting-edge Industry 4.0 technologies. The present study provides a thorough and inclusive survey of the existing research in the domain of Industry 4.0 specifically within the construction sector. This report evaluates the current level, future prospects, and scope of Industry 4.0 implementation in the construction industry of the United Kingdom. Additionally, it offers suggestions for future research. Off-site construction (OSC) is a highly efficient construction technique that has the potential to maximize time and cost savings, minimize resource wastage, and enhance the overall productivity of projects[14,18]. The objective of several study was to assess the existing body of literature on digital technology uses in OSC. Evaluating fifteen common digital technologies used in OSC projects, namely building information modelling (BIM), radio frequency identification devices (RFID),

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global positioning systems (GPS), the Internet of Things (IoT), geographic information systems (GIS), sensors, augmented reality (AR), virtual reality (VR), photogrammetry, laser scanning, artificial intelligence (AI), 3D printing, robotics, big data, and blockchain, scientometric analyses and a systematic review were conducted. This paper provides a comprehensive overview of the present implementation of these digital technologies and synthesizes the primary domain of application and constraints of each technology when used in OSC.

This study aimed to identify the difficulties encountered, evaluate the performance in relation to the project specifications, and assess the potential of Industry 4.0 to address these issues[25]. The results indicate that respondents possess a comprehensive understanding of Industry 4.0. The manufacturing and automotive sectors have much benefited from the significant applications of digital technologies, particularly the digital twin (DT)[14]. This phenomenon offers a prospect for the amalgamation of the tangible realm with the virtual realm. Distributed technology (DT) has the capacity to revolutionize the construction sector and offer solutions to certain obstacles it faces. The result indicated digital technologies positively enhance delivery time and minimizes cost. The objective of this study is to evaluate the level of knowledge, preparedness for implementation, and obstacles related to Construction 4.0 technologies in Nigeria[26]. The results indicate a notable disparity in the viewpoints of the participants, namely for 36% of the elements of Construction 4.0 technologies. The results indicate complete consensus in the survey respondents' rankings of the difficulties associated with Construction 4.0. The study presented data on the current state of Construction 4.0 technologies in the NCI with the aim of improving practical implementation and project delivery.

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At present, the industry's primary emphasis is on adopting building information modeling (BIM), sometimes to the detriment of investigating other cutting-edge Industry 4.0 technologies[76]. This report evaluates the current level, future prospects, and scope of Industry 4.0 implementation in the construction industry of the United Kingdom. The primary objective of this study is to examine the correlations between the practices of human resource development and organizational management effectiveness within the framework of Iraqi public universities[33]. The present study reveals that human resource development (HRD) methods, including talent development, training and development, organizational development, and career development, exert a favourable and substantial influence on the effectiveness of organizations.

The research investigated the relationship between staff training and development (T&D) and the strategic success of several private universities in Ogun State, Nigeria. The results indicated that expanding training and development initiatives will lead to a corresponding improvement in organisational performance[45]. The research validates that implementing a training and development employee retention plan is essential for organizations aiming to enhance or achieve their target level of performance. This paper assesses the impact of employee development on the achievement of organizational objectives at Rift Valley Machinery Services Limited, Kenya[68]. The study concluded that the management of remuneration and the development of employees had more significant beneficial impacts on the performance of the firm. AN examination into the opportunities and threats of construction 4.0 on the workforce was carried out in Southwest Nigeria[220]. The result shows that there was a high level of implementation of Prefabrication and BIM. The study further revealed opportunities such as increased collaboration, creativity, workers' efficiency and a major threat which is retrenchment of workers. Investigation into the knowledge and skills gap among professionals within the Nigerian construction industry

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was done[213]. The findings revealed a moderate knowledge level of Construction 4.0 technologies and a low level of training among professionals.

2.3.4 Artificial Intelligence and Cost Management

Additionally, it offers suggestions for future research. Off-site construction (OSC) is a highly efficient construction technique that has the potential to maximize time and cost savings, minimize resource wastage, and enhance the overall productivity of projects[14]. The objective of several study was to assess the existing body of literature on digital technology uses in OSC. Evaluating fifteen common digital technologies used in OSC projects, namely building information modelling (BIM), radio frequency identification devices (RFID), global positioning systems (GPS), the Internet of Things (IoT), geographic information systems (GIS), sensors, augmented reality (AR), virtual reality (VR), photogrammetry, laser scanning, artificial intelligence (AI), 3D printing, robotics, big data, and blockchain, scientometric analyses and a systematic review were conducted. This paper provides a comprehensive overview of the present implementation of these digital technologies and synthesizes the primary domain of application and constraints of each technology when used in OSC. A comprehensive analysis was conducted on the current state, development of the concept, essential technologies, and six specific areas of implementation throughout the many stages of a project's lifecycle: building information modelling, structural system integrity, facilities management, monitoring, logistical processes, and energy simulation[42]. This study demonstrates that Digital Transformation (DT) has significant potential to facilitate resolutions to the myriad issues encountered in the construction sector.

The impact of digitalization on overall project performance[24]. Results of the regression analysis indicate that digitalization has different degrees of influence on project

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performance as assessed by quality, time, and cost. There is a weak correlation between the relationship model and time performance. Similarly, the relationship model is weak for cost performance. This paper examined the risks associated with the construction project by conducting a literature survey (LS) and developing a project risk management (PRM) framework based on Industry 4.0 technologies[26]. An analysis of the PRM framework has revealed that the abrupt failure and unpredictability of equipment are significant hazards linked to heavy machinery in building projects. An investigation was conducted to assess the viability of 3D printing in the construction business by surveying industry professionals[23]. A robust association was discovered between 3D printing in residential developments and operational performance statistics (OPS). The research provides curriculum makers with vital information regarding the scarcity of skills in the footwear sector in South Africa[56]. The research findings indicate that the human resource management is confronted with a significant obstacle from employees, namely an increased rate of absence that adversely affects the operations of the company.

The objective of this study is to assess the impact of training on job performance and career planning through the mediation of work motivation[61]. Findings indicated that both training and motivation have the potential to enhance job performance. Training, motivation, and job performance have the potential to enhance the career advancement of people in the workplace. The objective of this study is to examine the correlation between training and development (T&D) approaches and the performance of local government organizations[32]. The findings indicate that there is a notable correlation between training and development (namely job orientation, job rotation, workshop & conference, and classroom lectures) and organizational performance. Furthermore, the results indicated that training and have a substantial correlation with the quality-of-service delivery. The objective of this study is to examine the impact of organizational learning capability on

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the innovative performance and strategic performance of small and medium-sized firms[63]. The results indicate that the adaptability of an organization to learn affects the innovative performance of small and medium-sized firms. However, the impact of the adaptability on organizational performance was not statistically significant. The present study investigated the correlation between the development of managerial abilities and the organizational profitability (OP) of multinational corporations in Rivers State, Nigeria[66]. revealed that there is no statistically significant correlation between the growth of conceptual skills and technical skills and profitability.

2..3.5 3D Technology and Quality of Work

The objective of this study is to fill the current void in the literature by investigating the positive outcomes of Industry 4.0 digitalization mechanisms within the framework of sustainable construction management[15]. The results reported in this study enhance the theoretical understanding of the factors that influence the implementation of Industry 4.0 digitalization approaches in the construction industry. Gaining a comprehensive understanding of the function of 3D printing in connection to OPS dimensions in residential construction projects in Malaysia would facilitate the acceptance of 3D printing by construction experts. The findings were verified by exploratory factor analysis (EFA). The objective of this study is to evaluate the level of knowledge, preparedness for implementation, and obstacles related to Construction 4.0 technologies in Nigeria[26]. The results indicate a notable disparity in the viewpoints of the participants, namely for 36% of the elements of Construction 4.0 technologies. A classification of the current literature on the uses of Construction 4.0 technologies is proposed in this study[17]. In summary, the analysis indicates that research on Construction 4.0 is strongly correlated with the construction phase.

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An empirical case study was undertaken then, employing a post-positivist perspective and inductive reasoning, to examine the perceptions and adoption of Industry 4.0 by practitioners in the UK construction industry[34.] The findings of the literature review suggest that Industry 4.0 is a relatively new idea, with industrialized countries, particularly Germany, taking the lead in its advancement. The case study results corroborated the literature analysis, indicating that professionals in the UK construction industry had a positive outlook on the capacity of Industry 4.0 to rejuvenate their sector. This work introduces a multi-criteria decision-making approach called ConFIRM to assess the strategic preparedness of construction companies for the adoption of Industry 4.0[67]. The findings revealed that the human capital component is the paramount determinant influencing the effectiveness of Industry 4.0 deployment. More precisely, the cognitive flexibility, expertise, abilities, and proficiencies of the personnel in the construction industry. A scarcity of research exists on cognitive interfaces (CI) to enhance digital technology applications. Thus, this study examined the significance and anticipated obstacles that may impede the implementation of Construction incentivisation (CI) from promoting digital technologies and proposed methods to enhance digital technology applications in the construction industry[45]. The findings provide practical policy measures that can alleviate these problems and enhance the performance of digital technology applications in the sector through the CI.

The objective of this study is to examine the correlation between training and development and the effectiveness of organizations inside private colleges in Nigeria[29]. The researchers have identified two research questions: firstly, a correlation between training and development; secondly, a direct influence of development programs on organizational effectiveness. The research provides curriculum makers with vital information regarding the scarcity of skills in the footwear sector in South Africa[56]. The

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research findings reveal that employees pose a significant obstacle to human resource management, specifically an increased absence rate that negatively impacts the company's operations. The objective of this study was to examine the influence of training and development on the productivity of employees and the management performance[49]. The survey results indicate that a significant majority of the participants expressed agreement on the positive impact of training and development on their efficiency and job productivity. Secondly, a significant majority of the respondents expressed agreement that training and development improved the functioning of the organization. Appreciable levels of efficacy and quality have been observed in the training programmes.

The objective of this study is to examine the correlation between training and development (T&D) approaches and the performance of local government organizations[32]. The findings indicate that there is a notable correlation between training and development (namely job orientation, job rotation, workshop & conference, and classroom lectures) and organizational performance. Furthermore, the results indicated that training and have a substantial correlation with the quality-of-service delivery. Furthermore, there is no correlation between job rotation and the provision of high-quality services.

2.3.6 Employee Skill Development on Industry 4.0 Technology and Performance

A study investigates the elements that impact the preparedness and implementation of Industry 4.0 practices among small and medium-sized enterprises in Denmark, using a mixed-method framework[70]. One significant discovery was that the lack of knowledge among managers about the factors driving Industry 4.0, rather than their perception of significant obstacles, impeded the progress of small and medium-sized enterprises (SMEs) in developing their preparedness and implementing Industry 4.0 technology. The paper empirically investigates the relationship between Construction 4.0, technological

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innovation skills, and company[32]. Results indicate that Construction 4.0 has a substantial beneficial impact on company performance, with technical innovation skills acting as a mediator between construction 4.0 and firm performance. The present study investigated the criteria and interconnections associated with the formation of prevailing professional skills, namely social skills that exert an impact on organizational learning, company sustainability, and the improvement of operational efficiency[67]. The study revealed that professional and social skills, including as communication, leadership, problem-solving, and teamwork, had a significant impact on the organizational performance of hotel enterprises in Phuket.

