Empirical Study for the Impact of Utilizing Industry 4.0 on Supply Chain Integration in Egyptian Architecture Engineering Construction (AEC) Industry

دراسة تجريبية عن تأثير استخدام تكنولوجيا الثورة الصناعية الرابعة على تكامل سلاسل التوريد في قطاع العمارة والهندسة والإنشاءات في مصر

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Abstract:

Purpose – While digital technologies revolutionized industries worldwide, their adoption in Egypt's Architecture, Engineering, and Construction (AEC) sector has been slow. This research empirically examines the impact of Industry 4.0 transformation (IR4.0) on supply chain integration (SCI) within Egypt's AEC industry.

Design/methodology/approach – A quantitative approach with a survey administered to 144 AEC companies located in Greater Cairo, was employed to collect data. SPSS statistical software (version 25) was used for data analysis using the following statistical methods: descriptive statistics, reliability and validity testing, normality Tests, and Ordinal Data Analysis.

Findings – The findings reveal that IR4.0 has a positive impact on SCI

Implications – This research fills an Empirical Gap due to the scarcity of information and the challenges involved in collecting data from the Egyptian AEC industry supply chain parties, and fills a Population Gap, by targeting a diverse population with varying sources of data and information collection, which posed a significant challenge.

Keywords: **Industry 4.0, AEC industry structure, Supply chain integration, Digital Transformation, BIM, Egyptian AEC Industry, Technological Integration, Construction Technology.**

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ملخَّص:

الغرض: بينما أحدثت التقنيات الرقمية ثورة في الصـــناعات في جميع أنحاء العالم، كان تبنيها في قطاع الهندســـة المعمارية والهندســـة والبناء في مصـــر بطيئًا. يدرس هذا البحث تجريبيًا تأثير تحول الصـناعة 4.0 (IR4.0) على تكامل سلسلة التوريد (SCI) داخل صناعة الهندسة المعمارية، والهندسة والبناء في مصر.

التصميم / المنهجية / النهج: تم استخدام نهجًا كميًّا مع مسح تم إجراؤه على 144 شـركة هندسـة معمارية وهندسـة وبناء تقع في القاهرة الكبرى لجمع البيانات. تم اسـتخدام برنامج SPSS الإحصائي (الإصدار 25) لتحليل البيانات باستخدام الأساليب الإحصائية التالية: الإحصــاء الوصــفي، واختبار الموثوقية والصــلاحية، واختبارات الطبيعية، وتحليل البيانات الترتيبية.

النتائج: تكشف النتائج أن IR4.0 له تأثير إيجابي على .SCI .

الآثار المترتبة على هذا البحث: يملأ هذا البحث فجوة تجريبية بســـبب ندرة المعلومات والتحديات التي تنطوي عليها عملية جمع البيانات من أطراف ســلســلة توريد صــناعة AEC المصــرية، ويملأ فجوة سكانية، من خلال اســتهداف مجموعة متنوعة من السكان بمصادر مختلفة لجمع البيانات والمعلومات؛ مما شكل تحديًا كبيرًا.

الكلمات المفتاحية: الصـناعة 4.0، هيكل صـناعة الهندسـة المعمارية والإنشـاءات، تكامل ســلســلة التوريد، التحول الرقمي، نمذجة معلومات البناء، صـــناعة الهندســـة المعمارية والإنشاءات المصرية، التكامل التكنولوجي، تكنولوجيا البناء.

Introduction

The dynamic business ecosystem, driven by customer demands and the need for adaptability, highlights the importance of advanced technologies in supply chains (Fatorachian & Kazemi, 2021), shifting competition from individual companies to entire supply chains (Alfalla-Luque, Medina-Lopez, & Dey, 2012). Digital transformation (DT) is key to fostering integration and creating new opportunities (Venkatesh & Davis, 2000). In the AEC industry, IR4.0 technologies, such as Building Information Modeling (BIM), have revolutionized planning, design, construction, and operations (Azhar, 2011). However, adoption is slow, with countries progressing at different rates (International Data Corporation - IDC, 2020). Despite technological advancements, implementing IR4.0 remains challenging, requiring significant changes to supply chain operations. Consequently, many companies are adopting business process re-engineering (BPR) to promote IT capabilities and facilitate IR4.0 adoption (Patrucco, Ciccullo, & Pero, 2020).

Fergusson & Teicholz (1996) noted the AEC industry's fragmentation into horizontal, vertical, and longitudinal dimensions, leading to decentralized project organization. Recently, however, the industry has embraced Industry 4.0-driven supply chain integration practices to better organize information, processes, human resources, and supply chains for improved integration (Fergusson & Teicholz, 1996).

Hall D. M., (2018) offered a conceptual overview of emerging structure re-organization efforts aimed at integration within the AEC industry. He described the Collaborative modular clusters as an ideal structure for Building Information Modeling coordination, where this approach support supply chain integration practices.

Therefore, this study aims to investigate empirically the impact of utilizing IR4.0 transformation on supply chain integration in Egyptian AEC industry.

The research was guided by the following major research question:

*RQ1***.** To what extent does the utilization of IR4.0 impact the supply chain integration in Egyptian AEC industry?

The research also aimed to answer the following minor questions:

RQm1. do the IR4.0 technologies enhance the integration with supplier?

RQm2. do the IR4.0 technologies increase the internal integration within the company?

RQm3. do the IR4.0 technologies enhance the integration with customer?

Literature Review

1. AEC Global Market Insights

The AEC industry Globally projected a compound annual growth rate (CAGR) of 3.3 percent, at a value of US$8.9 trillion in 2022, and based on data from 2019 and 2021, this growth trajectory indicates that by 2023, the total global value of the industry will reach approximately US$12.26 trillion. (Rafsanjani & Nabizadeh, 2023). This substantial growth reflects the ongoing expansion and development driven by increasing demand for infrastructure, urbanization, and technological advancements.

Figure-1 illustrates the breakdown of the global value distribution among three main sub-sectors: Transport infrastructure, Industrial infrastructure, and Building infrastructure. The building infrastructure sub-sector stands out as the largest contributor, having a central role in the industry's overall performance.

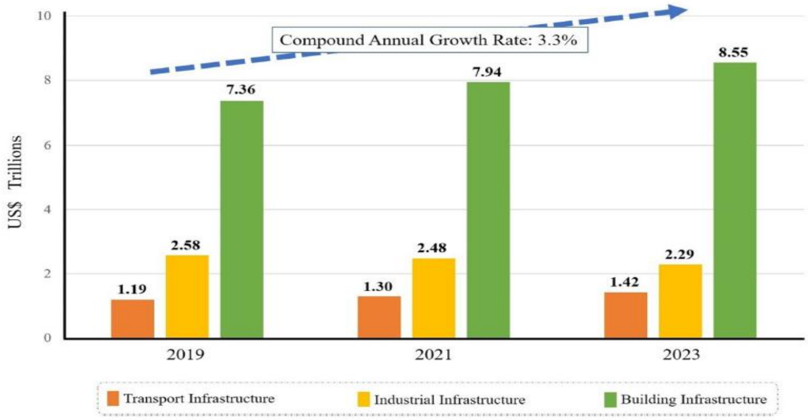

Figure 1 Global value of AEC industry, (Rafsanjani & Nabizadeh, 2023).

2. Egyptian AEC Local Market Size

Egypt's construction market is projected to be worth USD 50.78 billion in 2024 and increase at a compound annual growth rate (CAGR) of 8.39% to reach USD 75.97 billion by 2029, where the Egyptian project market is the largest in Africa, and the third in the Middle East and North Africa (MENA) (Mordor Intelligence, 2023).

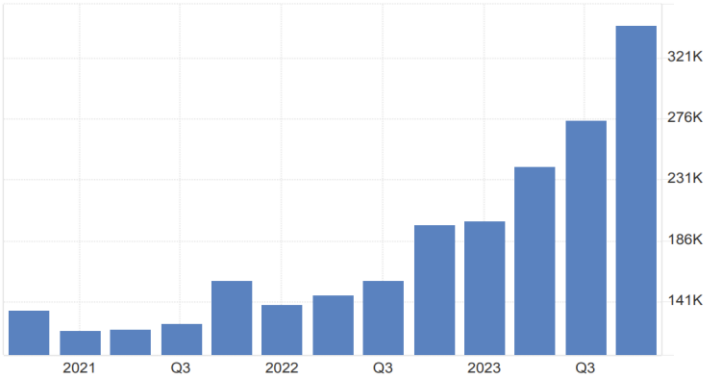

Figure 2 Egypt GDP from Construction - EGP Million, Ministry of Planning.

The annual bulletin for Construction Statistics of private Sector issued in 2022 by CAPMAS, shows the following insights compared to that of 2019:

- Value of executed contracts reached 497.7 billion pounds in 2020 compared to 554.9 billion pounds in 2019 a decrease by 10.3%.
- Net value of fixed assets at end of year reached 130.6 billion pounds in 2020, compared to 145.8 billion pounds in 2019, a decrease by 10.4%.
- Number of workers reached 521151 in 2020 compared to 486770 workers in 2019, an increase by 7.1%.

3. Industry 4.0

The term IR4.0 was first introduced at Hanover-Fair event in Germany 2011; to represent the fourth industrial revolution, it has become the most widely recognized term in both academic and industrial circles in recent years (Bibby & Dehe, 2018). Several studies have explored the IR4.0 transformation and identified three key paradigms within it: the smart product, the smart machine and the augmented operator (Koh, Orzes, & Jia, 2019). Therefore, IR4.0 necessitates a philosophical shift centered on four fundamental concepts: intelligence, products, communication, and information network (Oztemel & Gursev, 2020).

Recently, there has been a growing need for generally a widely accepted definition of IR4.0, (Oztemel & Gursev, 2020). Although many recent studies have attempted to define IR4.0, there is no consensus on a universal definition, its dimensions or assessment models (Erboz, Hüseyinoglu, & Szegedi, 2022), without a clear and standardized framework, it becomes difficult to assess how prepared a company is to adopt IR4.0 technologies and integrate it into the operations. However, Prause & Weigand (2016) provided a foundational definition for IR4.0 as a "combination of cyber physical systems with automated systems". This definition lacks a detailed explanation or guidance on how to assess a company's readiness for IR4.0, as well as the specific dimensions that should be tested.

