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INTEGRATION OF IPD AND IOT ON CONSTRUCTION INDUSTRY SUPPLY CHAIN PERFORMANCE WITH A SUSTAINABLE DEVELOPMENT APPROACH

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SUMMARY: *Currently, sustainable development has become one of the most fundamental priorities for decision-makers and policy formulators to build a healthier environment, an advanced social setting, and a more robust economy. As one of the sectors with the most significant and complex production system pressures worldwide to achieve sustainable development goals, the construction industry has an essential contribution in the context of economic growth and improves living conditions without damaging future generations' opportunities or depleting natural resources. Because of the complexity and wide range of activities in the supply chain in this industry, it is necessary to employ proper methods and approaches to optimize performance, decrease costs, and use resources more efficiently. Thus, adopting new technologies and understanding their attributes offer promising solutions. This research proposes a model for incorporating Integrated Project Delivery and Internet of Things technologies in supply chain management for construction projects in Iran, focusing on sustainable development. The study comprises three phases: (I) Criteria Collection and Validation: Identifying effective parameters from integrating IPD and IoT on supply chain performance with a sustainable development approach; (II) Importance Weight Calculation: Using the fuzzy SWARA method to determine the significance of each criterion and sub-criterion; (III) Objective Prioritization and Solution Proposals: Employing the fuzzy ARAS method to prioritize objectives and propose solutions. The findings indicate that project savings (cost and time) and operational efficiency are top priorities from the perspectives of project management, technical factors, economic factors, and industry growth. Operational efficiency and project savings, with desirability scores of 78.77% and 78.36%, rank first and second, respectively. Supply chain visibility, remote operations, and augmented reality, with desirability scores of 70.77%, 70.66%, and 69.71%, follow in priority for integrating Internet of Things and Integrated Project Delivery in supply chain management performance within the construction industry, focusing on sustainable development.*

KEYWORDS: *Integrated Project Delivery, Internet of Things, Supply Chain Management, Sustainable Development, Construction Industry, MCDM Methods.*

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1. INTRODUCTION

Construction praxes centered around sustainable development aims have emerged as a recent construction practice paradigm, which presents exciting challenges and opportunities in construction project management. Sustainable construction is now becoming mainstream in the industry, as it has enormous advantages in designing and building structures that minimize pollution and using a new methodological vision capable of creating conditions for quality of life within human communities. Therefore, using information technology and modern technologies is essential to guarantee increased lifespans (Product Lifecycle Management), efficiency throughout time, and operation based on three critical dimensions of sustainable development: social, economic, and environmental (Fei et al, 2021). To remain competitive and sustain current industries, every field must embrace Information Technology and advanced technologies. These tools enable industries to transform their operations and gain a competitive advantage. Information technology presents new opportunities to enhance competition and improve production and operational efficiency by introducing innovative management methodologies and leveraging business capabilities. Rapid urban expansion, increasing urbanization, and growing energy demand have created an urgent need for housing and sustainability. Managing the construction industry according to sustainable development principles has become critical. The advent of data-driven smart systems, such as the Internet of Things (IoT), has revolutionized the operational efficiency of major industries, including construction (Ben-Daya et al., 2017; Taj et al., 2023).

Supply chain management (SCM) is one of the domains that benefits the most from the evolution of information and communication technology, particularly with the advent of the IoT. By increasing data creation, tracking associated events, and making information collection, transmission, storage, processing, and sharing easier, this technology has significantly improved construction operations, resulting in tangible differences in daily workflows (Ben-Daya et al., 2017; Taj et al., 2023).

The global IoT market size was $405.69 billion in 2023, according to a report published by Precedence Research. What is particularly interesting is its projected growth, with the market expected to reach approximately $3,152.17 billion by 2033 at a compound annual growth rate (CAGR) of 22.68% from 2024 to 2033, as illustrated in Figure 1. This remarkable increase underscores the essential need for businesses to prepare for the era of IoT, establishing it as a foundation for achieving market leadership in the future.

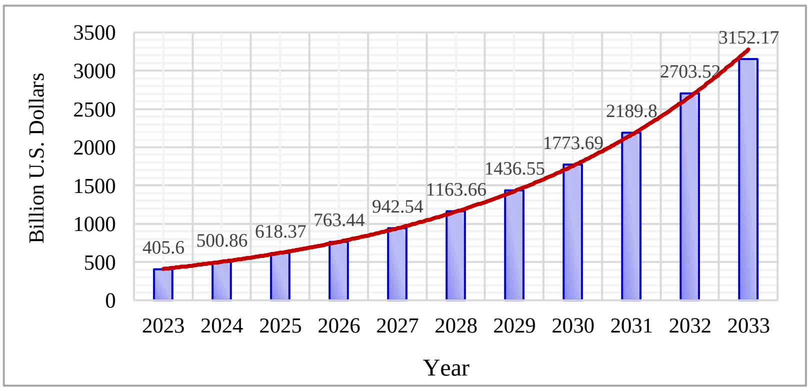

Figure 1: Increasing investment in the IoT industry (Precedence Research, 2023).

Increasing costs and delays in fully integrating construction project components necessitate radical changes in project management. Poor communication and ineffective risk management among clients, consultants, and contractors in supply chain management (SCM) lead to cost overruns, delays, poor design integration, and weak client-consultant relationships, which are major causes of significant issues (Keely and Ilozor, 2022; Kent and Becerik-Gerber, 2010; Zhang and Hu, 2018).

To address these challenges, there is growing interest in modern methodologies like Integrated Project Delivery (IPD). Quality Improvement Methodologies (QiMs) are used to enhance quality and productivity, manage risks, reduce costs, and expedite project timelines (Ma et al., 2018). Understanding that IPD inherently supports sustainable development is crucial. The collaborative efforts of project stakeholders, in addition to achieving sustainability goals, foster collective creativity and the open exchange of ideas while simultaneously driving significant economic changes within the project through innovative strategy discovery for energy conservation and pollution reduction. IPD lays the foundation for future projects and provides social benefits by promoting social justice and ensuring stakeholder participation across all areas. This results in accelerated project delivery, cost reduction, and improvements in quality and productivity. Moreover, the commitment of all parties to minimizing environmental damage enhances the project's overall value (Adel et al., 2023).

The most important reason for using the IPD method is to reduce costs or optimization by creating detailed and fully structured project plans and increasing efficiency compared to other methods from all stakeholders. IPD is described in Table 1 as a three-level collaboration model (conventional, advanced, and essential). This framework allows for the comparison of IPD's characteristics as both a philosophy and a delivery method (Figure 2). Any contract that encourages collaboration or risk sharing can be considered integrated project delivery. Integration can be seen as a philosophy or a delivery method, depending on the principles applied. These principles include contractual aspects (fairness to stakeholders, risk-sharing, financial transparency, joint criteria development, collaborative decision-making) and behavioral aspects (mutual respect and trust, willingness to collaborate, open communication), and various catalysts that can aid in optimizing project outcomes (NASFA et al., 2010).

Table 1: Features of different levels of IPD (NASFA et al., 2010).

Level of Collaboration	**Type of Collaboration**	**Collaboration Contract**	**Type of Contract**	**Design Team**	**Execution Team**
1	Conventional	Not required	Open book, lump sum with Guaranteed Maximum Price (GMP); fixed cost	Selected based on qualifications	Selected based on qualifications or best value (price)
2	Advanced	Some collaboration contracts required (early involvement of stakeholders, use of BIM, sharing models, etc.)	Open book, lump sum with GMP; fixed cost	Selected based on qualifications	Selected based on qualifications or best value (price)
3	Essential	Some multi-party collaboration contracts required	Some multi-party collaboration contracts required	Selected based on qualifications	Selected based on qualifications or best value (price)

The main goal is to create a high-quality final product with better collaboration among project components and increased viability among stakeholders. A successful IPD project requires the involvement, support, and commitment of governments and authorities, as well adopting lean practices and radical technologies like IoT in construction (Ghassemi and Becerik-Gerber, 2011; Kahvandi, 2017; Ma et al., 2017).

Despite the rapid technological advancements in the developed world, such as IoT and IPD (Hosseini et al., 2018), the construction industry in many less-developed countries often remains unchanged and heavily reliant on traditional methods (Fernando et al., 2017). Deploying IoT and IPD in SCM properly requires significant time and financial investment with substantial government subsidies and industry support. Therefore, a well-structured plan is necessary to achieve these objectives.