An analysis was conducted to assess the influence of training on employee performance, considering that the combined performance of individuals will ultimately drive organizational performance[9]. The study demonstrated that the training acquired by employees by enhancing their skills, knowledge, and abilities had a substantial impact on production. The present study investigated the correlation between employee training and the overall performance of deposit money banks operating in Abia State, Nigeria[56]. The study revealed a strong and statistically significant correlation between staff training and organisational success. A study evaluated the influence of training on the performance of employees in the technology-oriented instructional institution[36]. Evidence indicates that the design of training, assessment of training needs, style of training delivery, and evaluation of training have a notable and beneficial impact on the performance of employees. This study assessed the influence of training and development on organisational performance[34]. The primary results of the study indicate that training and development effectively enhances the performance of the personnel within the department. The department offers training and development programs that lack contextual relevance to the employees' job responsibilities.

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The objective of this study was to evaluate the impact of training and development on employee performance in the commercial bank of Ethiopia. The multiple linear regression analysis revealed a statistically significant positive relationship between training and development on employee performance. The present study aimed to analyse the impact of training and development strategies on organisational performance by mediating employee performance[73]. The research reveals that the implementation of training and development initiatives has a substantial impact on both the performance of the firm and its employees. Furthermore, the study also reveals that the impact of training and development programs on organizational success is mediated by employee performance. The impact of skill development on organizational performance was done both the positive and negative aspects of skill development[43]. reveals that talent development has a dual impact on company outcomes, namely on innovation and voluntary turnover rate. Furthermore, the study reveals that the impact of talent management significantly differs among different organizational environments. This study presents an analysis of the current state of training and development methods at Life Insurance Corporation in India and investigates the suggested correlation between training and the productivity of the organization[38]. The data presented indicates that the Training in Life. Insurance corporation is rated as average, and there is no substantial difference in the perception of employees about the training and development practices.

This study investigated the impact of employees' training and development on the performance of organizations in Nigeria[74]. The findings disclosed that the training and development of personnel have a substantial impact on the success of firms. The objective of this study was to examine the influence of workers' training and development (T&D) strategies on the performance of organizations in the banking sector of Tanzania, specifically focusing on NBC bank in Mwanza city[75]. The survey revealed that while

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employees receive on-the-job training through various approaches, they choose mentorship and coaching, as well as job rotation, as these methods facilitate the acquisition of skills and information necessary for the effective and efficient execution of their specific daily responsibilities. The present study investigated the correlation between the development of managerial abilities and the organizational profitability (OP) of multinational corporations in Rivers State, Nigeria[66]. revealed that there is no statistically significant correlation between the growth of conceptual skills and technical skills and profitability.

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2.4 Conceptual Model

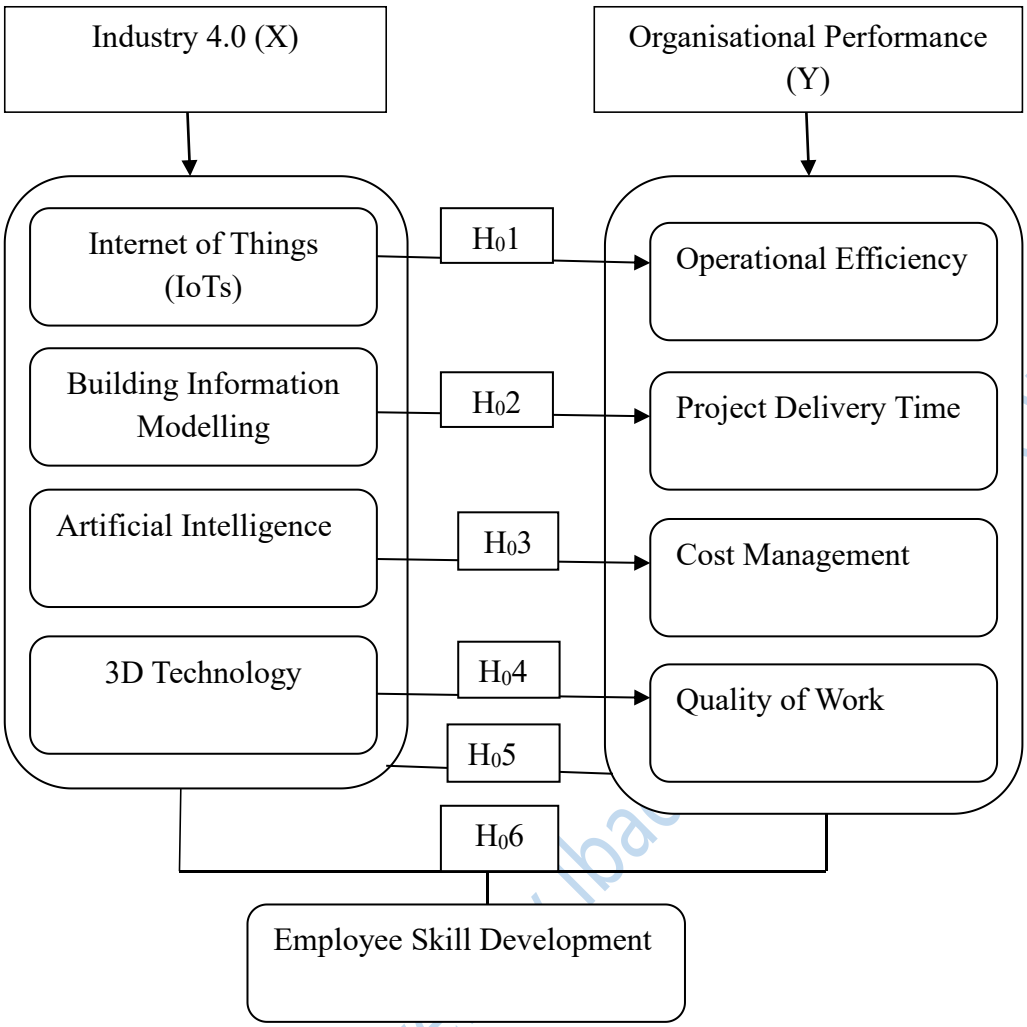

Figure 2.1: Conceptual Model

Source: Researcher Conceptual Framework, 2024

2.5 Summary of Gaps in Literature Reviewed

This study explored the effects of Industry 4.0 technology, employee skill development, and organizational performance of construction industries in Nigeria, However, several gaps often emerge in such research, limiting its scope and relevance. These gaps frequently revolve around the limited focus on technology, inadequate understanding of workforce adaptability, the lack of longitudinal data, variations across different company types, and the unexplored relationship between skill development and performance

metrics. Addressing these gaps would yield more comprehensive insights into how Industry 4.0 impacts the construction sector.

One significant gap in this study studies is the narrow focus on specific Industry 4.0 technologies. Industry 4.0 encompasses a broad range of innovations, including artificial intelligence (AI), robotics, automation, Internet of Things (IoT), and big data analytics, all of which can impact the construction industry in different ways. However, this study tends to concentrate on select technologies, such as IoT, without accounting for the integrated use of multiple systems. The exclusion of other relevant technologies may lead to incomplete conclusions, as the cumulative effects of various Industry 4.0 technologies working together can be transformative[201]. This limited focus prevents a more nuanced understanding of how construction companies leverage multiple technologies to enhance their performance and employee skills holistically.

Another gap is the insufficient exploration of how employees respond to technological changes, particularly in terms of learning curves and resistance. Adopting Industry 4.0 technologies requires employees to upskill rapidly to work with new tools and systems. However, resistance to change, fear of job displacement, and insufficient training can slow the adoption process[200]. This study focuses on the positive aspects of skill development but fail to address these challenges, leading to an overly optimistic portrayal of technology's impact on the workforce. Additionally, the varied pace at which employees adapt to new technologies—whether due to age, education level, or prior experience can lead to uneven performance across a company.

Further, a critical limitation in this study is the reliance on short-term data, which may not adequately capture the long-term effects of Industry 4.0 on construction companies. Many of the benefits related to skill development and performance are unlikely to manifest

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immediately after implementing new technology. Construction firms may experience productivity increases, safety improvements, and operational efficiencies over a period. However, studies often fail to track these changes longitudinally, providing only a snapshot of the immediate aftermath of technology adoption[202]. This absence of long-term data limits the study's capacity to assess whether skill gains and performance improvements are sustainable or diminish over time as technologies become more commonplace or as workforce resistance grows.

Moreover, variations in company size and resource availability are often inadequately addressed. Large construction companies, with greater financial and technical resources, can afford to implement cutting-edge technologies and invest in comprehensive training programs for their workers. In contrast, smaller companies may struggle with the high costs of adopting Industry 4.0 technologies and providing the necessary training for employees[203]. By failing to distinguish between the capacities of different-sized companies, there arise the gap of generalizing findings that may only apply to well-resourced firms. This gap reduces the applicability of the research across the diverse range of construction companies that vary greatly in size, resources, and workforce capabilities.

In addition, regional and cultural variations significantly affect the success of Industry 4.0 adoption and employee skill development, yet these factors are often overlooked. The regulatory environments, cultural attitudes toward technology, and workforce education levels differ vastly across regions, influencing how effectively construction companies implement new technologies[204]. For instance, regions with robust infrastructure and technological readiness may experience smoother transitions to Industry 4.0 technologies compared to regions with limited resources and slower technological adoption. Studies that fail to consider these geographic and cultural differences may present overly

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generalized conclusions that do not reflect the complex realities of construction practices globally.

Finally, there is need to examine the direct link between skill development and company performance metrics. While it is generally assumed that enhanced employee skills lead to better company performance, few studies concretely establish this relationship using measurable data. Improved skills in areas like machinery operation, project management, or safety protocols should ideally lead to increased productivity, reduced project completion times, and better safety records[205]. However, without specific metrics demonstrating these correlations, the assumption that skill development directly enhances performance remains largely speculative. A deeper exploration of how particular skill improvements translate into measurable performance indicators would strengthen the practical relevance of such studies.

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Chapter Three

Methodology

This chapter presents the research methodology used for this study and how it guided the data collection method. It provides an overview of the major philosophical assumptions that underpins the research approach, discussing the researcher's pragmatic stance to research and the consequent choice of both the qualitative and quantitative research approach for the study. The subsequent section also discusses the rationale for data collection phases, the instruments of data collection including justifications and validity of the instruments

3.1 Research Design

The research design serves as a structured framework to facilitate the execution of research endeavours. This study employod a mixed method research design. Mixed methods research refers to an approach that combines both qualitative and quantitative methodologies in a study.[1] This approach allows researchers to gather and analyze study integrates both quantitative and qualitative methodologies to address the research questions. The use of mixed methods research facilitates the acquisition of a more comprehensive understanding compared to doing just quantitative or qualitative studies in isolation.[2] The use of a mixed-method research design facilitates a holistic comprehension of the research objectives. and enhance the validity of their results.[3] The system has the capacity to handle a wide range of data types, resulting in more comprehensive and

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valuable insights. The flexibility in data collecting and processing promotes a comprehensive viewpoint and enhance the research robustness.[4] The study will utilize quantitative measures through surveys or performance metrics, while qualitative measures such as interviews and questionnaires will also be used.