Koh, Orzes, & Jia, (2019), summarized content of 88 selected papers created by Lu, (2017) defined IR4.0 as "*an integrated, adapted, optimized, service-oriented and interoperable manufacturing process in which algorithms, big data and high technologies are included*." This definition emphasizes technology as a central dimension of IR4.0. It introduces two key concepts: integration and interoperability. Integration refers to the seamless connection of various systems and processes, while interoperability highlights the ability of different systems to work together by understanding and utilizing each other's functions (Lu, 2017).

According to Piccarozzi, Aquilani, & Gatti, (2018) 54 percent of the papers were conceptual in nature, primarily consisting of literature reviews and the development of frameworks. Regarding empirical studies, 21 percent of the papers utilized quantitative methods (Survey), while 25 percent employed qualitative approaches. This indicates that while conceptual research dominates the field, empirical studies using both quantitative and qualitative methods are also significant in exploring the practical aspects of IR4.0.

Researchers have begun to use other popular terms, such as IR4.0 Readiness, IR4.0 roadmaps, and IR4.0 Maturity, either interchangeably or as complementary concepts (Schumacher, Erol, & Sihn, 2016), in an effort to better define and conceptualize IR4.0 models. These terms described different stages of adopting IR4.0 technologies. The term IR4.0 roadmap indicates the short and long-term goals, where the term readiness indicates the measures to test the company's capabilities and preparedness to apply the new technology, where the term IR4.0 maturity indicates the ongoing improvement process to achieve the advanced maturity level (Erboz, Hüseyinoglu, & Szegedi, 2022).

3.1 IR4.0 Maturity

The concept of IR4.0 Maturity refers to the degree to which a company has successfully integrated IR4.0 technologies such as automation, big data, artificial intelligence (AI), and the Internet of Things (IoT), among others into its operations, and the effectiveness with which these technologies are leveraged to drive business transformation (Erboz, Hüseyinoglu, & Szegedi, 2022).

The maturity model for IR4.0 was used by the researcher to conceptualize the IR4.0, as it is an essential tool for organizations to assess their progress in embracing IR4.0 technologies.

Bibby & Dehe (2018) proposed a conceptual framework to assess the IR4.0 maturity. Their conceptual framework mainly created to assesses the maturity of IR4.0 concepts in the defence sector. The framework investigates the maturity of Industry 4.0 concepts through semi-structured interviews, workshops and item scoring. The data collected from both qualitative and quantitative sources during the study were analyzed to evaluate the maturity level of the focal firm in utilizing IR4.0 technologies. The proposed conceptual framework incorporates the factors of integration and interoperability highlighted by Lu (2017), which emphasize that the dimensions of IR4.0 primarily encompass: *Technology* and *Human Behavior*, along with company's *Strategy* is crucial to ensuring IR4.0 interoperability at four levels.

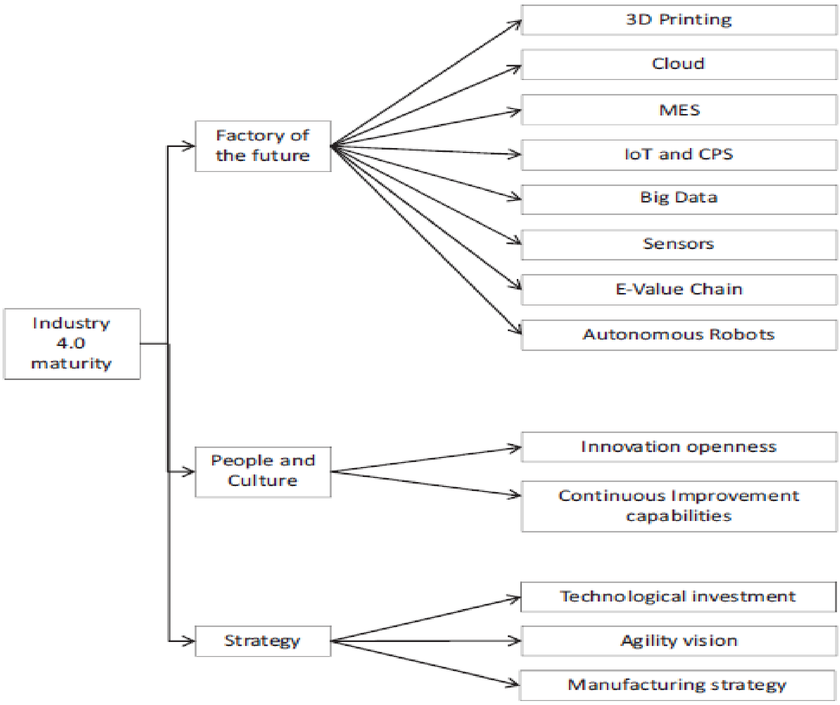

Figure 3 Industry 4.0 conceptual framework, (Bibby & Dehe, 2018).

3.1.1 Technology (Factory of the future)

Literature has identified technology as a key dimension for IR4.0. Several studies have emphasized various technological trends that are shaping this evolution, such as: data analytics and Internet of Things (IoT) (Erboz, Hüseyinoglu, & Szegedi, 2022).

Vaidya, Ambad, & Bhosle (2018) mentioned nine pillars of IR4.0 that will convert the production of separated and optimized cells into a completely automated, integrated, and optimized production flow, which will lead to the integration between suppliers, producers, and customers and also between human and machines. **These nine pillars are:**

1- the big and Analytics,

2- Autonomous Robots,

3- Simulation,

4- System Integration: Horizontal and Vertical System Integration,

5- The Industrial Internet of Things,

6- Cyber security and Cyber Physical Systems (CPS),

7- The Cloud,

8- Additive Manufacturing, and

9- Augmented Reality.

Bibby & Dehe (2018) operationalized the IR4.0 technological concept by exploring the ‘Factory of the Future’ practices and he concluded eight key technologies which identified by literature as key attributes of Industry 4.0:

1- Additive Manufacturing – 3D printing (3DP),

2- Cloud,

3- Manufacturing Execution System (MES),

4- Internet of Things (IoT) and Cyber-physical systems (CPS),

5- Big Data,

6- Sensors,

7- e-Value Chains, and

8- Autonomous Robots.

This research adopted the eight attributes defined by Bibby & Dehe, (2018) to measure the technology dimension. These attributes will be measured through 16 specific indicators, as outlined in **Appendix-1**. The selection of these attributes was based on their relevance to the unique challenges and opportunities within the AEC sector.

3.1.2 Employee & Culture

The AEC industry is labor-intensive, it incorporates 13.6% of the labor in the Egyptian market (CAPMAS, 2022). Therefore, it is important to test the human behavior toward the new IR4.0 technologies; Thus, many theories addressed this behavior because literatures consider it as the most decisive in the success or failure of technology utilization within the company (Lindsay, Jackson, & Cooke, 2011).

Several studies highlight the necessity of establishing and promoting a digital culture across the organization in order to successfully navigate the digital transformation journey (Leal-Rodríguez, et al., 2023), and whereas, the influence of individuals is significant, that makes the "People and Culture" dimension an essential component of Industry 4.0 implementation (Bibby & Dehe, 2018).

For that People & Culture have two attributes: Openness to innovation & Continuous improvement, (Erboz, Hüseyinoglu, & Szegedi, 2022), which are vital for the implementation of IR4.0. **Appendix-1** show the IR4.0 Employee & culture dimension's attributes & Measures.

3.1.3 Strategy

It is vital for companies to have a strategy for IR4.0 transformation, which called IR4.0 road map (Schumacher, Erol, & Sihn, 2016), this road map shall illustrate each new phase of the digital transformation due to the large investments required to adopt the new technologies. However, it will be challenging for companies to apply their strategies if they have limited understanding of the IR4.0 concept (Erboz, Hüseyinoglu, & Szegedi, 2022). Therefore, companies need to ensure that they have the capacity and full understanding of the requirement of IR4.0 in terms of people culture, required investments, and the targeted technologies.

We can conclude the challenges facing companies in creating an effective strategy are not limited to technological investments required for the acquisition of new technology, but are also to have an agility vision for Industry 4.0 maturity (Erol, Jäger, Hold, Ott, & Sihn, 2016), in addition to the manufacturing strategy (Bibby & Dehe, 2018). **Appendix-1** provides the IR4.0 strategy attributes & Measures.

4. Supply Chain Integration

Supply Chain is difined as a “set of a company’s operations that interlinked and interacting directly and indirectly to transform inputs into outputs that are delivered to the end customer", (Patrucco, Cicculloo, & Pero, 2020), and it depend on information flows, material flows and cash flows. This indicates the importance of information flow within the supply chain, to remove the communication barriers and eliminate redundancies by coordinating, monitoring and controlling processes (Power, 2005).

Although, the AEC industry is characterized by the significant fragmentation into three dimensions: horizontal, vertical and longitudinal, which drive organizing large projects to be decentralized modular clusters, Fergusson & Teicholz, (1996) found that AEC industry is increasingly implementing supply chain integration practices (SCIP) utilizing IR4.0. to facilitate information organization, processes, human resources, and supply chains, to achieve integration by transforming the organization into a ‘collaborative modular cluster’. This transformation allowed SCs to achieve horizontal and vertical integration without the need of contractual or structural changes (Hall, 2018).

The majority of SCI concepts recognize two flows through the chain: one is the flow of commodities, and the other is the equally significant flow of information (Prajogo & Olhager, 2012), this reflects two interrelated forms forward integration for the flows of materials and backward integration for the coordination and flow of the information. Therefore, SCI require a solid commitment from all supply chain partners.

Prajogo & Olhager's (2012) provided a framework examined the impact of long-term relationships on supply chain integration and performance, highlighting the mediating role of information technology, information sharing, and logistics integration. **The study tested six hypotheses and yielded the following results:**

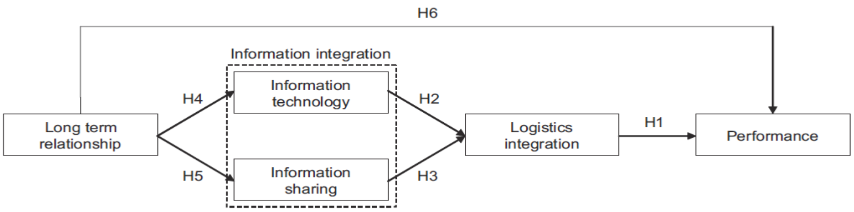

Figure 4 framework proposed by Prajogo & Olhager (2012).

- **H1**: Logistics integration has a positive relationship with performance.
- **H2**: The intensity of information technology connection between firms and their suppliers has a positive relationship with logistics integration.
- **H3**: The intensity of communication between firms and their suppliers has a positive relationship with logistics integration.
- **H4**: Long term relationship with suppliers has a positive relationship with information technology connection between firms and their suppliers.
- **H5**: Long term relationship with suppliers has a positive relationship with communication between firms and their suppliers.
- **H6**: Long term relationship with suppliers has a positive relationship with performance.