This study takes a comprehensive approach, initially introducing the IoT and IPD in the context of supply chain management within the construction industry while addressing the existing challenges and requirements. It then explores these challenges and the interplay of these requirements, informed by relevant studies and sustainable development goals. In the final stage, the study identifies the critical parameters to effectively adopt IoT and IPD in construction supply chain management. It prioritizes the primary and secondary criteria using fuzzy multi-criteria decision-making methods (fuzzy SWARA and fuzzy ARAS). Ultimately, the research concludes by offering strategies to optimize the use of these technologies in alignment with sustainable development, particularly in developing countries such as Iran.

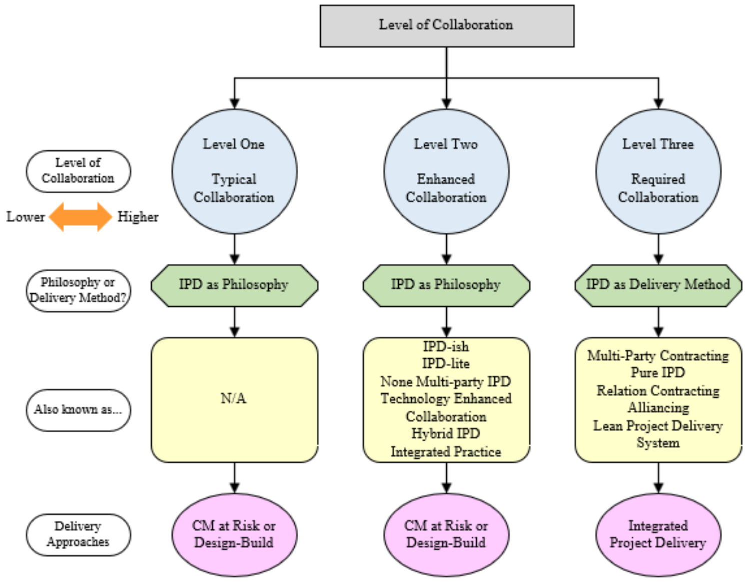

Figure 2: Comparison of different levels of IPD (NASFA et al., 2010).

2. LITERATURE REVIEW

The construction sector is growing, and recent years have seen significant breakthroughs. However, it still faces new challenges, such as rising costs, project delays, lack of information sharing, poor stakeholder interaction, and unsatisfactory organizational performance. While the challenges of supply chain management have been well researched, the broader application of modern methods and technologies and their impact on construction supply chain management requires further exploration. Several studies and analyses have examined changes in SCM due to recent developments in information and communication technology.

2.1 Supply chain management in the construction industry

Banihashemi et al. (2023) have identified and ranked challenges in green supply chain implementation in construction, focusing on green design, management, and implementation using the fuzzy BMW method. Kim and Nguyen (2020) have highlighted issues such as a shortage of capable leaders and stakeholders, misconceptions about supply chain concepts, ineffective subcontractors and suppliers, and organizational resistance. Nguyen et al. (2018) have classified seven critical barriers to construction supply chain management in Vietnam, including industry attributes, organizational supply chain competence, stakeholder coordination perception, support tools, weak relationships, innovation voids, and inadequate IT. Zhang et al. (2024) have studied quality management in the supply chain of modular construction and proposed a systematic approach for improvement. Chen et al. (2024) have examined construction supply and demand uncertainties using a multi-product, multi-period model to evaluate supply chain flexibility. This model was simulated for mathematical formulation as shown by Chen and Hammad (2023). Pham et al. (2023) conducted a comprehensive study of supply chain risk management. Mathiyazhagan et al. (2018) have identified and prioritized the key factors influencing green supply chain management adoption in India, finding that government-related criteria were the most critical, followed by market, suppliers, customers, internal drivers, and the environment. Amornsawadwatana (2011) analyzes Thailand's construction industry to determine factors that impact supply chain management, aiming to reduce logistics costs and implement effective practices. Teklay (2021) has explored supply chain and logistics management in construction projects in Addis Ababa, Ethiopia, highlighting that poor supply chain management leads to delays, rework, cost overruns, and decreased efficiency. Additionally, late payments and lack of information sharing among stakeholders were identified as significant challenges.

2.2 Supply chain management and Internet of Things in the construction industry

In the study by Ali et al. (2020), critical aspects such as equipment monitoring, environmental impact reduction, security risk detection, augmented reality, and inventory management were achieved concerning IoT integration in construction supply chains within the China-Pakistan Economic Corridor. Elghaish et al. (2021) have assessed the significance of IoT and blockchain in construction. Ethirajan and Kandasamy (2021) have conducted a study on the importance of IoT in SCM, preparing a guide for implementing IoT to overcome material shortages, reduce maintenance costs, and address safety hazards while enhancing workers' well-being. Khurshid et al. (2023) have identified IoT applications in construction and discussed associated challenges. Shahrayini et al. (2021) have evaluated blockchain technology in construction and emphasized using BIM and IoT for improved supply chain management. Gamil et al.'s (2019) research identifies and assesses challenges facing IoT adoption in construction projects, including safety and security issues, lack of standards, ignorance of benefits, misrepresentation of IoT, and potentially unstable connectivity. Pishdad-Bozorgi et al. (2020) have suggested that the Internet of Things represents a new opportunity for the construction supply chain and blockchain information sharing can foster trust and sustainable performance. Medina-Borja et al. (2023) have analyzed IoT opportunities and obstacles in SCM, providing guidelines to overcome barriers and leverage opportunities. Lu et al. (2021) have proposed a new scheme for applying IoT in intelligent construction supply chain management, involving the establishment of an intelligent construction object network to address emerging challenges.

Ding et al. (2023) have assessed the effect of IoT on the supply chain and logistics industry in China with respect to sustainable development (economic, social, and environmental sustainability). Using this grey prediction model, they have predicted IoT will make progressive achievements in various fields of supply chains, and by 2025, China's market share in these sectors may have climbed to 30% due to its transformation into an IoT-based economy. In their study, Osunasanmi et al. (2022) compared the supply chain management in the construction industry of the UK and Australia utilizing advanced models of BIM and IoT. Both countries' contractors stated that supply chain performance would be enhanced by better knowledge sharing, innovation access, communication, and trust between the two nations' commercial entities. Lee et al. (2022) have investigated the implementation of IoT in Malaysia, which can increase supply chain management, organizational performance, and sustainability in the economic, social, and environmental fields.

2.3 Supply chain management and integrated project delivery in the construction industry

Sharif et al. (2022) explores the implementation and challenges of IPD applications in the Middle East. They have found that the primary impediments to enacting IPD were cultural inertia and limited awareness of the transformation. This study also presents recommendations for the construction industry in the Middle East to adopt and apply IPD effectively. Khanna et al. (2021) conducted a feasibility study on using IPD in infrastructure projects in developing countries, especially India. They have found that, although there have been advances in adopting IPD, BIM, and ICT processes, these are not yet sufficient to effectively deliver large infrastructure projects in developing countries. The main challenges identified were resistance to change, lack of expertise and skills, and ignorance among project owners.

Mesa et al. (2020) have modeled and evaluated supply chain integration in an integrated project delivery system by conducting a conceptual and qualitative analysis of the application of the virtual design team model using two real case studies in IPD projects. The results show that project organization is a crucial factor in construction supply chain performance. Koolwijk et al. (2018) have found that using IPD alone is insufficient to create the desired level of supply chain integration among stakeholders.

Capuyan and Jocson (2024) examine the enhancement of supply chain management efficiency in the modular construction sector in the Philippines through IPD, proposing a comprehensive framework tailored to the Philippine construction industry. Walker and Matinheikki (2019) investigates IPD procedures within the context of lean supply chain management by integrating lean theory into better practices for IPD and logistics protocols to facilitate project delivery management.

Amade et al. (2016) have identified and evaluated challenges in construction supply chain management, indicating that there is limited understanding, ill-defined strategic benefits, poor trust, lack of common standards, and a narrow focus beyond procurement or product distribution. Kelly and Ilozor (2020) have researched the links between various project criteria and the use of IPD in the United States. Analyzing data from 93 construction projects, they found that IPD can help resolve many challenges in the construction industry, particularly in meeting sustainable development goals. Zuber et al. (2019) study IPD's impact on construction projects in Malaysia, suggesting that an optimal IPD approach is essential for overcoming delivery challenges and ensuring project success. In a separate study, Jones (2014) has explored how IPD can improve design and construction processes aligned with sustainable development principles, emphasizing the importance of creating safer, greener, and more sustainable environments.