3.2 Population of the Study

The study population size of one hundred and seventeen (117) was obtained from the field of study of this research based on the information provided by the Human Resource departments of each of the selected construction firm. The population for this study was obtained from five (5) construction firms namely, China Civil Engineering Construction Corporation, Reynolds Construction Company, Hitech Construction Company Limited, Setraco Nigeria Limited, and Kopek Construction Limited, all this construction firms have their headquarters located in Lagos State.

Table 3.1: Population of the Study

S/N	Selected Construction Companies	Population
1	China Civil Engineering Construction Corporation,	32
2	Reynolds Construction Company	28
3	Hitech Construction Company Limited	23
4	Setraco Nigeria Limited	16
5	Kopek Construction Limited	18
	Total	117

Source: HR Department of each Selected Construction Companies, 2024

3.3 Sample and Sampling Techniques

The Sampling Technique used in this study was Stratified Sampling Method. A total population of 117 respondents were considered. The sample size was determined with the

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use of the Cochran (1968) statistical formula for finite population. This formula relates the population size to the level of significance as illustrated below:

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

Where

n = Sample Size Desired N = Overall Population

n0 = Cochran Formular sample size for infinite population (385)

Therefore,

$$n = \frac{385}{1 + (385-1)/ 117}$$

$$= \frac{385}{4.282}$$

$$= 90$$

In other to ascertain the number of questionnaires to be distributed to each of the Selected Construction Companies, the researcher adopted Bowler (1996) proportionate allocation formula as follows:

Nh= n*nh/N Where:

Nh= Number of units to be distributed to each Selected Construction Companies

nh = Total population of respondents in each Selected Construction Companies

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n = Determined sample size

N = Total Population size

Nh = Determined sample size by Total population of respondents in each institution

Total Population size

1. China Civil Engineering Construction Corporation = 90 x 32/117 = 25
2. Reynolds Construction Company = 90 x 28/117 = 22
3. Hitech Construction Company Limited = 90 x 23/117= 18
4. Setraco Nigeria Limited = 90 x 16/117 = 11
5. Kopek Construction Limited = 90 x 18/117 = 14

Table 3.2: Sample Size

S/N	Selected Construction Companies	Respondents
1	China Civil Engineering Construction Corporation,	25
2	Reynolds Construction Company	22
3	Hitech Construction Company Limited	18
4	Setraco Nigeria Limited	11
5	Kopek Construction Limited	14
	Total	90

Source: Field Survey, (2024)

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3.4 Description of the Research Instrument

A structured questionnaire was developed for this research. The use of questionnaire is relevant because it helps in collecting feedback based on perception and opinion of the respondents. The questionnaire is an easy way of collecting data on a large scale within a short span. The items in the questionnaire were adopted and self-developed. The validated scale to be adopted would be measured on a five-point Likert scale. The first section sort for the demographic features of respondents like Age, gender, cadre. The second section of the questionnaire asked five open ended questions as it relates to Internet of Things & Operational Efficiency, Building Information Modelling and Project Delivery Time, Artificial Intelligence and Cost Management, 3D technology and Quality of Work, Robotics and Organizational Performance and finally Employee Skill Development and Organizational Performance.

Pilot Study

The researcher tested the questionnaire using a pilot study to make sure it was relevant, and people understood it. The pilot study was conducted on 10% of the sample size using 12 of respondents from Ratcon limited. The scores were subjected to KMO and Bartlet test to ascertain consistency of the instruments in measuring what it was purported to measure. During the pilot study, majority of the questionnaire items and responses were modified and adjusted by a senior academic Staff who is a professor in the field, as well as the researcher's supervisor at the Faculty of Management and Social Sciences, Department of Management and Accounting, Lead City University. Hence, this predicated the final copy of the questionnaire that was administered to the respondents. The validity and reliability of the research instrument were ascertained using Statistical Package Social Sciences (SPSS).

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3.5 Validation of Research Instrument

The questionnaire was validated using content and face validity. For the criterion and face validity, the instrument was validated by the researcher's supervisor and two other scholars in the department, were used to modify the questionnaire taking into consideration the existing literature measured the variables.

3.6 Reliability of the Instrument

Coefficient alpha (Cronbach alpha) was used to test reliability of the instrument. The range of the coefficient qualities is from 0 to 1. An instrument that has a reliability that is high would have a coefficient value that is near 1, but a value that is near 0 would show that the instrument has a very low reliability or has no reliability.

Table 3.3: Reliability Statistics

Industry 4.0 dimensions	0.946
Employee Skill Development	0.898
Organizational Performance dimensions	0.913

Source: Field Result, 2024

3.7 Method of Data Collection

Data was collected primarily to address the objective of this study. This is because it helps to reduce the possibility of incorrect data and equally provides the opportunity to gain a better understanding of the respondent under investigation. The instruments will be administered personally. For the purpose of clarity, the researcher explained the study purpose to the respondents. The self-administration is to ensure a high rate of return and

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also enable the respondents to ask and obtain clarification on the issues that were not clear to them or that need explanations.

3.8 Method of Data Analysis

For the analysis of data, the statistical package for social sciences (SPSS) was used. The statistical tools used to analyze the data include the following: descriptive analysis using frequency tables and percentages. Also, simple linear and multiple regression analysis in respect to the study hypothesis was used to measure the degree of the effects of independent variables on the dependent or outcome variables. Another statistic called R-square would be calculated based on the percentage of variations in the dependent variable that can be explained by the independent variable. After distributing the questionnaires, data would be collected, coded and analyzed through the use of the Statistical Package for Social Science (SPSS). Regression analysis and descriptive statistics would be used to validate the data

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Endnotes

1. J. PierréBruwer, "An *Introduction to Research Methodology" (n.d.), https://www.academia.edu/9185702/An_introduction_to_Research_Methodology.*

2. S. C. Mat, S Maat & N. Mohd, "*A Descriptive Analysis on Entrepreneurial Intention among Engineering Technology Students," **Asian Social Science*** 11(24), 2015, p286.

3. M. Nancy, B, William & D. Paul Reynolds, *"Exploring Start-up Event Sequences".* **Journal of Business Venturing,** 11(3), 1996, 151–166.

4. M. Nancy B. William & D. Paul Reynolds, "*Exploring Start-up Event Sequences*," **Journal of Business Venturing** 11(3), 1996, 151–166.

5. S.C. Mat, S. Maat & N. Mohd. *"A Descriptive Analysis on Entrepreneurial Intention among Engineering Technology Students".* **Asian Social Science,** 11(24), 18, 2015, p286.

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Chapter Four

Results and Discussion of Findings

This chapter offers the empirical results from the data analysis conducted, interpretation of the findings and discussion of the study results. The main objective of this study is to evaluate the effect of Industry 4.0 Technology, Employee Skill Development and Performance of Construction Companies, Southwest Nigeria. To achieve the objective of the study, the research was conducted through questionnaire which was used to obtain the required information. This chapter is divided into Two, the first part details the analysis of information of the respondents, this part precedes others because it confirms whether the sample collected is representative enough. The second part deals with the analysis of data on the objective based on descriptive and inferential statistics. Data analysis was conducted using Statistical Product and Service Solution.

4.1 Demographic Data Analysis

This section consists of background and respondents' information that describes basic characteristics such as years of experience and employment cadre of the respondents. To this effect, the results are presented in Table 4.2

Table 4.1 Demographic Characteristic of Respondents

Variables	Category	Frequency	Percentage
Age	1 - 5	22	24.4%
	6 – 10	33	36.7%
	11 and above	35	38.9%
Total		**90**	**100%**
Gender	Mgt	29	32.2%
	Civil Engr	37	41.1%
	Architects	11	12.2%
	Others	13	14.4%
Total		90	100%

Source: Field Survey (2024)

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Table 4.1 presents the demographic and personal profile of respondents used for this study.

Response Rate

For this study, questionnaires were distributed to 90 respondents and amazingly 90 questionnaires were returned this number represented 100% response rate. The high response rate was recorded because the researcher administered the instrument with the help of research assistants who put concerted efforts to repeatedly visit and request the respondent to fill the instrument. The response result is presented in Table 4.2

Table 4.2: Questionnaire Response Rate

S/N	Selected Construction Companies	Administered
1	China Civil Engineering Construction Corporation,	25
2	Reynolds Construction Company	22
3	Hitech Construction Company Limited	18
4	Setraco Nigeria Limited	11
5	Kopek Construction Limited	14
	Total	90

Source: Field Survey, (2024)

4.2 Presentation of Data

4.2.1 Presentation of Research Question

This section focuses on the responses of the respondents to statements concerning Internet of Things & Operational Efficiency. Respondents indicated whether they “strongly agree”, “agree”, “Undecided”, “disagree”, or “strongly disagree” with the statements provided. Below are the statements and the tables showing the frequency and percentage distribution of responses along with their interpretations.

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Table 4.3: Internet of Things & Operational Efficiency

S/NO	Internet of Things & Operational Efficiency	SA%	A%	N%	D%	SD%	$\bar{x}$	σ^2
Q1	The implementation of IoT solutions has significantly improved the overall efficiency of our operations.	4.3	13	30.8	43.2	8.6	2.61	0.967
Q2	IoT technologies have led to a noticeable reduction in operational costs within our organization.	10.8	21.1	49.2	14.6	4.3	3.19	0.964
Q3	Our ability to monitor and manage real-time data has improved due to the adoption of IoT systems.	2.2	39.5	36.8	17.3	4.3	3.18	0.894
Q4	The integration of IoT devices has enhanced our decision-making processes by providing more accurate and timely information.	4.3	16.8	27	43.2	8.6	2.65	1
Q5	IoT implementation has led to a significant reduction in downtime and improved overall equipment effectiveness (OEE).	2.2	21.6	28.1	45.9	2.2	2.76	0.891

Source: Researcher's Field Survey Result (2024)

Table 4.3 describes the responses of participants as regards the Internet of Things & Operational Efficiency. In Q1, the table shows that majority of the respondents, precisely (43.2%) disagree with the statement. Also, a significant number of the respondents specifically (30.8%) were neutral while (13.0%) respondents tend to agree with the statement. (8.3%) of the respondents strongly disagree as opposed to the remaining (4.3%) who strongly agree with the statement. The implication of the mean at 2.61 indicates that most of the respondents are inclined towards disagree. In Q2, a vast number of the respondents (49.2%) are neutral while (21.1%) agree with the statement. Also (10.8%) of

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the respondents strongly agree while (14.6%) disagree with the statement. Only (4.3%) of the respondents strongly disagree with the statement. The implication of the mean at 3.19 indicates that most of the respondents are leaning towards agree. In Q3, a greater number of the respondents (39.5%) elected to agree with the statement. Although (36.8%) of the workforce were neutral, (17.3%) of the respondents disagree while (4.3%) strongly disagrees with the statement. Only (2.2%) of the workforce strongly agree with the statement. The implication of the mean at 3.18 indicates that most of the respondents are leaning towards agree. In Q4, Majority of the respondents, precisely (43.2%) of the workforce tend to disagree with the statement while (27%) of the respondents are neutral. (16.8%) tends to agree with the statement while (8.6%) of the workforce strongly disagree with the statement. Only (4.3%) of the workforce tend to strongly agree with the statement. The implication of the mean at 2.65 indicates that most of the respondents are leaning towards disagree. Finally, in Q5, respondents constituting a majority of 45.9% disagree with the statement while (28.1%) are neutral. Also (21.6%) of the workforce agree with the statement. The implication of the mean at 2.76 indicates that most of the respondents are leaning towards disagree.