H2 & H3 present the significant impact of information technology integration on the logistics integration and accordingly the supply chain performance. See figure 2-8.

Jajja et al. (2018) identified SCI as “Strategic collaboration with key supply chain partners and an effective and efficient management of intra- and inter-organizational activities related to the flow of products, services, information, finance and joint decision-making are identified as supply chain integration.” they provided three dimensions for SCI: supplier integration, internal integration, and customer integration.

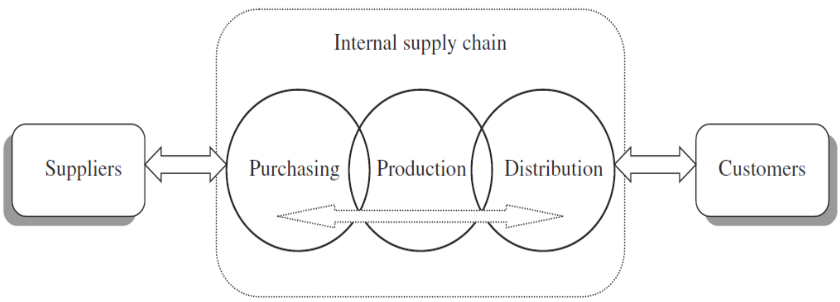

Figure 5 Company’s Supply-chain integration (Chen & Paulraj, 2004).

4.1 Internal integration

It is the degree to which the company organizing its practices, procedures, and behaviors of the internal functional units to accomplish internal collaboration to meet the client requirements (Chen & Paulraj, 2004). Several empirical studies suggested that collaborative cross-functional integration is positively associated with performance (Chen & Paulraj, 2004); Therefore, unifying company's internal procedures, practices, and strategies are the main aim of internal integration (Erboz, Hüseyinoglu, & Szegedi, 2022).

Jajja et al., (2018) identified four Measurs and three attibutes, focusing on the importance of information sharing between functional departments, and between purchasing and sales departments regarding production schedules and available resources, along with cooperation in decision-making. Refer to Appendix-1 for the internal integration attributes and measures.

4.2 Supplier integration (logistics integration)

It is a form of external integration that connects logistics activities across company boundaries (Chen & Paulraj, 2004). It is also considered as forward integration when focusing on the flow of materials from suppliers to production, and backward integration when dealing with information flow from production to suppliers using information technologies (Prajogo & Olhager, 2012). Long-term relationships with suppliers are central to supply chain information management, a dynamic capability that creates databases to improve performance and achieve customer satisfaction. (Jajja, Chatha, & Farooq, 2018). An operational advantage of improved logistics integration between supply chain partners is cost savings (Tiwari, 2020).

Prajogo & Olhager (2012) identified a valid and reliable four measures for logistics integration includes: (1) Inter-organizational logistic activities are closely coordinated; (2) Our logistics activities are well integrated with suppliers' logistics activities; (3) We have a seamless integration of logistics activities with our key suppliers; (4) Our logistics integration is characterized by excellent distribution, transportation, and/or warehousing facilities.

Furthermore, Jajja et al. (2018) identify four attributes for the supplier integration include the flow of information and products, control and planning, mutual active and engaged partnership, and Trust and commitment between producer and supplier. For further details, refer to Appendix-1 for Supplier integration attributes and measures.

4.3 Customer integration

It is also a form of external integration. Two attributes were revealed by letirature to address customer integration: Customer satisfaction and Customization (Tiwari, 2020), Supply chain partners become more integrated with key customers' processes and aligned with their objectives through the use of technology (Chen & Paulraj, 2004). Collaboration with key customers in the product design and shared decision-making, enable to better understand customer challenges. This leads to the creation of information-sharing and planning systems to address operational and production issues (Jajja, Chatha, & Farooq, 2018). Appendix-1 provides Supplier integration attributes and measures.

5. Industry 4.0 and SCI

Supply chain digitalization is a growing topic in literature, with evidence suggesting that integrating these technologies thoughtfully, along with evaluating and redesigning necessary organizational aspects, can significantly improve supply chain performance (Patrucco, Ciccullo, & Pero, 2020). Whereas, IR4.0 is an efficient tool to enhance Information flow and sharing across supply chains (Chen & Paulraj, 2004). Integrating key aspects like information, physical goods, and financial processes supports the development of sophisticated, end-to-end supply chains (Tiwari, 2020). Recent research has explored the relationship between IR4.0 technologies and SCI. Some studies indicate a positive relationship between the implementation of cloud computing and informational-physical SCI. (Bruque-Cámara et al., 2016), and since IR4.0 consists of IoT, Clouds, Additive Manufacturing - 3DP, MES, Big Data, Sensors, e-Value Chains, and Autonomous Robots (Bibby & Dehe, 2018), it will enhance the information sharing within the supply chain and achieve supply chain integration.

Fatorachian & Kazemi (2021) concluded that IR4.0 technologies enhance performance through integration and connectivity at the supply chain level. At the individual supply chain level, benefits arise from improved integration, automation, and digitization, leading to better analytical capabilities and performance. Table 2-7 summarizes their findings, showing that IR4.0 impacts supply chain performance by improving supply chain processes as a mediating variable. Table 1 provides the findings of the research. Findings indicate that IR4.0 has an impact of supply chain performance through improving the the Supply chain process as a mediating variable.

Table 1 Impact of IR4.0-enabling-technologies on supply chain processes and the resulting performance improvements

Supply chain process	Performance improvements (Analytical themes)
Product development and production	• Improved production planning and control • Improved product design/ development and production process • Enhanced production efficiency and productivity
Fulfilment, procurement, and logistics	• Improved planning and control • Improved distribution • Effective order fulfilment management • Reduced Bullwhip effect • Improved procurement and supplier relationship management • Effective purchasing
Inventory management	• Improved product distribution and delivery • Accurate inventory planning and control • Increased operational efficiency
Retailing	• Improved operational efficiency and productivity • Enhanced forecasting and planning • Improved responsiveness and revenue growth

Another model developed by Di Maria et al., (2022) addressed the relation between IR4.0 and Circular Econolmy concept, whith a mediating role of SCI. They used two components to test the IR4.0: Smart- Manufacturing technologies, and Data-Processing technologies, **and tested and approved three main hypothesis:**

H1: Supply chain integration is positively associated with Circular Econolmy.

H2: The implementation of smart-manufacturing technologies dimention is positively associated with SCI.

H3: The implementation of data processing technologies is positively associated with SCI.

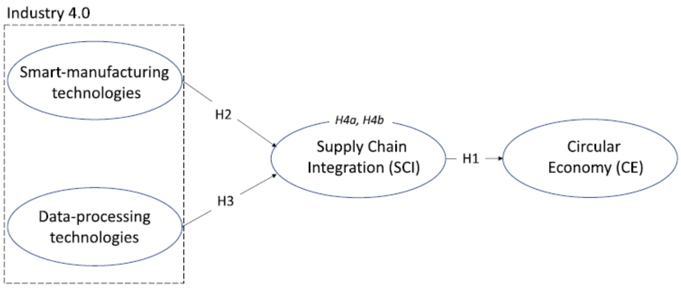

Figure 6 The theoretical model (Di Maria, De Marchi, & Galeazzo, 2022)

The study findings approved the significant and positive relation between SCI and Circular Econolmy supporting (H1), while only (H2) smart manufacturing technologies are positively associated with SCI, whereas (H3) data processing technologies are not.

Erboz et al., (2022) adopted a conceptual framework developed by Bibby & Dehe (2018) to test the relation between IR4.0, and SCP with a mediating role of SCI. the IR4.0 dimensions included: Strategy, technology, and Employee & Culture. **They tested Four Hypothesises:**

H1: Industry 4.0 has a positive impact on SCI.

H2: SCI has a positive impact on SCP.

H3: Industry 4.0 has a positive impact on SCP.

H4: SCI mediates the relationship between Industry 4.0 and SCP.

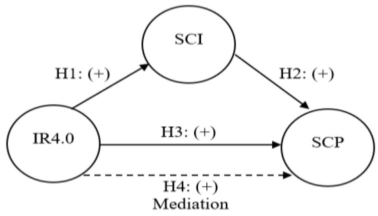

Figure 7 Theoretical framework (Erboz, Hüseyinoglu, & Szegedi, 2022)

One of the main conclusions of this study was to find empirical evidence for the impact of Industry 4.0 on SCI and SCP, where the findings revealed that H1, H2 and H3 were actually supported, while H4 for SCI mediating relation was partially supported. However, the study supported the direct relationships between IR4.0, SCI.

Therefore, the research hypothesis is proposed as follows:

H1. Industry 4.0 has a positive impact on SCI.

Problem Definition

To deliver high-quality services, gain competitive advantages, and meet customer requirements, supply chain management aligns the efforts of partner companies to create a seamless supply chain. (Zhang, Gunasekaran, & Wang, 2016). Utilizing IR4.0 technologies in Egyptian AEC industry for planning, designing, constructing, and operating projects, needs the supply chain to re-evaluate and re-engineer the business structure (Patrucco, Ciccullo, & Pero, 2020), and to create new practices where the business impact can be significant (Smith, 2014).

The utilization of IR4.0 was suggested to improve supply chain management significantly (Fatorachian & Kazemi, 2021) motivated by IR4.0 enhancement of supply chain performance (Sundram, Chandran, & Bhatti, 2016) with expected mediating role of SCI (Jajja, Chatha, & Farooq, 2018). Therefore, the research problem is to investigate empirically the impact of utilizing IR4.0 on supply chain integration in Egyptian AEC industry.

Therefore, the research was guided by the following major question:

RQ1: To what extent does the utilization of IR4.0 impact the supply chain integration in Egyptian AEC industry?

The research also aimed to answer three minor questions:

RQm1: do the IR4.0 technologies enhance the integration with supplier?

RQm2: do the IR4.0 technologies increase the internal integration within the company?

RQm3: do the IR4.0 technologies enhance the integration with customer?