2.4 Sustainable development and its goals

Sustainable development is a concept that seeks to meet the needs of the present without compromising those of future generations. In the context of construction, it is an effort to strike a balance between environmental sustainability and social equity on the one hand while preserving economic reality on the other. Essentially, any sustainable development needs to involve all actors at every stage, from the definition of a site and a program to the logistics/supply chain management phase, construction itself, maintenance (construction), and even demolition and transformations, linking every aspect in design. Assessing the sustainable development goals in the construction industry is crucial, especially in the context of the sector's reliance on new integrated technologies. These technologies not only enhance quality but also aim to eliminate delays that lead to rework, thereby contributing to cost savings and sustainability (Hemmati Farahani et al., 2023). These global goals, set by the United Nations, are a roadmap for countries worldwide to follow, comprising 17 international goals, 169 targets, and 231 unique indicators (Figure 3)(SDSN, 2016).

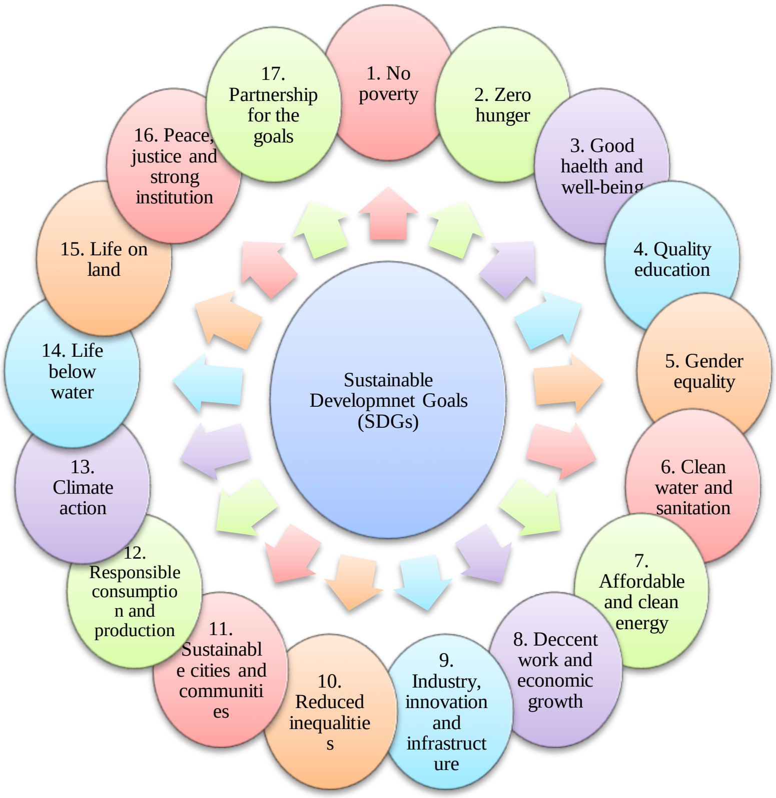

Figure 3: Sustainable development goals (SDSN, 2016).

Czajkowska (2018) conducted a study to determine how sustainable development can positively contribute to the construction industry. The focus of this article is the basic needs for sustainable development at various stages in design and implementation during construction processes. Furthermore, the report demonstrates how different sectors use energy resources and that construction activities are in high heat and electricity consumption due to coal usage. On the other hand, Mahpour (2018) identifies the circular economy as a sustainable concept that can be utilized to manage resources effectively and handle construction and demolition waste efficiently. Regona et al. (2024) argue that AI and IoT technologies could play a crucial role in achieving sustainable development goals throughout the lifecycle of construction projects, particularly SDGs 6, 9, 11, 13, 15, and 17.

In their study, Gade and Selman (2023) explore the initial implementation of sustainable development goals in a school construction project in Denmark. The results indicate varying levels of SDG integration perceived by different stakeholders, with SDGs 4, 9, 12, and 13 successfully entering the implementation phase. Li et al. (2021) emphasizes that blockchain-based intelligent technologies and IoT could significantly impact the sustainable development of prefabricated housing. Their article presents an intelligent platform that integrates service-oriented methods, IoT, and BIM to evaluate sustainable development goals in clever construction. Yevu et al. (2021), through a comprehensive review of essential research needs for achieving sustainable development goals and digitalizing the construction supply chain and logistics, highlighted the critical role of emerging technologies like IoT and BIM as opportunities for sustainable development in construction supply chain management.

2.5 Conceptual framework for common operational scope

For a successful project delivery, the active involvement of all stakeholders is crucial. Each stakeholder must engage with their respective responsibilities to effectively advance the project's interests. However, it is not just about individual efforts. The synergy of three main elements, i.e., an engaged community (People), a fine-tuned process (Process), and the right tools (Tools), is the key to successful collaboration, as depicted in Figure 4. It is the harmonious functioning of these elements that leads to project success. Despite each element being drastically distinct from the rest, these elements can be tacitly implemented in the construction industry through IPD, SCM, and IoT.

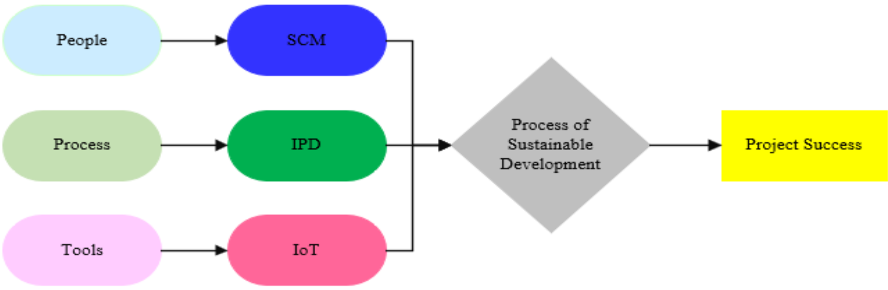

Figure 4: Conceptual common operational scope for achieving project success towards sustainable development.

3. METHODOLOGY

Figure 5 illustrates the general framework of the methodology used to accomplish the research goals. The current research consists of three phases:

- **Phase I:** Collecting and validating criteria for identifying effective parameters resulting from the integration of IPD and IoT in the construction industry's supply chain performance, with a sustainable development approach.
- **Phase II:** Calculating the importance weight of each criterion and sub-criteria using the fuzzy SWARA method.
- **Phase III:** Prioritizing the studied objectives using the fuzzy ARAS method and suggesting solutions.

This study, which seeks to develop a model integrating IoT and IPD in construction industry supply chain management to achieve sustainable development goals, is classified as fundamental-applied research. Furthermore, given the research objectives focused on exploring key topics in detail, a mixed-method approach (both quantitative and qualitative) was chosen. This research employs a mixed (quantitative-qualitative) approach to crystallize the fundamental themes in line with the objectives. Initially, qualitative data are collected using library and field tools. These data are then analyzed using quantitative methods. Research is sourced from articles, books, theses, resource databases, and the Internet, relating them to library studies. The target community includes professionals in Iran's construction industry, including 15 academic researchers, project managers, and design and consulting engineers. Field studies and questionnaires were used to gather data for this research. Figure 6 shows the characteristics of the experts including education, work experience, and field of activity.