4.4: Building Information Modelling and Project Delivery Time

S/NO	Building Information Modelling and Project Delivery Time	SA	A	N	D	SD	$\bar{x}$	σ^2
Q1	The use of BIM has significantly reduced the overall project delivery time in our organization.	10.3	21.6	43.2	16.2	8.6	3.09	1.065
Q2	BIM has improved the efficiency of project planning and scheduling, leading to faster project completion.	21.1	64.3	13	1.6	0	4.05	0.637

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Q3	The adoption of BIM has minimized delays caused by design changes or errors during the project lifecycle.	18.4	56.8	18.9	3.8	2.2	3.85	0.838
Q4	BIM has enhanced collaboration and communication among project stakeholders, resulting in quicker decision-making and project execution.	4.3	27	45.4	23.2	0	3.12	0.815
Q5	The integration of BIM into our project processes has led to better coordination and reduced rework, contributing to faster project delivery.	2.2	27	51.4	19.5	0	3.12	0.735

Source: Researcher's Field Survey Result (2024)

Table 4.4 describes the responses relating to Building Information Modelling and Project Delivery Time. In Q1, this table shows that a great number of the respondents constituting 43.2% of the workforce are neutral about the statement. Another (21.6%) of the respondents tend to agree with the statement. Also (16.2%) of the respondents disagree with the statement while (8.6%) of the workforce strongly disagree. Only (10.3%) of the entire workforce strongly agree with the statement. The implication of the mean at 3.09 indicates that most of the respondents are leaning towards agree. In Q2, the table also shows that most of the respondents (64.3%) agree with the statement. Furthermore (21.1%) of the respondents strongly agree with the statement. Although (13%) of the respondents were neutral, the remaining (1.6%) of the workforce disagree with the statement. No respondent strongly disagrees with the statement. The implication of the mean at 4.05 indicates that most of the respondents are leaning strongly towards agree. Most workers (56.8%) of the respondents agree with the statement in Q3 while (18.9%) are neutral. Also (18.4%) of the respondents strongly agree with the statement while (3.8%) disagree. Only (2.2%) strongly disagrees with the statement. The implication of

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the mean at 3.85 indicates that most of the respondents are leaning towards agree. Results from the table shows that (45.4%) of the respondents are neutral about the statement in Q4. (27%) agree with the statement, (23.2%) disagree while (4.3%) of the respondents strongly agree with the statement. None of the respondents strongly disagree with the statement. The implication of the mean at 3.12 indicates that most of the respondents are leaning towards agree. In Q5, Majority that is (51.4%) of the respondents are neutral while (27%) tend to agree with the statement. Also (19.5%) disagree with the statement while the remaining (2.2%) strongly agree. None of the respondents strongly disagree with the statement. The implication of the mean at 3.12 indicates that most of the respondents are leaning towards agree.

Table 4.5: Artificial Intelligence and Cost Management

S/NO	Artificial Intelligence and Cost Management	SA	A	N	D	SD	$\bar{x}$	σ^2
Q1	The implementation of Artificial Intelligence (AI) has significantly improved our organization's cost management strategies.	21.1	30.3	44.9	3.8	0	3.69	0.846
Q2	AI-driven analytics have enhanced our ability to predict and control costs more accurately	27.6	65.4	7	0	0	4.21	0.553
Q3	The use of AI has reduced the time and effort required for budgeting and financial forecasting, resulting in more efficient cost management.	16.2	63.8	20	0	0	3.96	0.602
Q4	AI tools have improved our ability to identify cost-saving opportunities and optimize resource allocation.	8.1	34.6	40.5	10.3	6.5	3.28	0.981
Q5	The integration of AI in our cost management processes has led to a reduction in overall project or operational costs.	1.6	23.2	40	20	- 15.10%	2.76	1.026

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Source: Researcher's Field Survey Result (2024)

Table 4.5 describes the frequency and percentage of responses as regards Artificial Intelligence and Cost Management. The table indicates that in Q1, a high number of respondents that is (44.9%) are neutral while (30.3%) tend to agree with the statement. (21.1%) strongly agree with the statement and (3.8%) disagree with the statement. None of the respondents strongly disagree with the statement. The implication of the mean at 3.69 indicates that most of the respondents are leaning towards agree. Majority of the respondents (65.4%) agrees with the statement in Q2, (27.6%) strongly agree and (7%) are neutral. None of the respondents disagree or strongly disagree with the statement. The implication of the mean at 4.21 indicates that most of the respondents are leaning towards agree. A great number of the respondents in Q3 that is (63.8%) agree with the statement, (20%) were neutral while (16.2%) strongly agree with the statement. None of the respondents disagree or strongly disagree with the statement. The implication of the mean at 3.96 indicates that most of the respondents are leaning towards agree. Most of the respondents in Q4 which comprises (40.5%) are neutral about the statement, (34.6%) agree with the statement while (10.3%) disagree with the statement. Only (8.1%) strongly agree with the statement leaving (6.5%) who strongly disagree. The implication of the mean at 3.28 indicates that most of the respondents are leaning towards agree. Finally (40%) of the respondents are neutral or undecided about the statement in Q5. (23.2%) agree, (20%) tends to disagree while (15.1%) strongly disagree and only (1.6%) strongly agrees with the statement. The implication of the mean at 2.76 indicates that most of the respondents are leaning towards disagree.

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Table 4.6: 3D Technology and Quality of Work

S/NO	3D technology and Quality of Work	SA	A	N	D	SD	$\bar{x}$	σ^2
Q1	The use of 3D technology has significantly enhanced the quality of our work outputs.	4.3	15.1	45.9	28.1	6.5	2.83	0.916
Q2	3D technology has improved the precision and accuracy of our design and construction processes, leading to higher quality outcomes.	2.2	21.6	52.4	21.6	2.2	3	0.78
Q3	The integration of 3D models has reduced the occurrence of errors and rework, positively impacting the quality of our projects.	5.9	40	33.5	18.4	2.2	3.29	0.91
Q4	3D visualization tools have improved our ability to identify potential issues early, contributing to better quality control.	8.6	27	44.9	19.5	0	3.25	0.868
Q5	The use of 3D technology has enhanced communication and collaboration among team members, leading to higher quality work.	0	15.1	33	37.3	14.6	2.49	0.921

Source: Researcher's Field Survey Result (2024)

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Table 4.6 shows the frequency and percentages of responses in regards to 3D technology and Quality of Work.The table above shows that most of the respondents that is (45.9%) are neutral about the statement in Q1. (28.1%) disagree with this statement, (15.1%) agree with the statement while (6.5%) strongly disagree with the statement as opposed to (4.3%) who strongly agree with the statement. The implication of the mean at 2.83 indicates that most of the respondents are leaning towards disagree. In Q2, (52.9%) of the

respondents are neutral about the statement. (21.6%) of the respondents agree with the statement as opposed to another (21.6%) of respondents who disagree with the statement. Of the remaining respondents (2.2%) strongly agree with the statement while the other (2.2%) strongly disagree with the statement. The implication of the mean at 3.00 indicates that most of the respondents are leaning towards neutral. Majority of the respondents in Q3 comprising (40%) tends to agree with the statement. (33.5%) indicated that they were neutral while (18.4%) disagree with the statement. The rest comprising (5.9%) and (2.2%) strongly agree and strongly disagree with the statement respectively. The implication of the mean at 3.29 indicates that most of the respondents are leaning towards agree. In Q4, a great number of the respondents precisely (44.9%) are neutral about the statement. (27%) tends to agree with the statement while (19.5%) disagree. Only (8.6%) strongly agrees with the statement. None of the respondents strongly disagree with the statement. The implication of the mean at 3.25 indicates that most of the respondents are leaning towards agree. Finally, in Q5 the highest number of respondents (37.3%) appeared to disagree with the statement. Another (33%) were neutral while (15.1%) agreed with the statement. The remaining (14.6%) strongly disagree with the statement meanwhile none of the respondents strongly agree with the statement. The implication of the mean at 2.49 indicates that most of the respondents are leaning towards agree.

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Table 4.7: Robotics and Organizational Performance

S/NO	Robotics and Organizational Performance	SA	A	N	D	SD	$\bar{x}$	σ^2
Q1	The implementation of robotics has significantly improved our organization's overall performance.	2.2	27.6	29.2	32.4	8.6	2.82	1.003
Q2	Robotics has increased the efficiency and productivity of our operations, leading to better organizational outcomes	75.1	20.5	2.2	2.2	0	4.69	0.625
Q3	The use of robotics has enhanced the quality of our products/services, contributing to improved organizational performance.	13	39.5	37.3	8.1	2.2	3.53	0.897
Q4	Robotics has enabled us to reduce operational costs, which has positively impacted our organization's performance.	33	3.8	2.2	18.9	42.2	2.66	1.771
Q5	The integration of robotics into our processes has improved our ability to meet customer demands and expectations, leading to higher organizational performance.	11.9	19.5	38.4	30.3	0	2.13	0.98

Source: Researcher's Field Survey Result (2023)

Table 4.7 shows the frequency and percentages of workers responses as regards Robotics and Organizational Performance. The table shows that in Q1 most of the respondents (32.4%) tend to disagree with the statement. (29.2%) are neutral while (27.6%) agree with the statement. Only (8.6%) of the respondents strongly disagree as opposed to (2.2%) who strongly agree with the statement. The implication of the mean at 2.82 indicates that most of the respondents are leaning towards disagree. In Q2, a great number of the respondents precisely (75.1%) strongly agree with the statement. Another (20.5%) also

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agrees with the statement. Of the remaining respondents (2.2%) are neutral while the other (2.2%) disagree with the statement, none of the respondents strongly disagree with the statement. The implication of the mean at 4.69 indicates that most of the respondents are leaning strongly towards agree. In Q3, majority of the respondents specifically (39.5%) of the workforce agree with the statement. (37.3%) are neutral while (13.0%) strongly agree with the statement. Also (8.1%) of the respondents as well as (2.2%) tends to disagree and strongly disagree with the statement respectively. The implication of the mean at 3.53 indicates that most of the respondents are leaning towards agree. The table also shows in Q4 that the highest number of respondents precisely (42.2%) of the respondents strongly disagree with the statement as opposed to (33.0%) who strongly agree with the statement. Also, it shows that (18.9%) of the workforce disagree while (3.8%) agree with the statement. Only (2.2%) are neutral. The implication of the mean at 2.66 indicates that most of the respondents are leaning towards disagree. Finally, in Q5, most respondents (38.4%) are neutral about the statement. (30.3%) disagree, (19.5%) agree while (11.9%) strongly agree with the statement. None of the respondents strongly disagree with the statement. The implication of the mean at 3.12 indicates that most of the respondents are leaning towards disagree.