Aim and Objectives of the Research

The research aimed to assess empirically the impact of utilizing IR4.0 on SCI in the Egyptian AEC industry. To achieve this aim, the researcher achieved the following objectives:

1. Conducted a comprehensive review of key topics:
    a. Examining the dimensions and measurement criteria of Industry 4.0 technologies;
    b. Identifying the factors that influence the adoption of Industry 4.0 technologies.
    c. Investigating the dimensions and measurement criteria of Supply Chain Integration;
2. Exploring the need for utilizing the new technologies: to facilitate both internal and external collaboration throughout the lifecycle of construction projects, emphasizing the importance of seamless communication and data flow.
3. Identifying the key factors that impact Supply Chain Integration in the AEC industry, particularly those that are influenced by emerging technologies, and understanding how these factors impact the overall efficiency and coordination within the sector.

4. Evaluating the effects of utilizing Industry 4.0 transformation on Supply Chain Integration in the Egyptian AEC industry, focusing on how the integration of advanced technologies can reshape the supply chain processes and enhance operational performance.

Research Hypothesis and Proposed Conceptual Framework

Building on the insights derived from the literature review, the researcher determined theoretical frameworks that explore the impact of utilizing new technologies on achieving supply chain integration.

This research developed the Proposed Conceptual Framework figure-to be tested in Egyptian AEC industry.

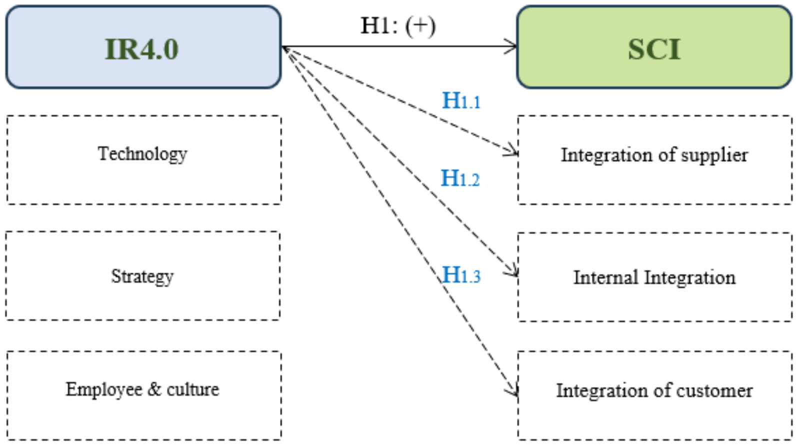

Figure 8 Research Theoretical framework, adapted from Erboz, et al. (2022)

Independent Construct

The independent construct of the study is IR4.0 that involves knowledge domains such as autonomous controls, robots, sensors, and computer management and related actors (Koh, Orzes, & Jia, 2019), and it consists of three components: Technology, Strategy, and Employee and culture. And is measured by 24 measurement items (Appendix 1).

Dependent Construct

The Dependent construct of the study is SCI, which is the degree of strategic collaboration with supply chain partners and managing internal and external processes cooperatively (Flynn, Huo, & Zhao, 2010). It consists of three components: Integration of supplier, Internal Integration, and Integration of customer. And is measured by 12 measurement items (Appendix 1).

The following hypotheses were generated to support this research:

H1. There is a positive impact for IR4.0 digital transformation on supply chain integration.

- **$H_{1.1}$:** There is a significant impact for IR4.0 digital transformation on Supplier integration (SI) dimension.

- **$H_{1.2}$:** There is a significant impact for IR4.0 digital transformation on Internal integration (II) dimension.

- **$H_{1.3}$:** There is a significant impact for IR4.0 digital transformation on Customer integration (CI) dimension.

Research Methodology

1. Research design and measures

The scale of the questionnaire derived from prior studies. A comprehensive literature review provided dimensions and measures. This research adopted the IR4.0 three components: strategy, employee and culture, and technology and its measures that developed by Erboz et al. (2022) to conceptualize the IR4.0. Also, for SCI components and measures, Jajja et al. (2018) provided a conceptual model that operationalize the SCI construct into three aspects: supplier integration, internal integration, and customer integrations. Table 2 summarize the selected processes for this research.

Table2 Research Design

Research Process	Selection	Reasons for the choice
Research Ontology	Objectivism	IR4.0 is considered a stable objective reality that can be observed and described; it can be investigated systematically through empirical study.
Research Paradigm	Positivism	A new model achieved for Industry 4.0 by systematically building on an existing model. The research through positivist paradigm follows procedures to reduce threats to research validity and reliability.
Research Approach	Deductive	Literatures provided model that directs which field observations to conduct. Deductive reasoning used to test empirical data with the model hypothesis.
Research Strategy	Survey	For validity and reliability controls, the survey was chosen for the research design to acquire sources of evidence.
Research Method Choice	quantitative approach	It helps to obtain a clear vision about utilizing IR4.0 within AEC companies. Quantitative data help in identifying the model and hypotheses that were supported by science using statistical techniques.
Time Horizon	Cross-sectional design	The studied the utilization of IR4.0 rather than its prevalence over time, so one-shot study design at one point in time accomplished the study's objectives.
Source of data	Primary and Secondary	**Secondary data:** List of multidisciplinary consultants registered in the Egyptian Syndicate of Engineering, and construction

		companies registered in the Egyptian Federation of Construction and Building Contractors (EFCBC) Grade 1 & 2 was the sampling frame, in addition to prior empirical studies. Collection Instrument: Soft copy **Primary data:** For the quantitative model and hypothesis supported by science, primary data collected through questionnaires.
Method for data collection	Questionnaire	**Questionnaire:** A scaled questionnaire obtain objectivity to subjective factors. Source: A mixture of online and in-person questionnaires with close-ended questions collected in the field.
Method for data analysis	SPSS v25	SPSS allows to conduct both descriptive and inferential statistical analysis, can handle large datasets efficiently, supports a wide range of advanced statistical techniques, has robust tools for data cleaning, includes features for testing the reliability, and is widely recognized and accepted in academic and research communities.

2. Sampling and data collection

Survey method employed. The unit of analysis was companies in Egyptian AEC industry. The targeted population was multidisciplinary consultants recognized by the Egyptian Engineering Syndicate, along with construction companies recognized by the EFCBC located in Greater Cairo. Based on Krejcie and Morgan’s (1970) table, a population of 223 companies required a sample of 144 companies to adequately represent a cross-section of that population.

A probability-sampling technique was used by means of the sampling frame and applying stratified sampling techniques for sample selection. The researcher collected the data from the Managers and Specialists levels. The required sample size was calculated at 384 employees across the 144 companies.

The following formula was used to Calculate the size of each stratum:

Stratum sample size = size of entire sample / population size x stratum size

Table 4 Stratified Sampling of AEC firms in Greater Cairo *(EFCBC, 2019)* and *(Egyptian Engineering syndicate, 2022)*.

Classification of Firms	Population	Stratum sample size	N. of targeted Employees
Multidisciplinary Engineering Consultancy	87	56	150
Construction Company 1st Grade	79	51	136
Construction Company 2nd Grade	57	37	99
Total	**223**	**144**	**385**

The questionnaire shared with 204 companies, 660 respondents. Number of responses were 433 across 181 companies, with response rate of 65.6%. The researcher reached out to respondents randomly via email, mobile phone, and social media platforms (WhatsApp, Facebook and LinkedIn), sharing with them with the URL to the questionnaire.

Table 5 Responses distribution by Stratum sample.

Stratum	N. Companies	Stratum size (Companies)	N. required respondent
Total	**Total Targeted**	**204**	**660**
Multidisciplinary Engineering Consultancy	Responded	67	162
	Not Responded	2	31
	Valid Responses	56	151
	Invalid Responses (duplication, invalid pilot samples, and incorrect data)	11	11
Construction Company 1st Grade	Responded	66	147
	Not Responded	9	104
	Valid Responses	57	138
	Invalid Responses (duplication, invalid pilot samples, and incorrect data)	9	9
Construction Company 2nd Grade	Responded	48	124
	Not Responded	12	92
	Valid Responses	40	116
	Invalid Responses (duplication, invalid pilot samples, and incorrect data)	8	8

Data Analysis

1. Statistical Methods and Techniques

The steps and statistical methods used to guarantee the reliability and validity of the findings and create a strong framework for interpreting the research findings and creating well-supported conclusions: Descriptive statistics, Reliability and validity testing, Normality Tests, Ordinal Data Analysis.

Table 6 weighted average of Likert scale.

Strongly Disagree	1 to 1.79
Disagree	1.80 to 2.59
Neither agree nor disagree	2.60 to 3.39
Agree	3.40 to 4.19
Strongly Agree	4.20 o 5

2. Description of characteristics study sample

Figure (9) shows the distribution of work fields for the sample of 385 cases. The contracting field was the largest percentage at 63.2% (243 cases), followed by the multidisciplinary engineering consulting field at 34.4% (132 cases), the suppliers field appears at a very small percentage of 2% (8 cases), while the manufacturing field is almost absent from the sample, representing only 0.4% (2 cases).

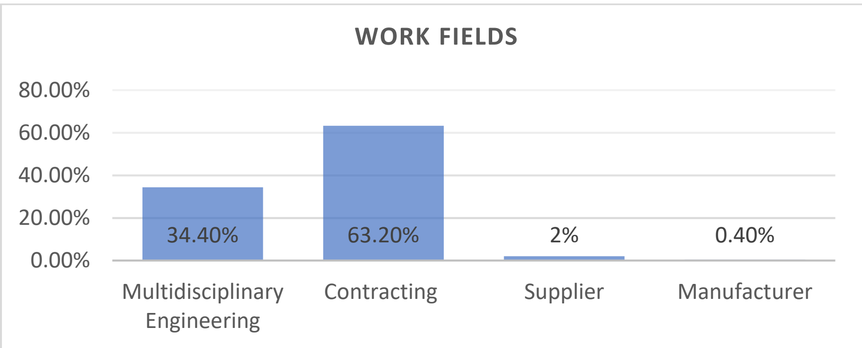

Figure 9 Work filed characteristics, Source: SPSS V25 output

Figure (10) shows that most participants (75.6%) hold a bachelor's degree, 19.6% of participants have a postgraduate degree (Master's) especially in the managers level, Finally, a small proportion of 4.8% of participants hold a doctorate degree at the expert levels and top management.