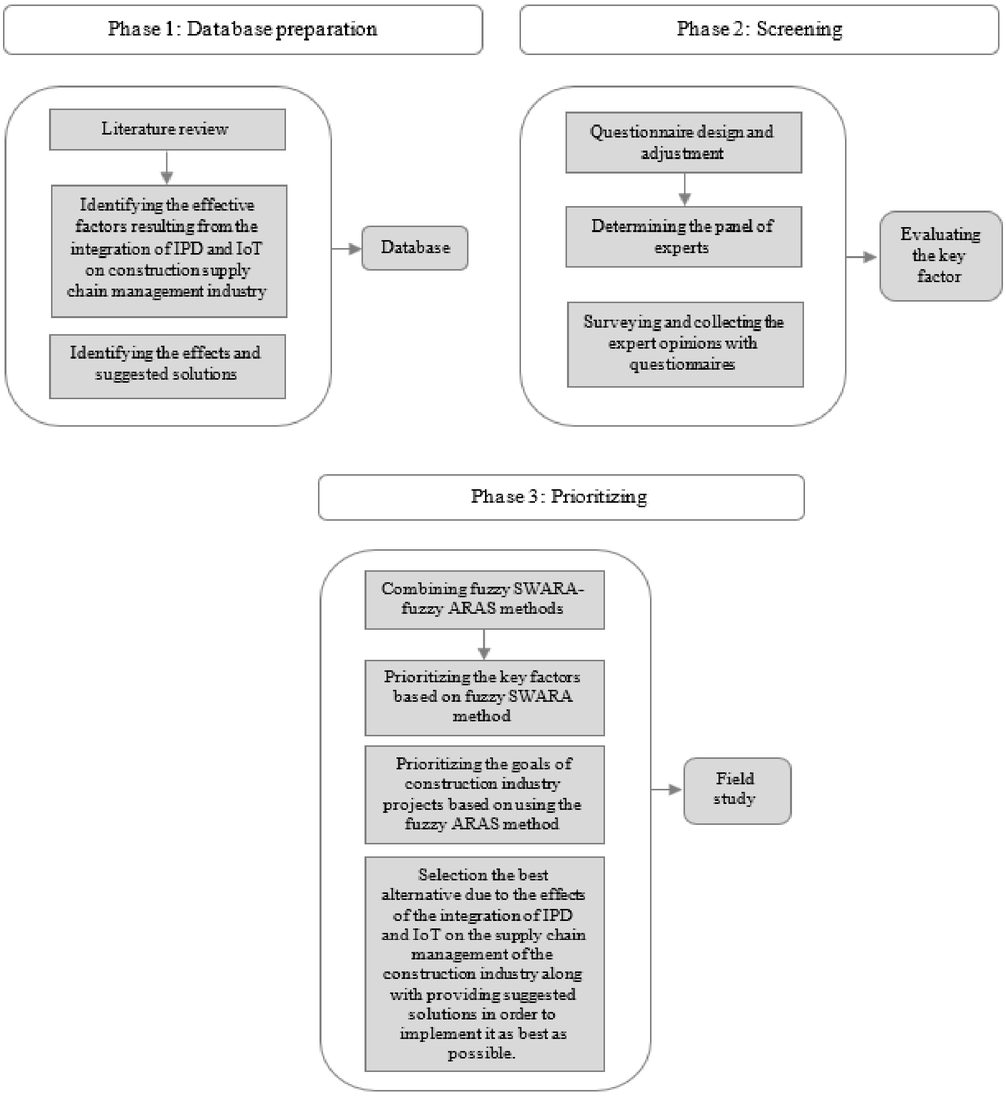

Figure 5: Flowchart of the problem-solving procedure in this research

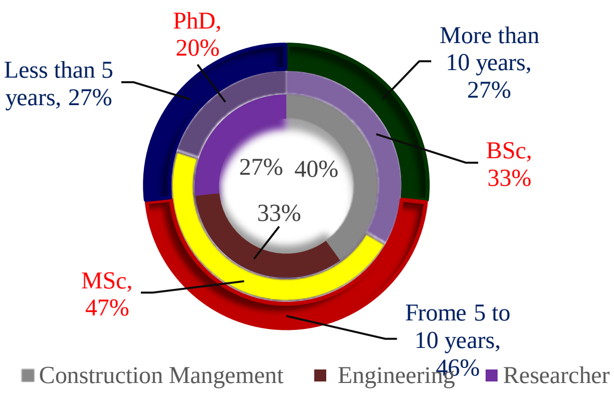

Figure 6: Respondents' Demographics (Inner Rring (Field of activity), Middle Ring (Education), and Outer Ring (Work Experience).

3.1 Identification and preparation of required information (Phase I)

In the initial step of this research, a database was created to analyze the effects of integrating IPD and IoT on sustainable development and its impact on supply chain performance. The goal is to provide guidance and support to stakeholders in achieving the United Nations Sustainable Development Goals within a construction project in Iran. This research involved reviewing relevant articles, global information networks, existing guidelines, regulations on modern technologies, supply chain management, and conducting a field study. Communication, interviews, questionnaire analysis, and expert inquiries were employed to identify the influencing factors. Figure 7 shows the primary and secondary criteria, along with the goals or options derived from combining the effects of IPD and IoT on sustainable development to enhance supply chain performance in the construction industry. Table 2 presents the scenario options identified by the study.

Table 2: Introduction of studied alternatives

Alternative	Information
Remote Operations	The Internet of Things enables real-time data of things like equipment, tools, and vehicles through sensors, therefore shaping a sort of next-generation supply chain in traditional construction that allows for accurate checks on activity elsewhere. It optimizes asset utilization, eliminates waste, and provides protection for resources. Support for managing inventory levels through alerts of the inventory in real-time helps in better coordination between suppliers, contractors, and project managers. Quality issues are monitored closely, ensuring that the agreed quality standards are met and expensive rework is avoided.
Supply Chain Visibility	Visibility: Process and transaction representation and monitoring must be precise and accurate. Operations and supply chain professionals gain better visibility through radio frequency identification (RFID) and product or equipment tagging, which gives essential insights into necessary information. This includes structure tracking, investment size, completion date of construction stages, raw material requirements, and tools and equipment information.
Augmented Reality (AR)	Augmented reality is when digital information is integrated with, or overlaid onto, the real world in real-time, frequently on a mobile device. This technology has practical applications in the construction industry, enhancing the physical environment (e.g., a living room) or adding more information for the user (e.g., highlighting a building in Tehran City). It integrates digital and 3D methods with real-space appearance, offering exciting possibilities in the construction process.
Operational Efficiency	Efficiency is quantity, but productivity is quality in Project Management for construction. Efficiency: An Efficient system can get the job done using the least resources without sacrificing effectiveness. It exists to measure how much profit comes out of necessary costs being inputted (how much revenue is produced for the cost) and check that the same is done well, i.e., there are better workarounds for a plan. This distinction is crucial for operations and supply chain professionals to understand, as it can significantly impact the success of a construction project.
Saving the Project (Cost and Time)	Managing construction project time and cost means planning, controlling, and managing how these two resources can best be employed for implementation (execution) during the lifecycle stage of an actual constructed project. It includes careful planning, tracking work progression to deliver the highest quality, optimizing resource utilization and risk management, and trying to reduce delays and cost overruns while ensuring on-time and within-budget project delivery.

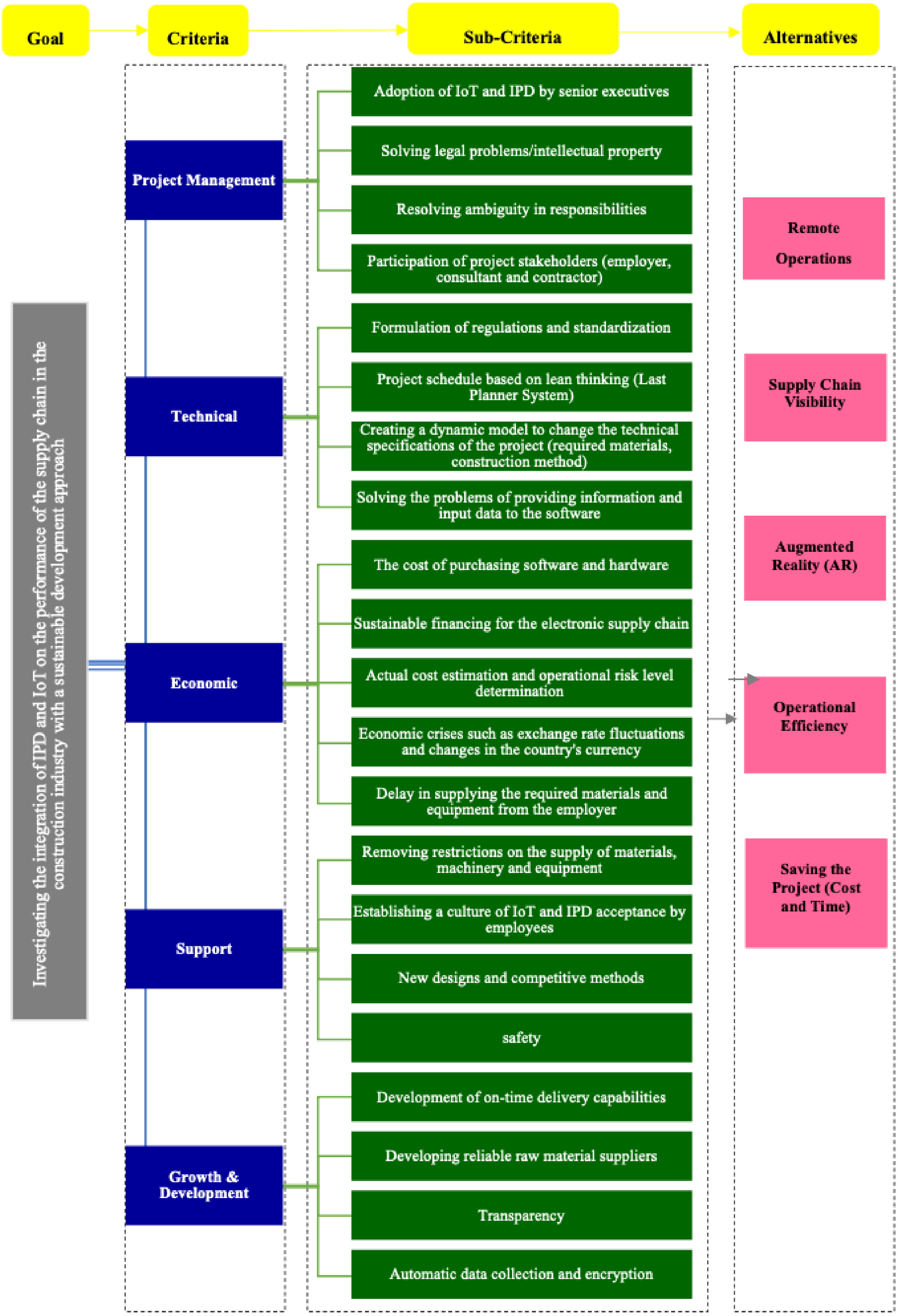

Figure 7: Flowchart of the problem-solving procedure in this research

3.2 Fuzzy SWARA method (Phase II)

The Stepwise Weight Assessment Ratio Analysis (SWARA), developed using an MCDM approach by Kersuliene et al. (2010, 2011), is an effective technique that has been proposed in the recent past. The method of reasonable difference analysis was chosen in 2010.