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Table 4.8: Employee Skill Development and Organizational Performance

S/NO	Employee Skill Development and Organizational Performance	SA	A	N	D	SD	$\bar{x}$	σ^2
Q1	To what extent do you agree that the on-the-job training provided by your company effectively equips you with the skills necessary to utilize Industry 4.0 technologies?	9.7	63.8	22.2	2.2	2.2	3.77	0.741
Q2	How effective do you believe off-the-job training programs (e.g., workshops, seminars) are in enhancing your skills related to Industry 4.0 technologies?	8.1	30.3	30.3	27	4.3	3.11	1.032
Q3	To what extent do you feel that the upskilling opportunities provided by your company positively impact your performance in relation to Industry 4.0 technologies?	10.3	33	45.9	8.6	2.2	3.41	0.868
Q4	How strongly do you agree that reskilling initiatives are necessary for your job role to effectively implement Industry 4.0 technologies?	18.9	44.9	29.7	6.5	0	3.76	0.833
Q5	To what degree do you believe that employee skill development through training and upskilling contributes to improved performance in your construction company when adopting Industry 4.0 technologies?	8.1	25.9	57.8	6.5	1.6	3.32	0.782

Source: Researcher's Field Survey Result (2024)

Table 4.8 shows the frequency and percentages of responses as regards Employee Skill Development and Organizational Performance. The table shows that in Q1 most of the respondents (63.8%) tend to agree with the statement. (22.2%) are neutral while (9.7%) strongly agree with the statement. Of the remaining respondents (2.2%) disagree as

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opposed to (2.2%) who strongly disagree with the statement. The implication of the mean at 3.77 indicates that most of the respondents are leaning towards agree. In Q2, (30.3%) of the respondents agree with the statement while another (30.3%) is neutral. Of the remaining respondents (27%) disagree while the other (8.1%) strongly agree with the statement. Only (4.3%) respondents strongly disagree with the statement. The implication of the mean at 3.11 indicates that most of the respondents are leaning towards agree. In Q3, majority of the respondents specifically (45.9%) of the workforce are neutral. (33%) agree while (10.3%) strongly agree with the statement. Also (8.6%) of the respondents as well as (2.2%) tends to disagree and strongly disagree with the statement respectively. The implication of the mean at 3.41 indicates that most of the respondents are leaning towards agree. The table also shows in Q4 that the highest number of respondents precisely (44.9%) of the respondents agree with the statement while (29.7%) are neutral. Also, it shows that (18.9%) of the workforce strongly agree while (6.5%) disagree with the statement. None of the respondents strongly disagree with the statement. The implication of the mean at 3.76 indicates that most of the respondents are leaning towards agree. Finally, in Q5, most respondents (57.8%) are neutral about the statement. (25.9%) agree while (8.1%) strongly agree as opposed to (6.5%) and (1.6%) who disagree and strongly agree with the statement respectively. The implication of the mean at 3.32 indicates that most of the respondents are leaning towards agree.

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4.2.2 Test of Hypotheses

Hypothesis One

$H_0$1: There is no functional relationship between Internet of Things and Operational Efficiency

In order to test the hypothesis, linear regression analysis was used. In the analysis, the values of Internet of Things were regressed on the values of Operational Efficiency.

The data for Operational Efficiency was generated by summing responses of all items used to measure the variable while that of Internet of Things was generated by adding responses of all items used to measure the variable. The regression test results are presented in Table 4.9.

Table 4.9. Regression Test Results

Model	R	R Square	Adj R Square	Std. Error of the Estimate
1	.663[a]	0.440	0.431	0.37617

Source: Author's Computation, 2024

a. Predictors: (Constant), Internet of Things

Table 4.9 above revealed that there is a strong relationship at R = .663 between Internet of Things and the level of Operational Efficiency. An examination of the table shows that R square = .440 which implies that Internet of Things accounts for 44% of variations having a significant effect on the level of Operational Efficiency.

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Table 4.10: Analysis of Variance

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	20.123	3	6.708	47.403	.000[b]
	Residual	25.612	181	0.142		
	Total	45.735	184			

Source: Author's Computation, 2024
Dependent Variable: Operational Efficiency
Predictors: (Constant), Internet of Things

Table 4.10 shows that the F-value is the Mean Square Regression (6.708) divided by the Mean Square Residual (0.142), yielding F=47.403. From the results, the model in this table is statistically significant (Sig =.000). Therefore, Internet of Things is a significant predictor of Operational Efficiency at $F_{(3,184)} = 47.403$.

Table 4.11: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.782	0.236		3.309	0.001
	IoT	0.23	0.054	0.266	4.272	0

Source: Author's Computation, 2024
a. Dependent Variable: Operational Efficiency

The table above revealed the degree of influence of Internet of Things on Operational Efficiency and its level of significance. The statistical results are given as; (Internet of Things; β=.230; t=4.272; p<0.01). The statistical result implies that Internet of Things is a statistically significant predictor of Operational Efficiency.

Linear Regression Model is given as $Y = a + \beta X$

Where Y = Operational Efficiency

a = constant

βx = Coefficient of X

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Therefore: Operational Efficiency = .782 + 0.230 IoT

Based on the results in the Anova table above, the significance level for all items are less than 0.01 therefore we accept the alternative hypothesis and reject the null hypothesis. That is, Internet of Things has a significant effect on the level of Operational Efficiency of the worker.

Hypothesis Two

Ho2: There is no significant effect between Building Information Modelling and Project Delivery Time

In order to test the hypothesis, linear regression analysis was used. In the analysis, the values of Building Information Modelling were regressed on the values of Project Delivery Time.

The data for Project Delivery Time was generated by summing responses of all items used to measure the variable while that of Building Information Modelling was generated by adding responses of all items used to measure the variable. The regression test results are presented in Table 4.12.

Table 4.12: Regression Test Results

Model	R	R Square	Adj R Square	Std. Error of the Estimate
1	.250[a]	0.063	0.047	0.45468

Source: Author's Computation, 2024
a. Predictors: (Constant), Building Information Modelling

Table 4.12 above revealed that there is a relationship at R = .250 between Building Information Modelling and the level of Project Delivery Time. An examination of the table shows that the R square = .063 which implies that Building Information Modelling

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accounts for only 6.3% of variations having a significant effect on the level of Project Delivery Time of the worker

Table 4.13: Analysis of Variance

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2.503	3	.834	4.035	.008[b]
	Residual	37.418	181	0.207		
	Total	39.921	184			

Source: Author's Computation, 2024
Dependent Variable: Project Delivery Time
Predictors: (Constant), Building Information Modelling

Table 4.13 shows that the F-value is the Mean Square Regression (0.834) divided by the Mean Square Residual (0.207), yielding F=4.035. The model in this table shows that Building Information Modelling is statistically significant at (Sig =.008) and is a significant predictor of Project Delivery Time at F (3,184) = 4.035.

Table 4.14: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.638	0.286		12.735	.000
	BIM	0.229	0.093	0.259	2.459	.015

Source: Author's Computation, 2024
a. Dependent Variable: Project Delivery Time

The table above revealed the degree of influence of Building Information Modelling on Project Delivery Time and its level of significance. The statistical results is given as; (Building Information Modelling β =.019; t=.171; p>0.05). The statistical result implies Building Information Modelling is a statistically significant predictor of Project Delivery Time.

Linear Regression Model is given as

Y = a + βX Where Y = Project Delivery Time

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a = constant

βx = Coefficient of X

Therefore: Project Delivery Time = 3.638 + 0.019BIM

Based on the results in the Anova table above, the significance level for Building Information Modelling is less than 0.01 therefore we accept the alternative hypothesis and reject the null hypothesis. That Building Information Modelling have a significant effect on the level of Project Delivery Time.

Hypothesis Three

Ho3: There is no significant effect between Artificial Intelligence and Cost Management

In order to test the hypothesis, linear regression analysis was used. In the analysis, the values of Artificial Intelligence were regressed on the values of Cost Management. The data for Cost Management was generated by summing responses of all items used to measure the variable while that of Artificial Intelligence was generated by adding responses of all items used to measure the variable. The regression test results are presented in Table 4.15.

Table 4.15: Model Summary

Model	R	R Square	Adj R Square	Std. Error of the Estimate
1	.740[a]	0.548	0.541	0.33794

Source: Author's Computation, 2024
a. Predictors: (Constant), Artificial Intelligence

Table 4.15 above revealed that there is a relationship at R= .740 between Artificial Intelligence and the Cost Management. An examination of the table shows that the R square = .548 which implies that Artificial Intelligence accounts for 54.8% of variations having a significant effect on the Cost Management.

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Tables 4.16: Analysis of Variance

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	25.064	3	8.355	73.155	.000[b]
	Residual	20.671	181	.114		
	Total	45.735	184			

Source: Author's Computation, 2024

a. Dependent Variable: Cost Management

b. Predictors: (Constant), Artificial Intelligence

Table 4.17 shows that the F-value is the Mean Square Regression (8.355) divided by the Mean Square Residual (0.114), yielding F=73.155. The model reveals that Artificial Intelligence is statistically significant at (Sig =.000) therefore it is a significant predictor of effectiveness at $F_{(3,184)} = 73.155$.

Table 4.17: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.806	.203		3.973	.000
	AI	.146	.047	.161	3.118	.002

Source: Author's Computation, 2024

a. Dependent Variable: Cost Management

The table above revealed the degree of influence Artificial Intelligence had on the Cost Management and its level of significance. The statistical results is given as; (Artificial Intelligence; β =.146; t=3.118; $p<0.05$). The statistical result implies that Artificial Intelligence is a statistically significant predictor of the Cost Management.

Linear Regression Model is given as

$Y = a + \beta X$ Where Y = Cost Management

a = constant

βx = Coefficient of X

Therefore: Cost Management = .806 + 0.146AI

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Based on the results in the Anova table above, the significant levels for Artificial Intelligence is less than 0.01 therefore we accept the alternative hypothesis and reject the null hypothesis. That is, Artificial Intelligence has a significant effect on the Cost Management.

Hypothesis Four

Ho4: There is no Significant Effect between 3D Technology and Quality of Work

In order to test the hypothesis, linear regression analysis was used. In the analysis, the values of 3D technology were regressed on the values of Quality of Work. The data for Quality of Work was generated by summing responses of all items used to measure the variable while that of 3D technology was generated by adding responses of all items used to measure the variable. The regression test results are presented in Tables 4.2.10a.

Table 4.18: Model Summary

Model	R	R Square	Adj R Square	Std. Error of the Estimate
1	.345[a]	0.339	0.104	0.44086

Source: Author's Computation, 2024
a. Predictors: (Constant), 3D technology

Table 4.18 above revealed that there is a relationship at R= .345 between 3D technology and Quality of Work. An examination of the table shows that the R square = .119 which implies that 3D technology accounts for only 33.9% of variations having a significant effect on Quality of Work.

Tables 4.19: Analysis of Variance

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.742	3	1.581	8.132	.000[b]
	Residual	35.179	181	.194		
	Total	39.921	184			

Source: Author's Computation, 2024
Dependent Variable: Quality of Work
b. Predictors: (Constant), 3D technology

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Table 4.19 shows that the F-value is the Mean Square Regression (1.581) divided by the Mean Square Residual (0.194), yielding F=8.132. The table shows that 3D technology is statistically significant at (Sig =.000). Therefore, it is a significant predictor of efficiency at F $(_{3,184})$ = 8.132.