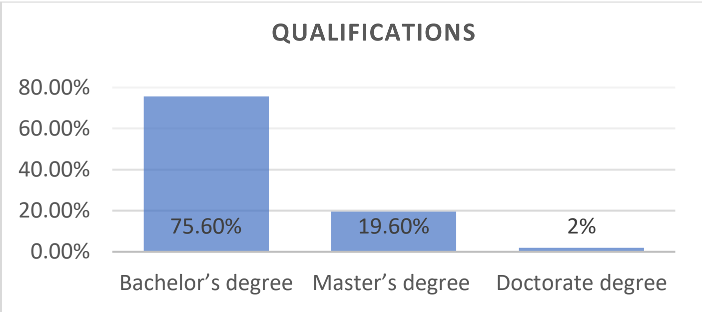

Figure 10 Qualification Characteristics, Source: SPSS V25 output

Figure (11) shows that the majority of participants have between 16 and 20 years of experience, making up 34.4% of the total respondents, which includes specialists, BIM managers, and project managers. Additionally, a significant portion of the respondents (34%) have over 20 years of experience, reflecting the perspectives of senior managers. Only 31.6% of participants have less than 15 years of experience.

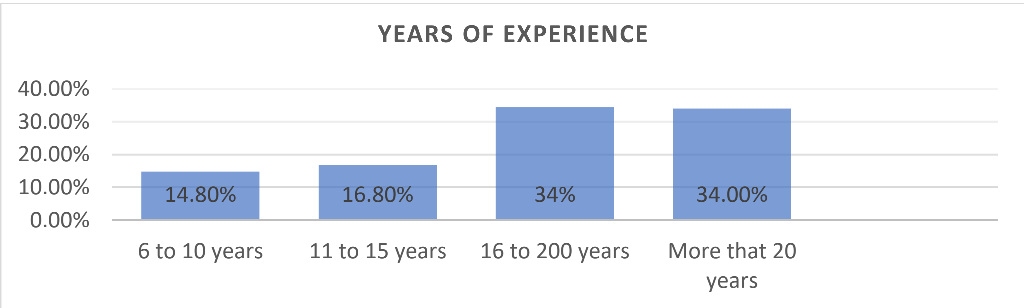

Figure 11 How long have you been working in the construction industry, Source: SPSS V25 output

Figure (12) illustrates the distribution of organization sizes. A majority of the organizations (64.8%) employ more than 250 people. In contrast, the very small proportion of organizations with fewer than 10 employees (0.8%) indicates that micro-sized companies are underrepresented in this sample.

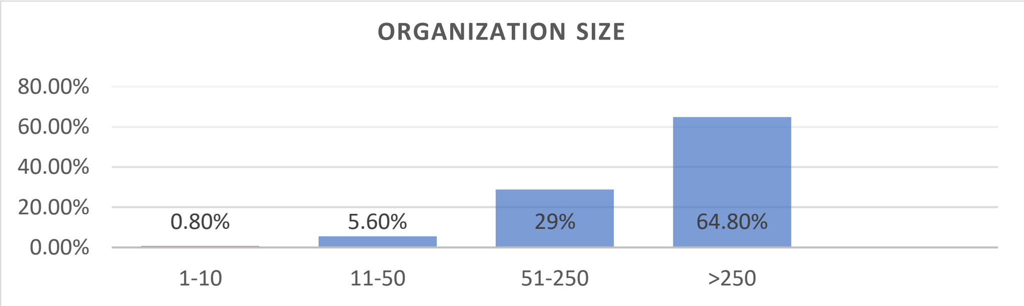

Figure 12 How many employees are there in your organization, Source: SPSS V25 output

3. reliability and validity

The researcher ensured that the measurement tool used in the study was both reliable and valid, thus strengthening the overall quality of the research findings.

Table (7) shows that the reliability coefficient for the total dimensions of the independent variable: IR4.0 ranges from 0.840 to 0.949 with a validity coefficient ranging from 0.917 to 0.974. While the reliability coefficient for the total dimensions of the dependent variable: SCI ranged from 0.90 to 0.931 with a validity coefficient ranging from 0.949 to 0.965. All values of the Cronbach reliability coefficient are greater than 0.7, which indicates that there is a high stability of the study dimensions.

Table 7 Reliability Statistics, Source: SPSS v25 output

Variables	construct	N of Items	Cronbach's Alpha	Validity
Industry 4.0 digital transformation (IDT)	Strategy (STR)	4	0.843	0.918
	Employee & culture	4	0.840	0.917
	Technology	16	0.949	0.974
Supply Chain Integration (SCI)	Supplier integration	4	0.900	0.949
	Internal integration	4	0.931	0.965
	Customer integration	4	0.905	0.951
All		36	0.976	0.988

Table (8) shows the reliability of internal consistency coefficient for the dimensions of the independent variable IR4.0, which was calculated using the Pearson correlation coefficient. The results indicate that the internal consistency coefficients of the dimensions range between 0.566 and 0.875, and these parameters are statistically significant at a significance level of less than 0.01, which indicates that the paragraphs of each dimension are well related to this dimension.

Table 8 Internal consistency coefficient for Industry 4.0, Source: SPSS v25 output

Construct	Item	r	Construct	Item	r
Strategy	STR1	.823**	Technology	TEC5	.683**
	STR2	.866**		TEC6	.818**
	STR3	.782**		TEC7	.815**
	STR4	.864**		TEC8	.699**
Employee & culture	EMP1	.783**		TEC9	.785**
	EMP2	.875**		TEC10	.729**
	EMP3	.786**		TEC11	.566**
	EMP4	.850**		TEC12	.808**
Technology	TEC1	.818**		TEC13	.820**
	TEC2	.793**		TEC14	.738**
	TEC3	.795**		TEC15	.633**
	TEC4	.810**		TEC16	.761**
** Correlation is significant at the 0.01 level (2-tailed).					

Table (9) results indicate that the internal consistency coefficients of the dimensions of the dependent variable Supply Chain Integration (SCI) range between 0.874 and 0.923, and these parameters are statistically significant at a significance level of less than 0.01, which indicates that the items of each dimension are well related to this dimension.

Table 9 Internal consistency coefficient for Supply Chain Integration (SCI), Source: SPSS v25 output

construct	item	r	construct	item	r	construct	item	r
Supplier integration	SI1	.875**	Internal integration	ii1	.900**	Customer integration	CI 1	.896**
	SI2	.874**		ii2	.919**		CI 2	.889**
	SI3	.897**		ii3	.923**		CI 3	.866**
	SI4	.873**		ii4	.898**		CI 4	.881**
** Correlation is significant at the 0.01 level (2-tailed).								

4. Descriptive statistics for study variables

Coefficient of variation calculated by formula: (standard deviation ÷ arithmetic mean) × 100. High value suggests greater variability and less consistency among respondents, whereas a lower value indicates greater consistency and stronger agreement among the participants.

Table 10 Descriptive analysis for independent variable, Source: SPSS v25 output.

Items	Std. Deviation	Mean	coefficient of variation	rank
1. Your company have clear availability of digital transformation roadmap.	0.91	3.77	24%	2
2. Your Company investing in technology infrastructure.	0.93	3.60	26%	3
3. Your company is easily customizing services to Clients' requests while offering the same service quality.	0.82	3.68	22%	1
4. Your company is partnering with external organizations to maintain technology.	1.29	3.41	38%	4

Strategy	0.83	3.62	23%	1
5. Employees in your company are familiar with new technology activities.	0.78	3.61	21%	1
6. Your company is investing in training of employees in new technology activities.	1.09	2.98	37%	4
7. Your company is using ‘zero paper’ to control, display and transport data.	0.87	2.67	32%	3
8. Your company is maintaining continuous improvement culture within the organization.	0.98	3.78	26%	2
Employee culture	0.77	3.26	24%	2
9. Your company is using advanced connectivity technology between services, equipment and employees.	0.87	3.38	26%	4
10. Your company uses technology with suppliers to increase connectivity and collaboration.	0.97	2.97	33%	10
11. Your company is Accessing data quickly and effectively from machines, systems, services.	0.92	3.31	28%	5
12. Your company is analyzing data to make decisions, information sharing and identifying trends	1.06	2.86	37%	13
13. Your company is using intelligent programs in the designing or construction process.	1.12	2.32	48%	15
14. Your company is storing information within a cloud	1.05	3.24	32%	9
15- Your company has the ability to see live designing and construction systems and respond to the changes immediately	0.83	3.24	26%	3
16- Ability of machines to run autonomously.	0.83	2.32	36%	12
17. Ability of clients to access designing and construction process and delivery dates.	0.95	2.97	32%	8
18. Your company is using Computer-Aided Design CAD software, building information 3D software (BIM, Civil 3D, etc.) and 3D printing (3DP) machines.	0.87	4.13	21%	1
19. Your company is Using 3D printing 3DP for the process of tooling, prototypes.	0.92	1.76	52%	16
20. Your company has the Connectivity of hard and soft resources into the cloud	0.97	3.09	31%	7
21. Your company has the ability of using digital media to bring information directly to employees.	0.93	3.20	29%	6
22. Your company Embracing digitalization for services, parts and machines	0.91	3.63	25%	2
23. Your company is using sensors on serviced and supplied parts.	0.91	2.21	41%	14
24.The extent of automation within the production	0.90	2.59	35%	11
Technology	0.71	2.95	24%	3

Table (10) shows that the arithmetic means for the Strategy dimension ranged from 3.41 to 3.77, with standard deviations between 0.817 and 1.293. The coefficient of variation values ranged from 22% to 38%, indicating varying response consistency. The statement with the highest agreement was: "Your company is easily customizing services to clients' requests while offering the same service quality," with the lowest coefficient of variation at 22% and an agreement rate of 78%, suggesting strong agreement among most respondents.

Table (10) shows that the arithmetic means for the Employee & Culture dimension ranged from 2.67 to 3.78, with standard deviations between 0.78 and 1.09. The coefficient of variation values ranged from 21% to 37%, indicating varying response consistency. The statement with the highest agreement was: "Employees in your company are familiar with new technology activities," with the lowest coefficient of variation at 21% and an agreement rate of 79%.

Finally, Table (10) shows that the arithmetic means for the Technology dimension ranged from 1.76 to 4.13, with standard deviations between 0.83 and 1.12. The coefficient of variation values ranged from 21% to 52%, indicating varying response consistency. The statement with the highest agreement was: "Your company is using Computer-Aided Design (CAD) software, Building Information Modeling (BIM), and Civil 3D," with the lowest coefficient of variation at 21% and an agreement rate of 79%.