The primary benefit of this approach is its effectiveness in validating experts' opinions and determining the relevant ratio of importance among different criteria (Zarbakhshnia et al., 2018). Stanujkic et al. (2015), another SWARA approach, has reported its advantages against AHP, such as fewer pairwise comparisons in SWARA, making it more appealing and easier to use. The previous studies provided good tools to calculate an importance ratio of criteria in sustainable supply chain contexts (Kannan et al., 2017; Hashemkhani Zolfani et al., 2013; Hashemkhani Zolfani et al., 2014). The most significant disadvantage of the MCDM methods is when non-assessable, ambiguous, inconsistent, and unacceptable information or ignorance issues arise, and the decisions are founded on incorrect data. That is why the fuzzy manner in which Kiani Mavi et al. (2017) adds the SWARA model to resolve this problem in 2016 is used. The fuzzy SWARA method's purpose is to present a different vision concerning methods such as AHP and ANP so that decision-makers and researchers can choose based on the current situation in the construction sector. Second, since previous research has separately discussed the influences of IPD and IoT on supply chain management in construction, the joint impacts of both parameters on supply chain management still need to be examined. This is why identifying influencing factors stresses expert knowledge in this area. Table 3 summarizes the steps of the fuzzy SWARA method.

Table 3: Steps of the fuzzy SWARA method.

Step	Description	Equations
1	The criteria are sorted in descending order of importance.	The evaluated criteria are classified from the most preferred to the least preferred according to the purpose of decision-making.
2	Determining the relative importance of the fuzzy j factor ($\tilde{S}_j$) compared to the previous factor (j − 1) with more importance from the point of view of experts.	According to Table 4, the relative importance of each criterion compared to the previous criterion is determined by using the provided verbal expressions.
3	Calculation of the value of the fuzzy coefficient ($\tilde{k}_j$) according to the equation (1):	$\tilde{k}_j = \begin{cases} 1 & j = 1 \\ \tilde{S}_j + 1 & j > 1 \end{cases}$ (1)
4	Calculation of the value of the initial fuzzy weight ($\tilde{q}_j$) according to the equation (2):	$\tilde{q}_j = \begin{cases} 1 & j = 1 \\ \tilde{k}_{j-1}/\tilde{k}_j & j > 1 \end{cases}$ (2)
5	Calculation of the fuzzy weight of criteria ($\tilde{w}_j$) according to the equation (3):	$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k}$ (3)
6	Calculating the de-fuzzified weight of criteria according to equation (4):	$w_j = \frac{1}{3}\,(\tilde{w}_j)$ (4)

Table 4. Introduction of studied alternatives (Zarbakhshnia et al., 2018).

Fuzzy Number	Linguistic Variable	Membership Function
$\tilde{1}$	Equally Important	(1, 1, 1)
$\tilde{2}$	Moderately Less Important	(2/3, 1, 3/2)
$\tilde{3}$	Less Important	(2/5, 1/2, 2/3)
$\tilde{4}$	Very Less Important	(2/7, 1/3, 2/5)
$\tilde{5}$	Very Much Less Important	(2/9, 1/4, 2/7)

3.3 Fuzzy ARAS method (Phase III)

In 2010, Turskis and Zavadskas introduced the fuzzy additive ratio assessment (ARAS) method, which extends the traditional ARAS methodology with a fuzzy scale. One of the Multi-Criteria Decision-Making (MCDM) methods involves ranking alternatives using an optimality function that measures their relative efficiency based on the values of criterion weights. Consequently, the fuzzy ARAS method is applicable not only for strategic decision-making. In the ARAS method, alternatives are ranked based on performance, revealing the proportions of each option for identifying the best alternative.

Depending on the terms and extent used, these methods may not yield practical solutions for a large number of alternatives or a vast dataset. Therefore, researchers have adapted fuzzy AHP methods or ANP applications to provide more reliable results to solve selection problems in different areas (Zolfani and Saparauskas, 2013; Mardani et al., 2017). The ARAS method has unique features compared to other ranking methods such as TOPSIS, VIKOR, or ELECTRE (Zavadskas and Turkis, 2011; Zavadskas et al., 2017). It calculates the performance and its ratio to identify the ideal alternative. The method also distinguishes between positive and negative criteria, assessing and prioritizing diverse alternatives according to multiple independently determined criteria (Zavadskas et al., 2017). In other words, the ARAS approach starts with the assumption that high-level features of the world can be approximated in familiar and simple terms. Therefore, the fuzzy ARAS technique is a feasible and novel approach for screening and ranking alternatives.

The fuzzy method is selected because it can convert qualitative indexes into numerical values and reflect uncertainty through the expected value between the observed value and expert estimates. In short, fuzzy sets provide a natural framework to model uncertainty arising from imprecision in data errors or vagueness in judgment. Table 5 summarizes the steps of the fuzzy ARAS method.

Table 5: Steps of the fuzzy ARAS method.

Step	Description	Equations	
1	Formation of fuzzy decision matrix: The first step is the formation of the decision matrix. The decision matrix of this method is a row-column matrix, the rows of which are research alternatives (m) and the columns are criteria (n), and each evaluation cell is an option for each criterion that is based on having the fuzzy spectrum completed. Verbal expressions and fuzzy numbers in Table 6 are used to evaluate options for each criterion.	$\breve{X} = \begin{bmatrix} \dots & \dots & \dots & \dots \\ \breve{x}_{i1} & \dots & \breve{x}_{ij} & \breve{x}_{in} \\ \breve{x}_{m1} & \dots & \breve{x}_{mj} & \breve{x}_{mn} \end{bmatrix}$ $i = 0.1. \dots .m \quad j = 1. \dots .n$	(5)
2	Convert negative criteria to positive: In this step, the levels of negative criteria should be reversed to become positive criteria. This process makes the decision matrix become a positive decision matrix.	$\otimes \mathrm{x_{ij}} = \frac{1}{\tilde{\tilde{x}}^*}$	(6)
3	Determining the hypothetical ideal value: In this step, the levels of negative criteria should be reversed to become positive criteria. This process makes the decision matrix become a positive decision matrix.	$\mathrm{x_{0j}} = \max_{i} \tilde{\mathrm{x}}_{\mathrm{ij}}.$ $for\ beneficial\ criteria$ $\mathrm{x_{0j}} = \min_{i} \mathrm{x_{ij}}.$ $for\ non-beneficial\ criteria$	(7) (8)
4	Fuzzy decision matrix normalization:	$x_{ij}^* = \frac{\tilde{\mathrm{x}}_{\mathrm{ij}}}{\sum^{m} \tilde{}}$	(9)

Step	Description	Equations
	In this step, by using Equation 9, the decision matrix is converted into a normal matrix.	
5	Weighting the normal decision matrix: In this step, we multiply the values of the normal matrix by the weights of the criteria to obtain the weighted matrix.	$\hat{x}_{ij} = \tilde{x}^{*}_{ij} * \tilde{w}_{i}$ (10)
6	Calculation of ARAS index (S)	$\tilde{S}_i = \sum \hat{x}_{ij}$ (11)
7	Calculation of the degree of desirability of alternatives (in percentage)	$S_i = \frac{l+m+u}{3}$ (12) $k_i = \frac{S_i}{S_0} * 100$ (13)

By following these steps, the fuzzy ARAS method enables a systematic and comprehensive evaluation of options, accounting for both quantitative and qualitative factors and addressing uncertainties inherent in decision-making processes.