Tables 4.20: Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.403	.265		12.859	.000
	3D	.258	.056	.340	4.589	.000

Source: Author's Computation, 2024
Dependent Variable: Quality of Work

The table above revealed the degree of influence 3D technology has on Quality of Work and its level of significance. The statistical result is given as (3D technology; β =.258; t=4.589; p<0.01). The statistical result implies that 3D technology is a significant predictor of Quality of Work.

Linear Regression Model is given as

Y = a + βX Where

Y = Quality of Work

a = constant

βx = Coefficient of X

Therefore: Quality of Work = 3.403 + 0.258(3D)

Based on the results in the Anova table above, the significant levels for 3D technology is less than 0.01 therefore we accept the alternative hypothesis and reject the null hypothesis. That is, 3D technology has a significant effect on Quality of Work.

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Hypothesis Five

$H_0$5: There is no significant effect of Industry 4.0 and organizational performance.

Table 4.21: Summary of Multiple Regression Analysis for the Effect of Industry 4.0 Technology Components on Organisational Performance of Selected Construction Companies in South-West, Nigeria

N	Model	*B*	T	Sig.	ANOVA (Sig.)	R	Adjusted R^2	F (4, 89)
89	(Constant)	35.212	6.217	.000	0.001[b]	0.751[a]	0.543	27.911
	Internet of Things	.036	.107	.915				
	Building Information Modelling	.412	1.179	.242				
	Artificial Intelligence	.677	2.133	.036				
	3D Technology	1.374	4.070	.000				

a. Dependent Variable: Organisational Performance

b. Predictors: (Constant), 3D Technology, Artificial intelligence, Internet of Things, Building information Modelling

Source: Researcher's Field Survey, 2024

Interpretation

Table 4.21 shows the multiple regression analysis results for the effect of industry 4.0 technology on organisational performance of the selected construction companies in South-West, Nigeria. The results revealed that artificial intelligence (β = .677, t = 2.133, p<0.05) and 3D Technology (β = 1.374, t = 4.070, p<0.05) both have a significant positive effect on organisational performance. However, internet of things (β .036, t = .107, p>0.05) and Building Information Modelling (β = .412, t = 1.179, p<0.05) both have positive and insignificant effect on organisational performance in construction companies in South-West, Nigeria. The results of the analysis revealed that two dimensions of industry 4.0 technology (artificial intelligence and 3D technology) have positive and significant effect on organisational performance of the selected construction

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companies in South-West, Nigeria. This suggests that artificial intelligence and 3D technology were important predictors of organisational performance of the selected construction companies in South-West, Nigeria.

The correlation *R* value was 0. 751. It showed that Industry 4.0 technology dimensions have a strong positive relationship with organisational performance. The *Adj.* R^2 was 0.543 implying that 54.3% of the variance in organisational performance of the selected construction companies in South-West, Nigeria was attributable to the industry 4.0 technology and its dimensions of (artificial intelligence, 3D technology, internet of things and building information modelling) while the remaining 45.7% changes that occurs is accounted for by other variables not captured in the model.

The predictive and prescriptive multiple regression models are thus expressed:

OP= 35.212+ .036IoT + 0.677Ai + 0.412BIM + 1.374 3DT + U_i--------Eqn i (Predictive Model)

Where:

OP = Organisational Performance

IoT = Internet of Things

Ai = Artificial Intelligence

BIM = Building Infrastructure Modelling

3DT = 3D Technology

The regression model revealed that if industry 4.0 dimensions were held constant at zero, organisational performance of the selected construction companies in South-West, Nigeria was 35.212 indicating that in the absence of industry 4.0 technology, organisational performance of the selected construction companies in South-West, Nigeria was 35.212, indicating a positive business performance. From the predictive

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model, two dimensions of the industry 4.0 technology (artificial intelligence and 3D technology) have significant positive effect on the organisational performance while internet of things and building information modelling have insignificant effect on organisational performance. This variable was not prescribed for the Construction Companies. From the prescriptive model, a unit change in industry 4.0 technology, artificial intelligence and 3D technology, internet of things and building information modelling would increase organisational performance by .677, 1.374, 0.412 and 0.036 units respectively. The results suggest that artificial intelligence and 3D technology are significant predictors of organisational performance among selected Construction Companies in South-West, Nigeria. Thus, Construction Companies in this region should focus on enhancing these dimensions of industry 4.0 technology in their operations to improve overall organisational performance.

The *F*-statistics (df = 4,89) = 27.911 at $p<0.05$) indicated that the overall model is significant for predicting the effect of industry 4.0 technology on organisational performance. This implies that the regression model is a good fit for predicting the effect of industry 4.0 technology on organisational performance. Also, since the p-value is less than 0.05, this implies that relationship between the industry 4.0 technology on organisational performance is significant. Based on these results, the null hypothesis one (H_{05}) which states that There is no significant effect of industry 4.0 on the organisational performance was rejected.

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4.3.6 Hypothesis Six

$H_0$6: Employee Skill Development has no Moderating Effect on the Interaction between Industry 4.0 Technology and Organizational Performance of Selected Construction Companies in Southwest Nigeria.

To evaluate the null hypothesis seven, hierarchical regression was applied whereby the analysis was carried out in the order of hierarchy. A composite score was obtained for the industry 4.0 Technologies (Xi) as adopted by Construction Companies in Southwest Nigeria and were used in the regression analysis.

Also, data for Organizational Performance (Y) was created by adding responses of all items for the variable, while that of Employee Skill Development (z2) was obtained from adding responses of all items for the variable. In addition, an interaction term for Industry 4.0 Technologies and Employee Skill Development (Xi*z2) was obtained by multiplying the composite score for Industry 4.0 Technologies and Employee Skill Development. The hypothesis would be supported if the effect of the interaction of Industry 4.0 Technologies and Employee Skill Development (Xi*z2) on Organizational Performance among Construction Companies in Southwest Nigeria is statistically significant. The results of the analysis step by step are presented in Table 4.22.

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Table 4.22: Summary of Hierarchical Regression Analysis for the Moderating Effect of Employee Skill Development on the Relationship between Industry 4.0 Technologies and Organizational Performance

Model[1,2]	Beta	t	Sig.	R	R^2	Adj. R^2	ΔR^2	ΔF	Sig. F Change
(Constant)[1]	1.237	8.288	.000	.554[a]	.306	.305	.306	162.176	.000
Industry40fac	.608	12.735	.000						
F & Anova Sig: 162.176(1,367), p=.000									
(Constant)[2]	1.273	4.141	.000	.660[c]	.436	.432	.009	5.665	.018
Industry40fac	.395	3.915	.000						
Empskilldev	.084	2.380	.018						

predictors: (Constant), Industry40 fac
b. Predictors: (Constant), Industry40fac, Empskilldev
Dependent Variable: Orgperf
Source: Researcher's Field Survey (2024)

Table 4.22 present hierarchical multiple regression results for the moderating effect of Employee Skill Development on the interactions Industry 4.0 technology Factors, and Organizational Performance. Results in Table 4.2.12 model 1 summarises the output for the analysis if moderation effect is not considered. Therefore, in this model, the independent variable was Industry 4.0 technology Factors. From the table, Model 1 reveals that R = 0.554, Adj. R^2 = 0.305, and F(1,367)=162.176, p = 0.000. The value of adjusted coefficient of determination, Adj. R^2 indicates that 30.5% of the variance in the Organizational Performance of Selected Construction Companies in Southwest Nigeria was explained by Industry 4.0 Technology factors. The remaining 69.5% of the total variation in Organizational Performance are explained by factors not included in the model. The explained variation in the interaction between Industry 4.0 Technology

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factors on Organizational Performance was found to be significant at p-value of 0.000 which is below the accepted threshold of 0.05. The regression coefficients section in Table 4.22 shows that the coefficient and constants were both positive and statistically significant given the p-value of 0.000. Hence, the model that establishes the effect of Industry 4.0 Technology factors on Organizational Performance was expressed as follows:

Orgperf = 1.237 + 0.608 Industry40fac ..... Eq. (4.6)

Where:

Orgperf= Organizational Performance

Industry40fac = Dimensions of Industry 4.0 technology

The Second model involved the introduction of interaction term of Industry 4.0 technology factors, and Employee Skill Development using regression model. Result in Table 4.22 indicates that the R square change is .009, and F-change of 5.665 with a corresponding p-value of 0.000 implied that the interaction term of Industry 4.0 Technology Factors, and Employee Skill Development have a positive and significant moderating effect on Organizational Performance of Selected Construction Companies in Southwest Nigeria (p=0.000). Furthermore, the interaction term of Industry 4.0 Technology factors, Employee Skill Development has a beta coefficient of 0.084, and a corresponding p-value of 0.000. Hence, this implies that Employee Skill Development moderates the functional relationship between Industry 4.0 Technology and Organizational Performance of Selected Construction Companies in Southwest Nigeria. The established regression equation from the result is stated as follows:

Orgperf =1.273+0.395Industry40fac + 0.084Empskilldev..... Eq (4.8)

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Where:

Orgperf = Organizational Performance

Industry40fac = Dimensions of Entrepreneurship Education

Empskilldev = Employee Skill Development

The results posit that Employee Skill Development moderates the functional relationship between Industry 4.0 Technologies and Organizational Performance of Selected Construction Companies in Southwest Nigeria. Based on this result, this study rejects the null hypothesis six which states that Employee Skill Development has no moderating effect on the interaction Industry 4.0 Technology on Organizational Performance of Selected Construction Companies in Southwest Nigeria.

Summary of Oral Interview

Results of the interview with the General Manager of China Civil Engineering Construction Corporation confirms that the firm has effectively integrated Industry 4.0 technologies to enhance its operational performance and project delivery. The Interviewee asserts that CCECC uses IoT to monitor on-site activities, enabling efficient resource management and reducing waste, which leads to cost savings and improved productivity. On BIM for Collaboration and Timeliness, He confirms that Building Information Modelling (BIM) is transforming project collaboration by providing a shared 3D platform, enhancing coordination among stakeholders, and reducing design errors, which shortens project timelines. Also, on the question about AI, the interviewee stated that AI helps optimize cost estimation, automate processes, and manage resources efficiently. This supports better budget management, risk mitigation, and improved project outcomes. Similarly, he claimed that CCECC uses 3D modelling and printing to

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detect design flaws early, minimizing delays and rework. It also explores innovative and sustainable solutions to enhance client satisfaction. Furthermore, the interviewee asserted that Automation of routine tasks boosts efficiency by reducing errors, allowing skilled employees to focus on complex tasks. CCECC is also exploring advanced robotics to further improve productivity. On Employee skill development, the response gotten proved that CCECC invests in training programs to ensure its workforce can effectively use advanced technologies, emphasizing a culture of continuous learning to maintain competitiveness. In conclusion the interviewee claimed that Industry 4.0 technologies collectively position CCECC as a leader in the construction industry, driving efficiency, innovation, and client satisfaction while preparing for future advancements.