Table 11 Descriptive analysis for Dependent variable, Source: SPSS v25 output.

items	Std. Deviation	Mean	coefficient of variation	rank
1. Your company is Information sharing with the main suppliers (about production plans, order management, delivery and inventory information).	0.95	2.80	34%	3
2. Your company is improving collaborative strategies with the main suppliers (development of supplier, risk-sharing, long term alliances)	0.93	3.30	28%	2
3. Your company is improving decision making with the main suppliers (about product design/development, quality improvement, cost and process design)	0.92	3.32	28%	1
4. Your company is developing a system with the main suppliers.	1.10	2.51	44%	4
Supplier integration	0.86	2.98	29%	3

5. Information sharing with the purchasing department (about sales, production progress and inventory level)	1.06	3.72	28%	4
6. Your company is Improving decision making with the purchasing department (about sales, production plans and inventory level)	1.01	3.73	27%	1
7. Information sharing with the sales department (about sales, production progress and inventory level)	1.01	3.69	27%	2
8. Your company is Improving decision making with the sales department (about sales, production plans and inventory level)	1.03	3.69	28%	3
Internal integration	0.93	3.71	25%	1
9. Information sharing with the main customers (about production plans, order management, delivery and inventory information)	0.99	3.23	31%	3
10. Your company is improving collaborative strategies with the main customers (risk sharing, long term agreements)	0.94	3.71	25%	1
11. Your company is developing a system with the main customers.	1.06	2.76	38%	4
12. Your company is improving decision making with the main customers (about product design/ development, quality improvement and process design)	0.99	3.67	27%	2
Customer integration	0.88	3.34	26%	2

Table (11) shows that the arithmetic means for the Supplier Integration dimension ranged from 2.51 to 3.2, with standard deviations between 0.92 and 1.10. The coefficient of variation values ranged from 28% to 44%. The statement with the highest agreement was: "Your company is improving decision making with the main suppliers" with a coefficient of variation of 28% and an agreement rate of 72%.

Table (11) shows that the arithmetic means for the Internal Integration dimension ranged from 3.69 to 3.73, with standard deviations between 1.01 and 1.06. The coefficient of variation values ranged from 27% to 28%, indicating moderate variability in responses. The statement with the highest agreement was: "Your company is improving decision-making with the purchasing department " with a coefficient of variation of 27% and an agreement rate of 73%.

The arithmetic means for the Customer Integration dimension ranged from 2.76 to 3.71, with standard deviations between 0.94 and 1.06. The coefficient of variation values ranged from 25% to 38%. The statement with the highest agreement was: "Your company is improving collaborative strategies with the main customers," with a coefficient of variation of 25% and an agreement rate of 75%.

Table 12 Sample trends towards the independent and dependent variables under study, Source: SPSS v25 output

Variables	Mean	Mean Difference	t	Sig. (2-tailed)	Std. Deviation	coefficient of variation	rank
Strategy (STR)	3.61	3.61	86.71	0.00	0.82	23%	1
Employee & culture	3.22	3.22	77.77	0.00	0.81	25%	3
Technology	2.97	2.97	81.09	0.00	0.72	24%	2
Industry 4.0 transformation	3.27	3.27	87.22	0.00	0.73	22%	1
Supplier integration	2.99	2.99	67.49	0.00	0.87	29%	2
Internal integration	3.47	3.47	66.78	0.00	1.02	29%	3
Customer integration	3.28	3.28	69.67	0.00	0.92	28%	1
Supply Chain Integration	3.25	3.25	75.62	0.00	0.84	26%	2

The coefficient of variation indicates a high level of agreement among respondents on the dimensions of IR4.0, with a 22% coefficient and a 78% agreement rate. This shows consistent views on digital transformation. The Strategy dimension had the highest consistency (23%), reflecting strong agreement on the strategic aspects of Industry 4.0 adoption. In contrast, the Technology dimension had the least consistency (24%), suggesting varied opinions on the role of technology in the digital transformation process.

The coefficient of variation shows moderate consistency in respondents' opinions on Supply Chain Integration, with a 26% coefficient and a 74% agreement rate. The Internal Integration dimension had the highest consistency and agreement (25%), indicating strong support for its importance. In contrast, the Supplier Integration dimension had the lowest consistency (29%), suggesting varied opinions and potential challenges in supplier collaboration and integration.

5. Correlation

The correlation matrix in Table (13) provides an overview of the relationships between variables related to IR4.0 transformation in companies. It is a crucial tool in statistical research, helping to identify the strength and direction of relationships between variable pairs, whether positive (both increase together) or negative (one increases as the other decreases).

The correlation matrix shows a strong, positive correlation between all the variables studied: strategy, employee culture, technology, supplier integration, internal integration, and customer integration. This indicates that improvements in one area are likely linked to advancements in others. For example, as a company's strategy aligns more with digital transformation goals, other factors like employee culture, technology adoption, and integration with suppliers, internal processes, and customers are also expected to improve. This suggests that the variables are interconnected and mutually reinforcing in the company's digital transformation journey.

Table 13 Results of correlation between variables, Source: SPSS v25 output

Correlations

		Strategy	Employee_culture	Technology	Supplier_integration	Internal_integration	Customer_integration
Strategy	Pearson Correlation	1	.816**	.827**	.679**	.614**	.722**
	Sig. (2-tailed)		.000	.000	.000	.000	.000
	N	385	385	385	385	385	385
Employee_culture	Pearson Correlation	.816**	1	.826**	.599**	.586**	.676**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
	N	385	385	385	385	385	385
Technology	Pearson Correlation	.827**	.826**	1	.678**	.578**	.749**
	Sig. (2-tailed)	.000	.000		.000	.000	.000
	N	385	385	385	385	385	385
Supplier_integration	Pearson Correlation	.679**	.599**	.678**	1	.610**	.782**
	Sig. (2-tailed)	.000	.000	.000		.000	.000
	N	385	385	385	385	385	385
Internal_integration	Pearson Correlation	.614**	.586**	.578**	.610**	1	.744**
	Sig. (2-tailed)	.000	.000	.000	.000		.000
	N	385	385	385	385	385	385
Customer_integration	Pearson Correlation	.722**	.676**	.749**	.782**	.744**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	385	385	385	385	385	385

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

6. Discussion Results of Study Hypotheses

6.1 Results of the first sub-hypothesis

$H_{1.1}$: There is a significant impact for Industry 4.0 on Supplier integration (SI) dimension.

To test the study hypothesis, a quality test of the study model is conducted to ensure the quality of the model outputs, as many tests were conducted, then the results of the measurement models are displayed.

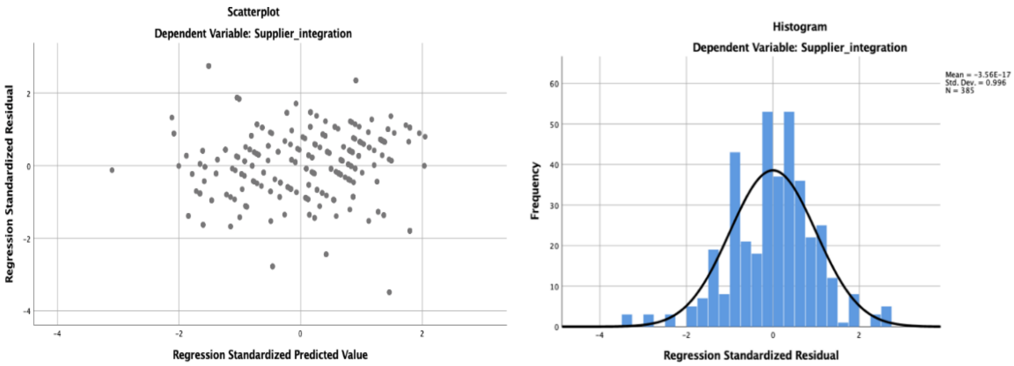

Figure 13 normal distribution for first sub-hypothesis residuals, Source: SPSS v25 output

Figure (13) includes two plots to evaluate the residuals of the regression model for the dependent variable, Supplier Integration. The first plot, a scatterplot, shows that the points are randomly distributed around the horizontal axis without a clear pattern, suggesting no major issues with the regression model. The second plot, a histogram, displays the distribution of the standard residuals, with a normal curve to indicate how closely the residuals follow a normal distribution. The plot shows the residuals' mean is near zero, and their standard deviation is around 1, supporting the validity of the regression model's assumptions. The following table presents the results of the multiple regression for the first sub-hypothesis of the first model.

Table 14 Results of the multiple regression for the first sub-hypothesis, Source: SPSS v25 output

	B	t	Sig.	Tolerance	VIF
(Constant)	0.232	4.599	0.000	-	-
Strategy (STR)	0.418	5.551	0.000	0.261	3.83
Employee & culture	0.045	4.601	0.000	0.262	3.81
Customer integration	0.472	5.387	0.000	0.248	4.028
R	R Square	Durbin-Watson	F	Sig.	
.711a	0.505	1.737	12.601	.000b	
a Dependent Variable: Supplier integration					

Table (14) shows that the variance inflation factor (VIF) values range from 3.81 to 4.028, which is below 5, indicating no collinearity problem, meaning the independent variables are not significantly correlated. The Durbin-Watson test value of 1.737 suggests that the model residuals are independent, with values between 1.2 and 2.5 considered appropriate, showing no significant autocorrelation. The correlation coefficient of 0.711 indicates a moderate correlation between the independent and dependent variables. The R^2 value of 0.505, which is above 30%, suggests that the independent variables (Strategy, Employee & Culture, and Customer Integration) explain 50.5% of the variance in Supplier Integration.

Also, the value of the F test reached (12) with a statistical significance value of (0.00) at a significance level less than 0.01, which indicates that the estimated study model is acceptable and valid for prediction, and therefore we accept the first sub-hypothesis, which states that:

There is a significant impact for Industry 4.0 on Supplier integration (SI) dimensions.

<u>The results of the multiple regression coefficients show the following:</u>

- The regression parameters indicate a positive impact of the Strategy (STR) dimension on the Supplier integration dimension, where the impact value reached 0.418 with a statistical significance value of 0.00 at a significance level of less than 0.01.

- The regression parameters indicate a positive impact of the Employee & culture (E&C) dimension on the Supplier integration dimension, where the impact value reached 0.045 with a statistical significance value of 0.00 at a significance level of less than 0.01.

- The regression parameters indicate a positive impact of the Technology (TECH) dimension on the Supplier integration dimension, where the impact value reached 0.472 with a statistical significance value of 0.00 at a significance level of less than 0.01.

6.2 Results of the second sub-hypothesis

$H_{1.2}$: There is a significant impact for Industry 4.0 on Internal integration (II) dimension.

To test the study hypothesis, a quality test of the study model is conducted to ensure the quality of the model outputs, as many tests were conducted, then the results of the measurement models are displayed.