Table 6: Fuzzy comparison scale in pairwise comparison matrix (Patil and Kant, 2014).

Fuzzy Number	Linguistic Variable	Membership Function
$\tilde{1}$	Equally Important	(1, 1, 3)
$\tilde{3}$	Weakly Important	(1, 3, 5)
$\tilde{5}$	Strongly More Important	(3, 5, 7)
$\tilde{7}$	Very Strongly Important	(5, 7, 9)
$\tilde{9}$	Extremely More Important	(7, 9, 11)

3.4 Research limitations and challenges

Understanding any new concept requires extensive qualitative studies to broaden relevant knowledge and recognize its impacts. Regarding IoT technology and the IPD method in supply chain management, proper qualitative research and emphasis on practical applications are essential to thoroughly comprehend how these technologies affect different aspects of the construction industry, particularly in supply chain management, to support sustainable economic, social, and environmental development. This area still needs to be explored in the Iranian construction sector. This research has identified challenges in Iran's construction industry, including the persistent downturn, reliance on traditional building methods and experienced contractors, economic constraints, engineers' reluctance to update their expertise, and a shortage of skilled professionals. It also underscores the necessity for regulatory, standardization, procedural changes, project communication issues, trust deficits, security concerns, and the lack of processes rooted in sustainable development and modern technology principles, including lean construction.

However, a shift in stakeholders' attitudes and initial motivation among industry leaders and decision-makers, driven by recognizing the simplicity and advantages of integrating IoT and IPD in supply chain management, could enable the construction industry to capitalize on these technologies' positive potential in pursuing sustainable development objectives.

4. FINDINGS AND DISCUSSION

4.1 Identification of criteria, sub-criteria (Phase I)

Table 7 presents the main criteria and sub-criteria, and the codes assigned to these two criteria. The indicators derived from library studies and in-person interviews with experts and industry professionals are categorized into five main groups (main criteria) and 21 sub-criteria. Based on these criteria and the sub-criteria, the research objectives will be screened and prioritized.

An expert questionnaire, comprising 15 questions, has been prepared to evaluate the importance of factors and their impact. This crucial task will be carried out by a diverse group of participants, including contractors, academic researchers, project managers, design engineers, and industry experts. These participants, identified through personal interviews and workshops, are not just practitioners in the field of construction project management, but esteemed experts whose contributions are highly respected and valued.

Table 7: Evaluation criteria and codes.

Main Criteria (Code)	**Sub-Criteria (Evaluation Criteria) (Code)**	**Influence**	**Reference(s)**
Project Management (C_1)	Adoption of IoT and IPD by senior executives (C_{1-1})	Beneficial criteria	(Sallam et al., 2023; Lane and Kant, 2021; Rash et al., 2023)
	Solving legal problems/intellectual property (C_{1-2})	Beneficial criteria	(Choi et al., 2004; Amankwa et al., 2022)
	Resolving ambiguity in responsibilities (C_{1-3})	Beneficial criteria	(Ali et al., 2020; Abdel-Basset and Mohamed, 2018)
	Participation of project stakeholders (employer, consultant and contractor) (C_{1-4})	Beneficial criteria	(Amade et al., 2016; Saad et al., 2022)
Technical (C_2)	Formulation of regulations and standardization (C_{2-1})	Beneficial criteria	(Tokar and Swik, 2019; Pagell and Shevchenko, 2013)
	Project schedule based on lean thinking (Last Planner System) (C_{2-2})	Beneficial criteria	(Cho and Ballard, 2011; Dave et al., 2016; Schimanski et al., 2020)
	Creating a dynamic model to change the technical specifications of the project (required materials, construction method) (C_{2-3})	Beneficial criteria	(Bajomo et al., 2022; Feng, 2012)
	Solving the problems of providing information and input data to the software (C_{2-4})	Beneficial criteria	(Lin, 2022; Khan et al., 2023)
Economic (C_3)	The cost of purchasing software and hardware (C_{3-1})	Cost criteria	(Ali et al., 2020; Kucera, 2017)
	Sustainable financing for the electronic supply chain (C_{3-2})	Beneficial criteria	(Zhao, 2023; Li, 2022)
	Actual cost estimation and operational risk level determination (C_{3-3})	Beneficial criteria	(Zhao, 2023; Zhao, 2022; Zivkovic and Komatina, 2017)
	Economic crises, such as exchange rate fluctuations and changes in the country's currency (C_{3-4})	Cost criteria	(Morina et al., 2020; Ke et al., 2018)
	Delay in supplying the required materials and equipment from the employer (C_{3-5})	Cost criteria	(Gebrehiwet and Lou, 2017; Larsen et al., 2015; Al-Kharashi and Skitmore, 2009)
Support (C_4)	Removing restrictions on the supply of materials, machinery and equipment (C_{4-1})	Beneficial criteria	(Shekarian et al., 2009; Shakerian et al., 2023; Sinito et al., 2023)

Main Criteria (Code)	Sub-Criteria (Evaluation Criteria) (Code)	Influence	Reference(s)
	Establishing a culture of IoT and IPD acceptance by employees (C_{4-2})	Beneficial criteria	(Khanna et al., 2021; Salim and Mahjoob, 2020; Li et al., 2024)
	New designs and competitive methods (C_{4-3})	Beneficial criteria	(Ali et al., 2020; Farahani et al., 2014)
	Safety (C_{4-4})	Beneficial criteria	(Canter, 2008; El-Hijazi and El-Amili, 2020)
Growth & Development (C_5)	Development of on-time delivery capabilities (C_{5-1})	Beneficial criteria	(Carvalho et al., 2022; Cardoso et al., 2015)
	Developing reliable raw material suppliers (C_{5-2})	Beneficial criteria	(Agrawal, 2014; Shojae et al., 2018)
	Transparency (C_{5-3})	Beneficial criteria	(Budler et al., 2023; Schafer, 2023; Montecchi et al., 2021)
	Automatic data collection and encryption (C_{5-4})	Beneficial criteria	(Lin, 2022; Shittu and Nabil, 2023)

4.2 Prioritization of criteria and sub-criteria (Phase II)

The second phase of this study involved constructing a pairwise comparison matrix for the survey experts to evaluate their judgments. A fuzzy scale was used in Table 4 to determine the relative priority importance of the criteria. The main criteria and sub-criteria weights were then obtained using the fuzzy SWARA method based on Table 3 and following specific steps. As a result, the associated fuzzy weights of the criteria and sub-criteria are explained in Table 8. The de-fuzzified weights and the relative and normalized weights of the investigated criteria are shown in Table 9.

The main criteria, which include project management, technical factors, economic factors, support factors, and growth and development factors, were compared pairwise along with sub-criteria for each main criterion. The rankings were determined using the fuzzy SWARA method.

Based on Table 9 and Figure 8, obtained from the evaluation and comparison of the main criteria, the economic factors criterion has the highest weight (0.383), followed by project management (0.248), technical factors (0.168), growth and development factors (0.117), and support factors (0.084). This indicates that economic factors are the most influential in evaluating parameters derived from IPD and IoT integration on supply chain performance in construction with a focus on sustainable development.

Within the economic factors criterion, the sub-criteria provide a detailed understanding of the factors influencing supply chain performance in the construction industry. The criterion of sustainable financing for the electronic supply chain, with a weight of 0.422, is the most influential. This is followed by the criterion of economic crises, such as currency fluctuations and changes in the national currency (0.251), which ranks second. The criteria of delays in supplying materials and equipment by the client, accurate cost estimation, determining operational risk levels, and software and hardware procurement costs, with normalized weights of 0.156, 0.099, and 0.071, respectively, also play significant roles in the evaluation process.

Regarding the project management criterion, which ranks second after economic factors, the most crucial sub-criterion is the acceptance of IoT and IPD by senior managers. This sub-criterion, with a normalized weight of 0.458, is essential in examining the parameters resulting from the integration of IPD and IoT on supply chain performance in the construction industry with a sustainable development approach. The sub-criteria of stakeholder participation (client, consultant, and contractor), clarification of responsibilities, and resolution of legal/intellectual property issues rank second to fourth, respectively, highlighting the need for a collaborative approach in project management.

Table 8: Fuzzy weights of criteria and sub-criteria.