Results from the interview response of the General Manager, Opereation at Reynold construction provides a comprehensive overview of the technological advancements integrated into its operations. It highlights the strategic use of various technologies like IoT, BIM, 3D technology, ML, and the anticipated use of robotics. The adoption of these technologies is staggered, with IoT being fully integrated, BIM and 3D technology at partial and moderate levels, and ML in its early stages. Robotics, though promising, has yet to be implemented due to cost and scale challenges. The impact of these technologies is evident across productivity, cost efficiency, safety, and project delivery. IoT has optimized equipment monitoring and safety measures, reducing downtime and accidents. BIM has improved collaboration in complex projects, aiding in better planning and cost estimation. The use of 3D technology has enhanced project visualization, helping identify design flaws early. ML has started improving predictive maintenance and resource allocation, with future growth expected as data infrastructure

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develops. Robotics, though not yet practical, is seen as a potential game-changer for automating labour-intensive tasks once the company scales further.

Overall, the response reflects a forward-looking approach, emphasizing the role of technology in enhancing operational performance, safety, and efficiency, while also acknowledging challenges such as training requirements, high costs, and data infrastructure needs. The firm's vision suggests a commitment to further expanding technological adoption for sustained growth and competitiveness.

The interview response from the Regional Manager at Hitech Construction Company Limited (HTC) provides an in-depth view of how the company integrates advanced technologies into its operations, particularly focusing on high-rise buildings and warehouse projects. The response underscores a commitment to innovation, emphasizing how technologies such as the Internet of Things (IoT), Building Information Modelling (BIM), Artificial Intelligence (AI), 3D technology, and robotics have transformed their construction processes and outcomes. IoT is highlighted as a core tool for improving operational efficiency, monitoring equipment, and enhancing safety through wearable devices, which have led to a decrease in workplace accidents. The company's use of BIM has significantly streamlined project management by enabling better collaboration among teams, improving project visualization, and reducing delays through efficient scheduling and coordination tools. The adaptation of AI is particularly impactful in cost management, risk mitigation, and procurement processes, showing how the company uses data-driven strategies to optimize financial outcomes and project planning. 3D technology has also played a pivotal role in enhancing design accuracy and streamlining communication with clients, aiding in early detection of design flaws and improving prefabrication processes, which reduces on-site construction times. The

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company's early exploration of robotics indicates a forward-thinking approach, focusing on automating labour-intensive tasks to boost efficiency and maintain quality, especially in the precise and high-risk environment of high-rise construction.

The response also highlights HTC's commitment to workforce development, illustrating the emphasis on training employees to adapt to and effectively use these new technologies. This strategy not only enhances operational efficiency but also fosters a culture of innovation and adaptability, positioning the company as a leader in technologically advanced construction. Overall, the interview response reflects a balanced approach to integrating technology and emphasizes the value of proactive investment in both human capital and technological resources to achieve long-term success and maintain a competitive edge in the high-rise construction industry. response to oral interview for Setraco Nigeria Limited proved that its integration of Industry 4.0 technologies, such as IoT, BIM, AI, and 3D modelling has significantly transformed its construction operations, enhancing efficiency, productivity, and safety. IoT is pivotal in optimizing resource management and site safety through real-time tracking and predictive maintenance. BIM streamlines project management by improving collaboration, reducing errors, and automating workflows, despite initial challenges related to software investment and training. AI optimizes cost management through predictive analytics and dynamic budgeting, leading to reduced costs and waste, while 3D modelling enhances design precision and stakeholder communication, aligning with sustainability goals. Robotics is also being explored to automate labour-intensive tasks, showing the company’s forward-looking approach. The interviewer noted that Employee skill development is a key focus, as the company invests in training programs and mentorship to adapt its workforce to these technologies, boosting productivity and innovation. The strategic adoption of these technologies has resulted in measurable

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improvements in operational efficiency, cost savings, and safety outcomes, reinforcing Setraco's competitive edge in the industry. Despite challenges like initial investment and skill acquisition, the company remains committed to maximizing these technologies to drive growth and excellence.

Responses from interview from the General Manager, Kopek suggests that Kopek Construction Limited has successfully integrated a range of advanced technologies into its operations, resulting in significant improvements across various aspects of its business. The company has leveraged IoT technologies to enhance efficiency through real-time monitoring of equipment and site conditions, leading to better maintenance practices and resource allocation. Their implementation of Building Information Modelling (BIM) has transformed project delivery timelines by facilitating early clash detection and improving stakeholder collaboration. While they encountered some challenges in adopting BIM, such as staff adaptation and hardware requirements, the benefits have outweighed these obstacles. Kopek has also harnessed AI for cost management, achieving more accurate budget forecasts and real-time expenditure tracking, which has led to substantial cost savings in areas like material usage and labour allocation. The firm's use of 3D technology has enhanced design precision and improved client communication. Automation and robotics have boosted productivity in repetitive tasks and improved on-site safety. To support these technological advancements, Kopek has invested heavily in employee skill development through comprehensive training programs and partnerships with technology providers. The company has fostered a culture of continuous learning and innovation, enabling it to remain competitive in the evolving construction industry. Overall, these technological integrations have resulted in tangible improvements in project timelines, budget management, and work quality,

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positioning Kopek Construction Limited at the forefront of the industry's technological revolution.

The interview report revealed that some of the 4IR technologies are being presently utilized by the selected construction companies at various degrees. It also revealed that increased level of adaptation of these technology is required to increase their outcomes while the need to be intentional about employee skill development for effective deployment of these techonologies

4.3 Discussion of Findings

The first objective of this study is to assess the effect of the Internet of Things (IoT) and on Operational efficiency of selected construction companies in Southwest Nigeria. In examining the data, the analysis showed that Internet of Things dimensions have strong positive and statistically significant relationship with Operational efficiency of selected construction companies in Southwest Nigeria (Adj R2 = 0. 431, F (3,184) = 47.403, p= 0.000). These findings corroborate the result of another study which discusses how General Electric's implementation of IoT and predictive analytics in manufacturing has led to significant reductions in unplanned downtime and improvements in equipment reliability. It also flows with the submissions of other empirical studies which have identified Siemens' use of IoT in its factories, noting the productivity gains and energy efficiency improvements achieved through IoT-driven process optimization. These results have also been supported by findings of how Walmart leverages IoT for supply chain management, highlighting the reduction in spoilage and improved inventory management as key outcomes. The result was also corroborated by A study published by DHL and Cisco which discusses how IoT technologies, such as smart sensors and RFID tags, have been integrated into logistics operations. The study found that IoT applications improved

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inventory management, reduced shipping times by 25%, and enhanced overall supply chain visibility. A study published further corroborated the results when it found that by equipping machinery with IoT sensors, a construction firm was able to perform predictive maintenance, reducing equipment downtime by 15% and lowering maintenance costs by 25%. This also improved project timelines and overall productivity.

The second objective of this study is to investigate Building Information Modelling (BIM) influence on the Project Delivery Time of selected construction companies in Southwest Nigeria. The data analysis showed that Building Information Modelling has significant effect on Project Delivery of construction companies in Southwest Nigeria. ($Adj\ R^2$ = 0. 047, F (3,184) = 4.035, p= 0.000). Contextually, Building Information Modelling (BIM) does not exist objectively and independently of project delivery time, because BIM is a digital representation of the physical and functional characteristics of a building or infrastructure project, and it is inherently tied to the lifecycle of that project.

Research studies have demonstrated that Building Information Modelling (BIM) significantly impacts project delivery in construction companies by enhancing efficiency, reducing errors, and improving collaboration. This is supported by a study which found that BIM adoption in construction projects led to a 40% reduction in unbudgeted change orders and a 7% decrease in project time. The study concluded that BIM's ability to identify potential design clashes and streamline communication among stakeholders was a key factor in these improvements.

Another study supported the result in its analysis on the impact of BIM on project success and found that companies using BIM reported higher satisfaction levels with project outcomes. The research showed that BIM contributed to better cost predictability, time savings, and overall project performance. These findings suggest that BIM's integration

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into project delivery processes can lead to more successful project execution, further reinforcing its importance in the construction industry.

The third objective of this study is to Consider the influence of Artificial Intelligence on Cost Management of selected construction companies in Southwest Nigeria. The data showed that Artificial Intelligence significantly influences Cost Management of selected construction companies in Southwest Nigeria (Adj R2 = 0. 541, F (3,184) = 73.155., p= 0.000). The findings from this study indicate that there is causal relationship between what the Artificial Intelligence and management of expense. This finding is supported by other studies which found that Artificial Intelligence (AI) can significantly influence cost management in construction companies by enhancing forecasting accuracy and optimizing resource allocation. For example, a study investigated the use of AI in cost estimation and found that AI-based tools, such as machine learning algorithms, improved cost prediction accuracy by up to 15% compared to traditional methods. These tools analyse historical data and project specifics to predict costs more reliably, reducing budget overruns and improving financial planning. Another study focused on AI's role in optimizing construction project budgets through dynamic risk assessment. The researchers demonstrated that AI systems capable of real-time risk analysis and cost adjustments could decrease cost variances by 20%. By continuously monitoring project data and adjusting cost forecasts based on emerging risks and uncertainties, AI helps construction companies manage their budgets more effectively, ultimately leading to better financial control and project success.

The fourth objective of the study was to examine how 3D technology affects the Quality of Work of selected construction companies in Southwest Nigeria. The result showed that 3D Technology significantly influences Quality of Work among construction companies

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in Southwest Nigeria. (Adj R2 = 0. 104, F (3,184) = 8.132, p= 0.000). Several research studies have demonstrated that 3D technology can significantly enhance the quality of work in construction companies. One such study examines the impact of Building Information Modelling (BIM) on construction project outcomes. The study found that BIM, a form of 3D technology, improved project coordination and communication among stakeholders, leading to a reduction in errors and rework. This improvement in project accuracy and efficiency ultimately contributed to higher quality outcomes in construction projects. Another research explored the use of 3D laser scanning technology in construction quality control. The study highlighted how 3D laser scanning provides precise and detailed representations of construction sites, enabling better detection of discrepancies between as-built conditions and design specifications. The ability to quickly identify and address these discrepancies before they escalate into major issues helps ensure that the final construction quality meets the required standards.

Additionally, a study investigated the role of 3D modelling in construction safety and quality management. The research revealed that 3D models facilitate comprehensive safety planning and hazard identification by providing a visual representation of construction sites. This proactive approach not only enhances safety but also reduces the likelihood of construction defects, as potential issues can be addressed during the planning stages. The study concluded that integrating 3D modelling into construction processes significantly improves both safety and quality outcomes.

The fifth objective of the study was to investigate the influence of industry 4.0 technology on organizational performance of the selected construction companies in Southwest Nigeria. It was found that industry 4.0 technology have a significant effect on Organizational Performance. ($Adj\ R^2$ = 0.543, F ($_{4,89}$) = 27.911, p= 0.000). The result

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gotten was corroborated by a study that investigated the use of industry 4.0 technologies in the construction industry, focusing on how these innovations affect productivity and project outcomes. Their research demonstrated that robotic systems, such as automated bricklaying and 3D technology, could significantly increase construction efficiency by reducing the time and labour required for repetitive tasks. This boost in productivity directly translated into improved organizational performance, as companies were able to complete projects faster and at a lower cost.