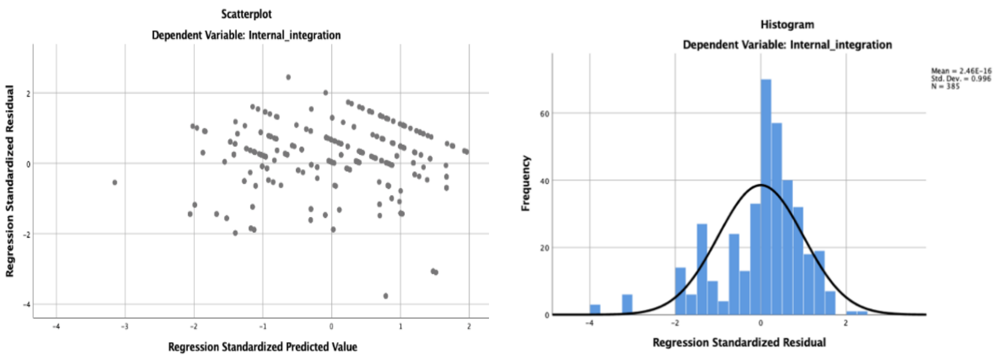

Figure 14 normal distribution for second sub-hypothesis residuals, Source: SPSS v25 output

Figure (14) includes two plots to evaluate the residuals of the regression model for the dependent variable, Internal Integration (II). The first plot, a scatterplot, shows that the points are randomly distributed around the horizontal axis without a clear pattern, indicating no major issues with the regression model. The second plot, a histogram, illustrates the distribution of the standard residuals, with a normal curve to show how well the residuals align with a normal distribution. The plot reveals that the mean of the residuals is near zero, and their standard deviation is approximately 1, supporting the validity of the regression model's assumptions. The following table presents the results of the multiple regression for the first sub-hypothesis of the first model of the study.

Table 15 Results of the multiple regression for the second sub-hypothesis, Source: SPSS v25 output

	B	t	Sig.	Collinearity Statistics	
(Constant)	0.568	3.045	0.002	Tolerance	VIF
Strategy (STR)	0.437	4.513	0.000	0.261	3.83
Employee & culture	0.247	2.551	0.011	0.262	3.81
Customer integration	0.179	3.587	0.013	0.248	4.028
R	R Square	Durbin-Watson	F	Sig.	
.635a	0.403	1.239	5.787	.000b	
a Dependent Variable: Internal integration					

Table (15) shows that the variance inflation factor values range from 3.81 to 4.028, which is below 5, indicating no collinearity problem and that the independent variables are not significantly correlated. The Durbin-Watson test value of 1.239 confirms the independence of the model residuals, with values between 1.2 and 2.5 considered appropriate, indicating no significant autocorrelation. The correlation coefficient of 0.635 suggests a moderate correlation between the independent and dependent variables. The R^2 value of 0.403, which is greater than 30%, indicates that the independent variables (Strategy, Employee & Culture, and Technology) explain 40.3% of the variance in Internal Integration.

Also, the value of the F test reached (5.7) with a statistical significance value of (0.00) at a significance level less than 0.01, which indicates that the estimated study model is acceptable and valid for prediction, and therefore we accept the second sub-hypothesis, which states that:

There is a significant impact for Industry 4.0 on Internal integration (II) dimension.

<u>**The results of the multiple regression coefficients show the following:**</u>

- The regression parameters indicate a positive impact of the Strategy (STR) dimension on the Internal integration dimension, where the impact value reached 0.437 with a statistical significance value of 0.00 at a significance level of less than 0.01.

- The regression parameters indicate a positive impact of the Employee & culture (E&C) dimension on the Internal integration dimension, where the impact value reached 0.247 with a statistical significance value of 0.00 at a significance level of less than 0.01.

- The regression parameters indicate a positive impact of the Technology (TECH) dimension on the Internal integration dimension, where the impact value reached 0.179 with a statistical significance value of 0.00 at a significance level of less than 0.01.

6.3 Results of the third sub-hypothesis

$H_{1.3}$: There is a significant impact for Industry 4.0 on Customer integration (CI) dimension.

To test the study hypothesis, a quality test of the study model is conducted to ensure the quality of the model outputs, as many tests were conducted, then the results of the measurement models are displayed.

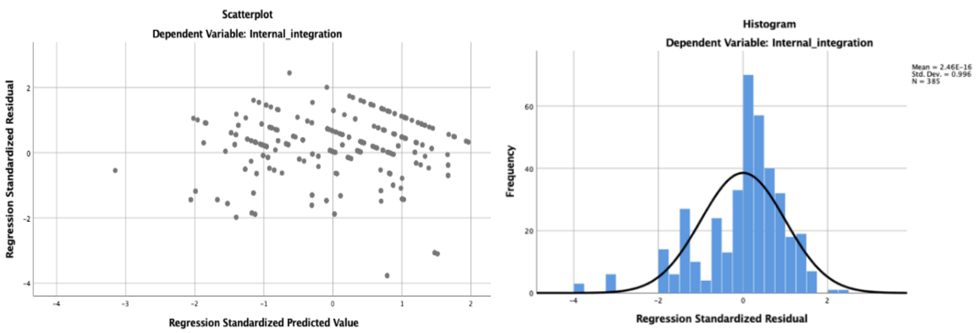

Figure 15 normal distribution for third sub-hypothesis residuals, Source: SPSS v25 output.

Figure (15) includes two plots to evaluate the residuals of the regression model for the dependent variable, Customer Integration (CI). The first plot, a scatterplot, shows that the points are randomly distributed around the horizontal axis without a clear pattern, indicating no major issues with the regression model. The second plot, a histogram, displays the distribution of the standard residuals, with a normal curve to demonstrate how closely the residuals follow a normal distribution. The plot shows that the mean of the residuals is near zero, and their standard deviation is approximately 1, supporting the validity of the regression model's assumptions. The following table presents the results of the multiple regression for the first sub-hypothesis of the first model of the study.

Table 16 Results of the multiple regression for the third sub-hypothesis, Source: SPSS v25 output

	B	t	Sig.	Collinearity Statistics	
(Constant)	0.112	2.807	0.020	Tolerance	VIF
Strategy (STR)	0.342	4.735	0.000	0.261	3.83
Employee & culture	0.063	2.864	0.039	0.262	3.81
Customer integration	0.584	6.947	0.000	0.248	4.028
R	R Square	Durbin-Watson	F	Sig.	
.772a	0.596	2.035	17.005	.000b	
A Dependent Variable: Customer integration					

Figure (15) includes two plots to evaluate the residuals of the regression model for the dependent variable, Customer Integration (CI). The first plot, a scatterplot, shows that the points are randomly distributed around the horizontal axis without a clear pattern, suggesting no major issues with the regression model. The second plot, a histogram, displays the distribution of the standard residuals with a normal curve, indicating how well the residuals follow a normal distribution. The plot shows that the mean of the residuals is close to zero, and their standard deviation is approximately 1, which supports the validity of the regression model's assumptions. The following table presents the results of the multiple regression for the first sub-hypothesis of the first model of the study.

Also, the value of the F test reached (17.0) with a statistical significance value of (0.00) at a significance level less than 0.01, which indicates that the estimated study model is acceptable and valid for prediction, and therefore we accept the third sub-hypothesis, which states that:

There is a significant impact for Industry 4.0 on Customer integration (CI) dimension.

The results of the multiple regression coefficients show the following:

- The regression parameters indicate a positive impact of the Strategy (STR) dimension on the Customer integration dimension, where the impact value reached 0.342 with a statistical significance value of 0.00 at a significance level of less than 0.01

- The regression parameters indicate a positive impact of the Employee & culture (E&C) dimension on the Customer integration dimension, where the impact value reached 0.063 with a statistical significance value of 0.00 at a significance level of less than 0.01

- The regression parameters indicate a positive impact of the Technology (TECH) dimension on the Customer integration dimension, where the impact value reached 0.548 with a statistical significance value of 0.00 at a significance level of less than 0.01

6.4 Results of the main hypothesis

H1. There is a positive impact for Industry 4.0 on supply chain integration (SCI).

To test the study hypothesis, a quality test of the study model is conducted to ensure the quality of the model outputs, as many tests were conducted, then the results of the measurement models are displayed.

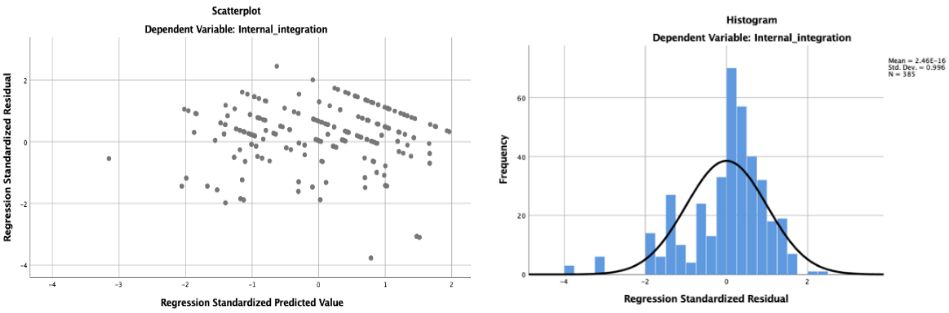

Figure 16 normal distribution for Main hypothesis residuals, Source: SPSS v25 output

Figure (16) includes two plots to evaluate the residuals of the regression model for the dependent variable, supply chain integration. The first plot, a scatterplot, shows that the points are randomly distributed around the horizontal axis without a clear pattern, indicating no major issues with the regression model. The second plot, a histogram, displays the distribution of the standard residuals, with a normal curve to show how closely the residuals align with a normal distribution. The plot shows that the mean of the residuals is near zero, and their standard deviation is approximately 1, supporting the validity of the regression model's assumptions. The following table presents the results of the multiple regression for the first sub-hypothesis of the first model of the study.

Table 17 Results of the multiple regression for the Main hypothesis, Source: SPSS v25 output.

	B	t	Sig.	Collinearity Statistics	
(Constant)	0.358	2.863	0.004	Tolerance	VIF
digital transformation	0.885	23.738	0.000	1	1
R	R Square	Durbin-Watson	F	Sig.	
.772a	0.595	1.713	6.499	.000b	
a Dependent Variable: Supply Chain Integration					

Table (17) shows that the variance inflation factor (VIF) is 1, which is less than 5, indicating no collinearity problem and that the independent variables are not significantly correlated. The Durbin-Watson test value of 1.713 confirms the independence of the model residuals, with values between 1.2 and 2.5 considered appropriate, indicating no significant autocorrelation. The correlation coefficient of 0.772 suggests a moderate correlation between the independent variables and the dependent variable. The R^2 value of 0.595, which is greater than 30%, indicates that the independent variables (Industry 4.0 digital transformation) explain 59.5% of the variance in Supply Chain Integration.