Criteria	Comparative Importance of Average Values s_j			Coefficient $k_j = s_j + 1$			Recalculated Weight $q_j = x_{j-1}/k_j$			Recalculated Weight $w_j = q_j/\sum_{k=1}^{n} \tilde{q}_k$		
C_3	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.311	0.410	0.606
C_1	0.286	0.567	1.500	1.286	1.567	2.500	0.400	0.638	0.778	0.124	0.262	0.471
C_2	0.286	0.567	1.500	1.286	1.567	2.500	0.160	0.407	0.605	0.050	0.167	0.367
C_5	0.286	0.667	1.500	1.286	1.667	2.500	0.064	0.244	0.470	0.020	0.100	0.285
C_4	0.268	0.667	1.500	1.286	1.667	2.500	0.026	0.147	0.366	0.008	0.060	0.222
C_{1-1}	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.348	0.479	0.616
C_{1-4}	0.400	0.800	1.500	1.400	1.800	2.500	0.400	0.400	0.556	0.154	0.266	0.440
C_{1-3}	0.286	0.567	1.500	1.286	1.567	2.500	0.160	0.335	0.555	0.061	0.170	0.342
C_{1-2}	0.667	1.000	1.500	1.667	2.000	2.500	0.064	0.177	0.333	0.025	0.085	0.205
C_{2-3}	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.386	0.513	0.616
C_{2-1}	0.400	0.900	1.500	1.400	1.900	2.500	0.400	0.526	0.714	0.155	0.270	0.440
C_{2-2}	0.400	0.900	1.500	1.400	1.900	2.500	0.160	0.277	0.510	0.062	0.142	0.314
C_{2-4}	0.400	0.900	1.500	1.400	1.900	2.500	0.064	0.146	0.364	0.025	0.075	0.224
C_{3-2}	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.348	0.444	0.606
C_{3-4}	0.400	0.700	1.500	1.400	1.700	2.500	0.400	0.558	0.714	0.139	0.261	0.433
C_{3-5}	0.400	0.700	1.500	1.400	1.700	2.500	0.160	0.346	0.510	0.056	0.154	0.309
C_{3-3}	0.400	0.800	1.500	1.400	1.800	2.500	0.064	0.192	0.364	0.022	0.085	0.221
C_{3-1}	0.286	0.533	1.500	1.286	1.533	2.500	0.026	0.125	0.283	0.009	0.056	0.172
C_{4-1}	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.451	0.527	0.616
C_{4-3}	0.667	1.000	1.500	1.667	2.000	2.500	0.400	0.500	0.600	0.180	0.264	0.369
C_{4-4}	0.667	1.000	1.500	1.667	2.000	2.500	0.160	0.250	0.360	0.072	0.132	0.222
C_{4-2}	0.400	0.700	1.500	1.400	1.700	2.500	0.064	0.147	0.257	0.029	0.078	0.158
C_{5-1}	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	0.370	0.476	0.616
C_{5-2}	0.400	0.800	1.500	1.400	1.800	2.500	0.400	0.556	0.714	0.148	0.264	0.440
C_{5-3}	0.286	0.667	1.500	1.286	1.667	2.500	0.160	0.333	0.555	0.059	0.159	0.342
C_{5-4}	0.286	0.567	1.500	1.286	1.567	2.500	0.064	0.213	0.432	0.024	0.101	0.266

For the technical factors criterion, which ranks third among the main criteria, the sub-criteria of creating a dynamic model for changing project technical specifications (required materials, construction method) (0.470), drafting regulations and standardization (0.268), scheduling projects based on lean thinking (final planning system) (0.161), and resolving issues in providing input data to the software (0.101) are the most influential sub-indicators in examining the technical factors.

Regarding the growth and development factors criterion, the sub-criterion of developing timely delivery capabilities ranks first with a weight of 0.448. The sub-criteria of developing reliable raw materials suppliers, transparency, automatic data collection, and encryption rank second to fourth with normalized weights of 0.261, 0.171, and 0.120, respectively.

Finally, the support factors criterion, which is the last criterion in the prioritization of the main criteria, includes sub-criteria such as resolving material, machinery, and equipment supply constraints, fostering a culture of IoT and IPD acceptance among employees, new plans and competitive methods, and safety. The comparative analysis of these sub-criteria reveals that the integration of IoT and IPD in the supply chain aligns with sustainable development, with weights of 0.515, 0.263, 0.137, and 0.085, respectively, ranked as top four most critical and influential sub-indicators of the support factors criterion.

As mentioned, economic factors are the most crucial among the criteria evaluated. Generally, the sub-criteria of the economic criterion, such as C_{3-2},C_{3-4} and C_{3-5}, are ranked first, third, and sixth out of the 21 criteria reviewed. This underscores the importance of economic factors in integrating IPD and IoT in construction supply chain management. On the other hand, criterion C_{1-1} is the second most important in the overall ranking, highlighting the need for senior project managers and decision-makers to embrace new IoT and IPD technologies. The significance of this criterion is such that, if managers neglect the use of new technologies in the construction industry, this could result in substantial national capital waste and impact the country's economy. Therefore, besides economic considerations, the outlook of senior project managers and decision-makers is crucial to complete a project.

Table 9: Normal and relative weight of the investigated criteria.

Evaluation Criteria	Aggregated Weights			De-fuzzified	Normalized Weights	Relative Weights	Rank	
							Group	Final
C_1	0.124	0.262	0.471	0.286	0.248		2	
C_{1-1}	0.384	0.479	0.616	0.493	0.458	0.114	1	2
C_{1-2}	0.025	0.085	0.205	0.105	0.098	0.024	4	15
C_{1-3}	0.061	0.170	0.342	0.191	0.178	0.044	3	9
C_{1-4}	0.154	0.266	0.440	0.287	0.266	0.066	2	5
C_2	0.050	0.167	0.367	0.194	0.168		3	
C_{2-1}	0.155	0.270	0.440	0.288	0.268	0.045	2	8
C_{2-2}	0.062	0.142	0.314	0.173	0.161	0.027	3	13
C_{2-3}	0.386	0.513	0.616	0.505	0.470	0.079	1	4
C_{2-4}	0.025	0.075	0.024	0.108	0.101	0.017	4	18
C_3	0.311	0.410	0.606	0.442	0.383		1	
C_{3-1}	0.009	0.056	0.172	0.079	0.071	0.027	5	14
C_{3-2}	0.348	0.444	0.606	0.466	0.422	0.162	1	1
C_{3-3}	0.022	0.085	0.221	0.110	0.099	0.038	4	11
C_{3-4}	0.139	0.261	0.433	0.278	0.251	0.096	2	3
C_{3-5}	0.056	0.154	0.309	0.173	0.156	0.060	3	6
C_4	0.008	0.060	0.222	0.097	0.084		5	
C_{4-1}	0.451	0.527	0.616	0.531	0.515	0.043	1	10
C_{4-2}	0.029	0.078	0.158	0.088	0.085	0.007	4	21
C_{4-3}	0.180	0.264	0.369	0.271	0.263	0.022	2	16
C_{4-4}	0.072	0.132	0.222	0.142	0.137	0.011	3	20
C_5	0.020	0.100	0.285	0.135	0.117		4	
C_{5-1}	0.370	0.476	0.616	0.487	0.448	0.052	1	7
C_{5-2}	0.148	0.264	0.440	0.284	0.261	0.031	2	12
C_{5-3}	0.059	0.159	0.342	0.187	0.171	0.020	3	17
C_{5-4}	0.024	0.101	0.266	0.130	0.120	0.014	4	19

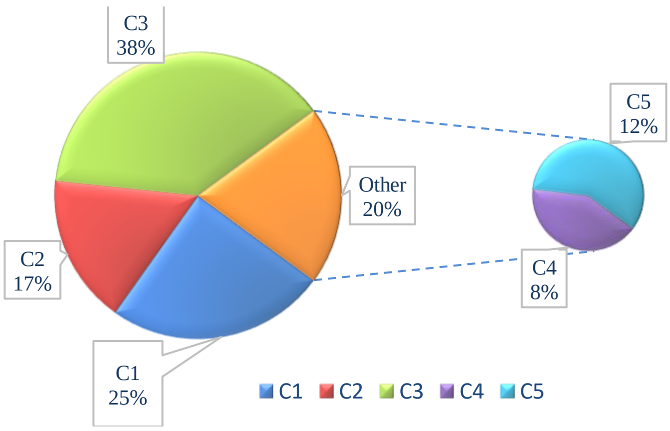

Figure 8: Comparison of main criteria.

4.3 Prioritization of alternatives (Phase III)

In this phase, the alternatives are prioritized using the fuzzy ARAS method based on the decision matrix and final weights obtained from the previous phase via the fuzzy SWARA technique. The first step involves forming the decision matrix according to the steps outlined in Table 5. In the fuzzy ARAS method, the ideal value for the criteria is selected using Equations 7 and 8, denoted as A_0. The ideal value is the highest for positive criteria, and for negative criteria, it is the lowest (Table 10). Negative criteria are converted to positive using Equation 6. The normalization matrix is then formed by summing the columns of the decision matrix (with all positive criteria) and dividing each fuzzy number by its column sum (Table 9).