Another relevant study explored the implementation of robotic technologies in modular construction. The study found that the use of robots for prefabrication and assembly tasks not only enhanced the precision and quality of construction but also led to a more streamlined and less error-prone process. This increased precision and efficiency improved overall organizational performance by minimizing rework and material waste, leading to cost savings and higher profitability for construction companies. Additionally, a study analysed the impact of industry 4.0 technology in the construction companies on project management and operational workflows. The research indicated that robotics contribute to better project management by automating complex tasks and providing real-time data for decision-making. This automation allows construction companies to optimize their resource allocation and workflow processes, leading to improved project outcomes and enhanced organizational performance. The study highlighted that companies leveraging robotics experienced increased operational efficiency and a stronger competitive edge in the industry.

The sixth objective of this study is to establish the moderating effect of employee skill development on the relationship between industry 4.0 technologies and organizational performance of the selected construction companies in Southwest Nigeria. The data

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showed that employee skill development moderates the functional relationship between industry 4.0 technologies and organizational performance of the selected construction companies in Southwest Nigeria (AdjR2 = 0.432, F=162.176, p= 0.000).

Chapter Five

Conclusion

This chapter comprises discussions associated with findings of the entire research. This includes summary of the work, findings both theoretical and empirical findings, conclusions, policy implication of the findings, recommendations, limitation of the research, suggestions for further study and contribution to knowledge.

5.1 Summary of Findings

This study aims to evaluate the effect of Industry 4.0 Technology, Employee Skill development, and Performance of Construction Companies in Southwest Nigeria. It precisely assessed the effect of Internet of Things (IoT), Building Information Modelling (BIM), Artificial Intelligence (AI), 3D technology on Operational efficiency, Project Delivery Time, Cost Management and Quality of Work. Alsothe study examined the moderating effect of employee skill development on the relationship between industry 4.0 technologies and organizational performance of the selected construction companies in Southwest Nigeria.

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This study was structured into five Chapters in an effort to achieve the earlier mentioned specific objectives. The introductory chapter presented a detailed background to the study which revealed industry 4.0 technology dimensions as a key driver of organizational performance.

Th review of previous related literature relevant to the concept of industry 4.0 technology dimensions including Internet of Things (IoT), Building Information Modelling (BIM), Artificial Intelligence (AI), and 3D technology. The review equally captured discussions on Operational efficiency, Project Delivery Time, Cost Management and Quality of Work which are organisational performance dimensions. Several definitions bothering on the variables identified above were reviewed to position the understanding of each variable within existing literature.

The theoretical review considered three theories which are of specific relevance to this study. The Socio-Technical Systems theory is an organizational approach that emphasizes the interaction between people (the social system) and technology (the technical system) within workplaces. The Experiential Learning Theory is a holistic approach to learning that emphasizes learning through experience while Organizational Learning Theory explores how organizations acquire, create, and use knowledge to improve their performance and adapt to their environments.

On the methodological chapter, the study adopted cross sectional survey design. This approach was chosen because it allowed for the gathering of a large amount of data from diverse individuals quickly and at a relatively low cost. Also, findings from quantitative studies are generalizable to the target population. Given the specific objective of the study, the population was gotten from five (5) construction firms. Using Scientific sample size formulas, 90 was obtained. A structured questionnaire was employed to collect data after

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it was scientifically certified to be valid and reliable for the intended purpose by the result of the pilot study.

Both descriptive and inferential statistics were adopted, specifically, the descriptive enhanced the analysis for all the study variables and it provided answer to the specific research questions of the study. on the other hand, the inferential statistics enabled the test of the six null hypotheses formulated in the introductory; hypothesis one to five been relative effect analysis was established through multiple regression while hypothesis six been a moderating effect analysis was established through hierarchical multiple regression analysis. The researcher ensured ethical consideration as required by the university.

The data analysis established the analytical technique adopted, interpretation of results and discussion of research findings. In all, six research questions, objectives and hypotheses were formulated and tested. The data analysis was carried out in line with the study's specific objectives and hypotheses from which patterns were investigated, interpretation and conclusions drawn. Both descriptive and inferential statistics were adopted to analyze the data. Frequency distribution table was employed in the analysis and interpretation of data collected using statistical product and service solution (SPSS) version 24 for the analysis.

The data generated were sorted, coded, analyzed and substituted in each of the functional relationship equations to obtain multiple regression models and establish the statistical significance of Industry 4.0 Technology, Employee Skill Development and Performance of Construction Companies, Southwest Nigeria.and final acceptance or rejection of the hypotheses were made. From the interpretation of data collected and findings of this study, the following can be summed up as the major empirical findings of this study:

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1. Internet of Things dimensions have strong positive and statistically significant relationship with Operational efficiency of selected construction companies in Southwest Nigeria (Adj R2 = 0. 431, F (3,184) = 47.403, p= 0.000).

2. Building Information Modelling has significant effect on Project Delivery of construction companies in Southwest Nigeria. (*Adj* R^2 = 0. 047, F (3,184) = 4.035, p= 0.000).

3. Artificial Intelligence significantly influences Cost Management of selected construction companies in Southwest Nigeria (Adj R2 = 0. 541, F (3,184) = 73.155., p= 0.000).

4. 3D Technology significantly influences Quality of Work among construction companies in Southwest Nigeria. (Adj R2 = 0. 104, F (3,184) = 8.132, p= 0.000).

5. Industry 4.0 technology have a significant effect on Organizational Performance. (*Adj* R^2 = 0.543, F $(_{4,89})$ = 27.911, p= 0.000).

6. employee skill development moderates the functional relationship between industry 4.0 technologies and organizational performance of the selected construction companies in Southwest Nigeria (AdjR2 = 0.432, F=162.176, p= 0.000).

5.2 Conclusion

Based on the empirical findings, this study concluded that there wa a statistically significant effect of Industry 4.0 Technology (Internet of Things, Building Information Modelling, Artificial Intelligence, and 3D technology) on each of the measures of Organizational Performance which include on Operational efficiency, Project Delivery

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Time, Cost Management and Quality of Work Construction Companies in Southwest Nigeria. Further analysis showed that Employee Skill Development moderated the functional relationship between Industry 4.0 Technology and Organizational Performance among Construction Companies in Southwest Nigeria.

Theoretically, the outcome of this study is in line with The Socio-Technical Systems theory and The Experiential Learning Theory which provided the theoretical underpinnings for this study. The theories were selected because their viewpoint relates to the variables under investigation. The Socio-Technical Systems theory explains the significance of Industry 4.0 to the performance of construction companies by emphasizing the need for an integrated approach that aligns advanced technological innovations with the social and organizational structures to enhance overall efficiency and productivity. In addition, the second underpinning theory explains the significance of Industry 4.0 to the performance of construction companies by highlighting how hands-on experience with advanced technologies fosters continuous learning, adaptation, and innovation, ultimately improving operational efficiency and effectiveness.

5.3 Recommendation

The recommendation from the outcomes in relation to the objective of this study is that:

The construction companies should prioritize the adoption of Internet of Things (IoT) technologies, which offer real-time monitoring, predictive maintenance, and improved resource management. By integrating IoT into daily operations, the firm can reduce downtime, optimize workflows, and enhance decision-making with data-driven insights. It's essential to train staff and invest in robust IoT infrastructure to fully leverage these benefits and remain competitive in the industry.

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Secondly, the construction firm should adopt Building Information Modelling (BIM), which enables efficient collaboration, streamlined workflows, and precise project planning. By using BIM, the firm can visualize the entire project lifecycle, identify potential issues early, and make informed decisions, reducing delays and rework. Implementing BIM also facilitates better coordination among stakeholders, ensuring that all parties are aligned and working towards a common goal. To maximize the benefits, the firm should invest in BIM training for its team and integrate the technology into its existing project management processes.

Thirdly, to enhance cost management, the construction company should adopt Artificial Intelligence (AI), which can analyse vast amounts of data to predict costs accurately, optimize resource allocation, and identify potential savings. AI-driven tools can automate budgeting processes, monitor expenses in real-time, and flag cost overruns before they escalate, allowing for more proactive financial management. By implementing AI, the firm can also improve decision-making through predictive analytics, ensuring projects stay within budget. To fully leverage AI's capabilities, the firm should invest in AI technologies tailored to construction and provide training to staff on their effective use.

With respect to the fourth objective of this study, the construction companies in Southwest Nigeria should adopt 3D technology, which allows for precise modelling, accurate visualization, and detailed project planning. By using 3D printing and modelling, the firm can create complex structures with higher precision, reducing errors and rework, and ensuring a higher standard of craftsmanship. This technology also enables better quality control by allowing for thorough testing and adjustments before actual construction begins. To maximize the benefits, the firm should invest in the latest 3D technology and train its workforce to utilize these tools effectively in their projects.

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Southwest Nigerian construction companies should adopt robotics to enhance organizational performance by automating repetitive tasks, improving precision, and speeding up project timelines. This will reduce Labour costs, minimize human error, and improve safety on construction sites, leading to higher productivity and better project outcomes. Robotics also allows for more complex, large-scale projects with consistent quality, giving the firm a competitive edge. Investment in advanced robotics technology and workforce training are essential.

Lastly, results showed that Employee skill development is crucial for harnessing the full potential of Industry 4.0 technologies in the construction industry in Southwest Nigeria. It is therefore recommended that, construction companies should upskill workers in areas like digital tools, data analysis, and advanced machinery, the firm should ensure that its workforce can effectively operate and integrate new technologies into daily operations. This not only improves organizational performance by enhancing productivity and efficiency but also positions the company as a leader in innovation within the industry. Investing in continuous learning and development will enable the firm to adapt to technological advancements, driving long-term success and competitiveness.

5.4 Contribution to Knowledge

The study provides empirical evidence demonstrating the positive relationship between Industry 4.0 technologies and organizational performance, validating theoretical concepts with real-world data. It identifies specific performance metrics (such as efficiency, cost reduction, and quality enhancement) that are positively influenced by Industry 4.0 technologies, offering a detailed understanding of how these technologies affect various aspects of performance. Also, the study contributed to knowledge through practical insights into how Industry 4.0 technologies can be effectively implemented in the

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construction industry, including best practices and strategies for overcoming common challenges.

Furthermore, the findings serve as a benchmark for other organizations in the construction industry, providing a reference point for evaluating their own technology adoption efforts and performance improvements.

5.5 Suggestion for Further Studies

The research findings on the substantial influence of Industry 4.0 technologies on organisational performance in the construction sector provide several opportunities for future investigation. An essential domain is investigating the enduring impacts of these technologies, especially the manner in which continuous usage affects performance over time and adjusts to changing industrial demands. Further research could investigate the sector-specific adaptations of Industry 4.0 technologies, examining how various building projects or regional patterns might impact the efficiency and implementation strategies of these technologies.

Furthermore, it is necessary to explore the incorporation of developing technologies, such as sophisticated artificial intelligence applications or next-generation robotics, in order to comprehend their collective impact on organizational performance. An examination of the obstacles and determinants of success in the adoption of technology, such as the influence of organizational culture and staff preparedness, would yield significant knowledge for facilitating more seamless implementation procedures. Lastly, conducting comparison studies across several industries or geographical locations could provide insights into the wider relevance of Industry 4.0 technologies and pinpoint optimal strategies that could be advantageous for the construction industry as a whole.

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