Also, the value of the F test reached (6.499) with a statistical significance value of (0.00) at a significance level less than 0.01, which indicates that the estimated study model is acceptable and valid for prediction, and therefore we accept the Main hypothesis, which states that:

There is a positive impact for Industry 4.0 on supply chain integration (SCI).

The results of the multiple regression coefficients show that regression parameters indicate a positive impact of the *industry 4.0 transformation* on Supply chain integration dimensions, where the impact value reached 0.885 with a statistical significance value of 0.00 at a significance level of less than 0.01.

7. Summary of the results of the field study

The study's results indicate that the IR4.0 transformation has a significant and positive impact on supplier integration. The impact of the strategy, culture and employees, and technology dimensions on supplier integration was confirmed, with the technology dimension having the largest impact (0.472), followed by strategy (0.418), and technology (0.045). The regression analysis revealed that 50.5% of the variance in supplier integration is explained by these dimensions, highlighting the importance of IR4.0 digital transformation in enhancing supplier relationships.

The study confirmed that the IR4.0 transformation has a significant impact on internal integration within organizations. The results showed that strategy plays a crucial role, with a positive impact of 0.437, followed by culture and employees (0.247), and technology (0.179). The coefficient of determination (R^2) indicates that 40.3% of the variance in internal integration can be explained by the dimensions IR4.0. These findings support the hypothesis that IR4.0 transformation enhances internal integration processes in organizations.

The results showed that the IR4.0 transformation has a strong positive impact on customer integration. The dimensions of strategy, culture, employees, and technology each contributed to improving customer integration, with technology having the largest impact (0.548), followed by strategy (0.342), and culture and employees (0.063). The analysis revealed that 59.6% of the variance in customer integration is explained by these dimensions, highlighting the significant role of IR4.0 transformation in achieving effective customer integration.

The results confirm that the IR4.0 transformation has a positive and strong impact on supply chain integration. The regression analysis showed that digital transformation explains 59.5% of the variance in supply chain integration, with an impact value of 0.885. This indicates that organizations adopting Industry 4.0 digital transformation can achieve high levels of integration across various components of the supply chain.

The study concluded that IR4.0 transformation is a key factor in enhancing supply chain integration dimensions—supplier integration, internal integration, and customer integration. The dimensions of strategy, culture & employees, and technology all play significant roles in supporting this transformation.

Conclusion, Recommendations, Limitations, and Recommendations for Future Research

1. Addressing research questions

RQ1: To what extent does the utilization of Industry 4.0 transformation impact the SCI in the Egyptian AEC industry?

The results of the multiple regression analysis show that the regression coefficients indicate a positive impact of IR4.0 on supply chain integration (SCI), with an impact value of 0.885 and a statistical significance of 0.00, well below the 0.01 significance level. This suggests that the relationship between IR4.0 digital transformation and SCI is statistically significant and strong, implying that adopting IR4.0 technologies positively influences the integration of supply chain processes. Therefore, the main hypothesis is accepted: **There is a positive impact for Industry 4.0 on supply chain integration (SCI).**

RQm1: do the IR4.0 technologies enhance the integration with supplier?

All three dimensions—Strategy, Employee & Culture, and Technology, demonstrate a significant positive influence on Supplier Integration, highlighting the importance of these factors in improving overall supply chain integration. Therefore, we accept the first sub-hypothesis, which states that: **There is a significant impact for Industry 4.0 on Supplier integration (SI) dimensions.**

RQm2: do the IR4.0 technologies increase the internal integration within the company?

All three dimensions—Strategy, Employee & Culture, and Technology, exhibit a significant positive influence on Internal Integration, emphasizing their role in promoting seamless coordination and collaboration within organizations. Therefore, we accept the second sub-hypothesis, which states that: **There is a significant impact for Industry 4.0 on Internal integration (II) dimension.**

RQm3: do the IR4.0 technologies enhance the integration with customer?

All three dimensions—Strategy, Employee & Culture, and Technology, demonstrate a significant positive impact on Customer Integration, with Strategy having the strongest effect. This underscores the interconnectedness of these dimensions and their collective importance in enhancing customer integration within the supply chain. Therefore, we accept the third sub-hypothesis, which states that: **There is a significant impact for Industry 4.0 on Customer integration (CI) dimension.**

2. Research recommendations

2.1 Practical recommendations

Based on the findings of this research, the following recommendations are provided for AEC companies seeking to enhance their supply chain integration and leverage Industry 4.0 technologies: *Invest in Industry 4.0 Technologies*, *Promote Cross-Functional Collaboration*, *Develop and Invest in Employee Training*, *Strengthen Supplier Relationships*, *Enhance Customer Integration*, *Implement Data-Driven Decision Making*, *Focus on Continuous Improvement and Innovation*, *Strengthen Change Management Practices.*

2.2 Policy Makers Implications

Based on the findings of this research, the following recommendations are provided for policy makers in the AEC industry to support the successful integration of Industry 4.0 technologies and enhance supply chains integration: *Encourage Industry 4.0 Adoption Through Incentives, Establish Industry Standards for Digital Transformation, Promote Collaboration Between Stakeholders, Support Research and Development (R&D) in Construction Technologies, Strengthen Digital Infrastructure and Connectivity, Facilitate Public-Private Partnerships (PPPs), Create Training and Certification Programs, Enhance Regulatory Frameworks for Technology Integration*, *Encourage Data Sharing and Transparency, Support Long-Term Industry Transformation Plans.*

3. Study limitations

A major challenge was the limited access to comprehensive data on all companies registered in the EFCBC nationally. As a result, the study's population was narrowed to companies in Greater Cairo for efficient data collection within the available timeframe and resources.

Due to limited transparency to disclose detailed information regarding their technological practices and processes, the researcher focused on Grade 1 and 2 construction companies and used multiple data collection techniques to gather relevant information, providing a comprehensive understanding of technology implementation in the industry.

A key limitation of the study was the lack of sufficient information on manufacturers and suppliers in the supply chain, who could significantly impact technology adoption in the construction industry. As a result, the researcher focused only on companies registered in the EFCBC and classified as contractors, excluding other important players like manufacturers and suppliers.

4. Recommendations for future research and development

The limitations discussed present valuable opportunities for future research. Expanding the sample to include manufacturers and suppliers, collecting data from a wider geographic area, and examining the challenges of adopting Building Information Modeling (BIM) and other Industry 4.0 technologies could offer a more comprehensive understanding of the factors influencing technology adoption in the construction industry. Addressing these limitations would provide deeper insights and contribute to the advancement of the field.

5. Conclusion

In conclusion, this research demonstrates the significant positive impact of IR4.0 technologies on SCI within the Egyptian AEC industry. By enhancing collaboration, reducing inefficiencies, and improving decision-making, technologies like BIM, IoT, and AI play a critical role in transforming the sector. Key factors such as skilled personnel, a culture of innovation, and clear communication are essential for successful implementation. The study emphasizes the importance of strategic alignment and organizational culture in adopting these technologies. Despite limitations in data collection, the findings highlight the potential for digital transformation to drive efficiency and sustainability in the industry. Future research could further explore the adoption challenges for smaller firms and the long-term impact of IR4.0 on AEC performance.

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Appendix 1

Table A-1: Measurement Items of the Study

Construct	Components	Code	Measurement Items	Code
Industry 4.0 (IR4.0) (Bibby & Dehe, 2018) (Erboz, Hüseyinoglu, & Szegedi, 2022)	Strategy	STR	Clear availability of Industry 4.0 roadmap	STR1
			Investing in Industry 4.0 infrastructure	STR2
			Easily customizing products to customers' requests while offering the same service quality	STR3
			Partnering with external organizations to maintain Industry 4.0	STR4
	Employee & Culture	E&C	Familiarity of employees with Industry 4.0 activities	E&C1
			Investing in training of employees in Industry 4.0 activities	E&C2
			Using 'zero paper' to control, display, and transport data	E&C3
			Maintaining continuous improvement culture within the organization	E&C4
	Technology	TECH	Using advanced connectivity technology between products, equipment, and employees	TECH1
			The level of technology usage with suppliers to increase connectivity and collaboration	TECH2
			Accessing data quickly and effectively from machines, systems, products	TECH3
			Analyzing data to make decisions, information sharing, and identifying trends	TECH4
			Using intelligent sensors in the manufacturing process	TECH5
			Storing information within a Cloud	TECH6
			Ability to see live manufacturing systems and respond to the changes immediately	TECH7
			Ability of machines to run autonomously	TECH8
			Ability of customers to access manufacturing process and delivery dates	TECH9
			Using Computer-Aided Design (CAD) software and metal alloys as the raw materials of 3D printing (3DP) machines	TECH10
			Using 3DP for the process of tooling, prototypes, or spare parts	TECH11
			Connectivity of hard and soft resources into the Cloud	TECH12
			Using digital media to bring information directly to employees	TECH13
			Embracing digitalization for products, parts, and machines	TECH14
			Using sensors on products and supplied parts	TECH15
			The extent of automation within the production	TECH16

Supply Chain Integration (SCI) (Jajja, Chatha, & Farooq, 2018); (Erboz, Hüseyinoglu, & Szegedi, 2022)	Supplier Integration	SI	Information sharing with the main suppliers (about production plans, order management, delivery, and inventory information)	SI1
			Improving collaborative strategies with the main suppliers (development of supplier, risk-sharing, long term alliances)	SI2
			Improving decision making with the main suppliers (about product design/development, quality improvement, cost, and process design)	SI3
			Developing a system with the main suppliers (Vendor Managed Inventory (VMI), Just in Time (JIT), Kanban, continuous replenishment activities)	SI4
	Internal Integration	II	Information sharing with the purchasing department (about sales, production progress, and inventory level)	II1
			Improving decision making with the purchasing department (about sales, production plans, and inventory level)	II2
			Information sharing with the sales department (about sales, production progress, and inventory level)	II3
			Improving decision making with the sales department (about sales, production plans, and inventory level)	II4
	Customer Integration	CI	Information sharing with the main customers (about production plans, order management, delivery, and inventory information)	CI1
			Improving collaborative strategies with the main customers (risk sharing, long term agreements)	CI2
			Developing a system with the main customers (VMI, JIT, Kanban, continuous replenishment activities)	CI3
			Improving decision making with the main customers (about product design/ development, quality improvement and process design)	CI4