In this study, all criteria except C_{3-1},C_{3-3}, and C_{3-4} are positive. The normalized matrix is then multiplied by the weights obtained from the fuzzy SWARA method (Table 11), and the fuzzy score for each criterion is calculated using Equation 11. In other words, Table 11 illustrates the weighted normalized fuzzy decision matrix created by multiplying the elements of the normalized matrix (shown in Table 10) by the criteria weights derived from the fuzzy SWARA method. The fuzzy scores are converted to crisp values using Equation 12, and the desirability percentage for each criterion is determined using Equation 13. The results are presented in Table 13 and illustrated in Figure 9.

Table 10: Fuzzy decision matrix.

Alternative	**Criteria**									
	C_{1-1}			C_{1-2}			…	C_{5-4}		
A_0	6.600	8.600	10.600	4.200	6.200	8.200	…	5.000	7.000	9.000
A_1	2.600	4.600	6.600	3.400	5.400	7.400	…	2.600	4.600	6.600
A_2	4.600	6.600	8.600	2.600	4.600	6.600	…	2.200	4.200	6.200
A_3	4.200	6.200	8.200	1.000	3.000	5.000	…	5.000	7.000	9.000
A_4	6.600	8.600	10.600	4.200	6.200	8.200	…	3.000	5.000	7.000
A_5	5.400	7.400	9.400	3.800	5.800	7.800	…	5.000	7.000	9.000

Table 11: Normalized fuzzy decision matrix.

Alternative	**Criteria**									
	C_{1-1}			C_{1-2}			…	C_{5-4}		
A_0	0.122	0.205	0.353	0.097	0.199	0.427	…	0.107	0.201	0.395
A_1	0.048	0.110	0.220	0.079	0.173	0.385	…	0.056	0.132	0.289
A_2	0.085	0.157	0.287	0.060	0.147	0.344	…	0.047	0.121	0.272
A_3	0.078	0.148	0.273	0.023	0.096	0.260	…	0.107	0.201	0.395
A_4	0.122	0.205	0.353	0.097	0.199	0.427	…	0.064	0.144	0.307
A_5	0.100	0.176	0.313	0.088	0.186	0.406	…	0.107	0.201	0.395

Table 12: Weighted normalized fuzzy decision matrix.

Alternative	**Criteria**									
	C_{1-1}			C_{1-2}			…	C_{5-4}		
A_0	6.600	8.600	10.600	4.200	6.200	8.200	…	0.003	0.020	0.105
A_1	2.600	4.600	6.600	3.400	5.400	7.400	…	0.001	0.013	0.077
A_2	4.600	6.600	8.600	2.600	4.600	6.600	…	0.001	0.012	0.072
A_3	4.200	6.200	8.200	1.000	3.000	5.000	…	0.003	0.020	0.105
A_4	6.600	8.600	10.600	4.200	6.200	8.200	…	0.002	0.015	0.082
A_5	5.400	7.400	9.400	3.800	5.800	7.800	…	0.003	0.020	0.105

Table 13: Ranking results from the fuzzy ARAS analysis.

Alternative	ARAS Index $(\tilde{S}_i)$			De-fuzzified $\tilde{S}_i$	k_i (%)	Final Rank
	s_{il}	s_{im}	s_{iu}			
A_0	0.353	1.044	3.527	1.641	-	-
A_1	0.152	0.650	2.677	1.160	70.66	4
A_2	0.244	0.757	2.483	1.161	70.77	3
A_3	0.256	0.770	2.406	1.144	69.71	5
A_4	0.322	0.893	2.643	1.286	78.36	2
A_5	0.309	0.887	2.681	1.293	78.77	1

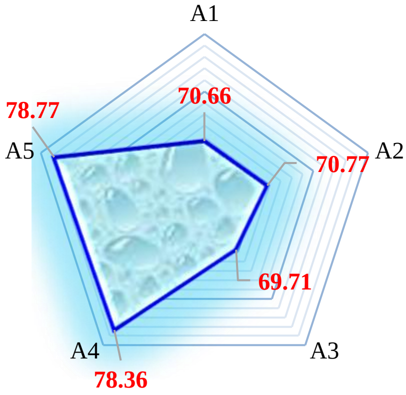

Figure 9: Radar chart to compare the studied alternatives.

The findings indicate that options for project cost and time savings, operational efficiency, supply chain visibility, remote operations, and augmented reality hold the highest priority based on the evaluated criteria. Project cost and time savings, along with operational efficiency, are more highly prioritized than other options from the perspectives of project management, technical factors, economic factors, and factors influencing the growth and development of the construction industry. The support factor is most important for the supply chain visibility option. Additionally, the economic criterion suggests that remote operations are crucial in reducing project costs and time (Figure 10).

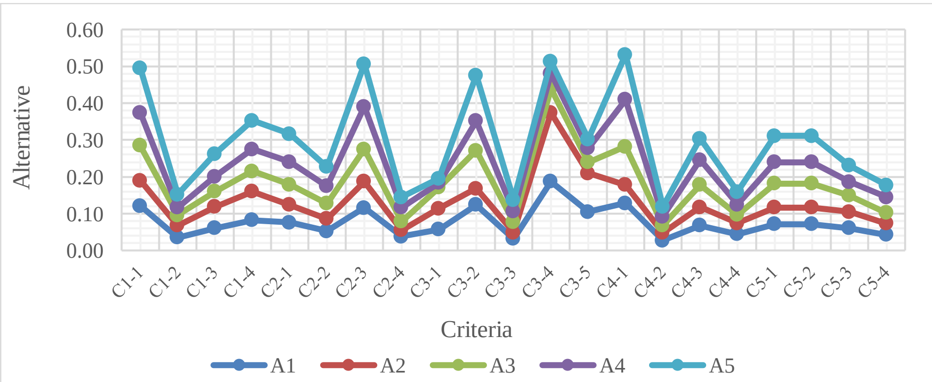

Figure 10: Changes of alternatives according to each sub-criterion.

Moreover, the simultaneous application of IPD and IoT in supply chain management lowers ongoing costs in construction projects. It provides a new and practical perspective on supply chain management, improving quality and productivity. In today's world, integrating these two technologies facilitates project management through enhanced monitoring and control and augments the project's reality.

The final prioritization of the studied options shows that operational efficiency project cost and time savings rank first and second, with desirability scores (k) of 78.77% and 78.36%, respectively. The supply chain visibility, remote operations, and augmented reality options rank next, with desirability scores of 70.77%, 70.66%, and 69.71%, respectively. These rankings are based on the criteria for integrating IPD and IoT in supply chain performance in the construction industry with a sustainable development approach (Figure 11).

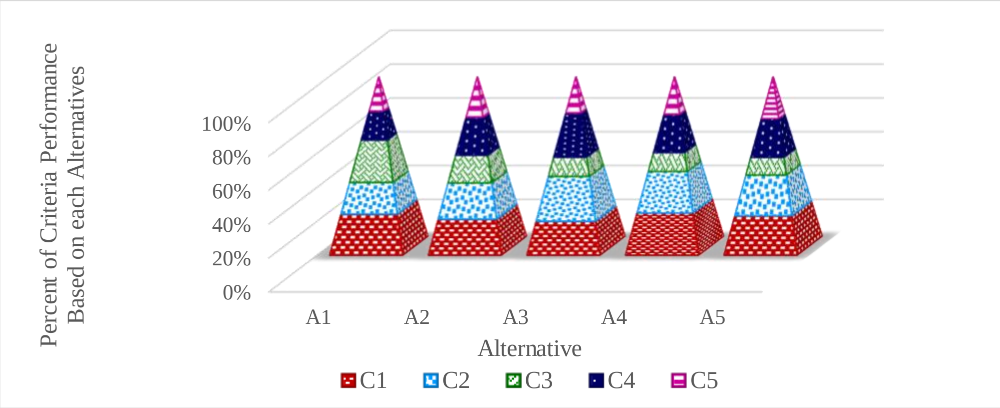

Figure 11: Ranking of alternatives based on each main criterion.

5. CONCLUSION

The construction management process in Iran involves dividing projects into stages, estimating cost, time, and resource needs for each phase, and using the Critical Path Method (CPM) to determine the sequence of activities. Parts of the work are either outsourced or managed internally, with the start of each phase determined by the schedule and workload. The Project Control Department monitors progress, ensuring alignment with the schedule and budget.3

Traditional supply chain methods in Iran's construction industry focus primarily on project completion, often neglecting important criteria such as reducing execution time, saving resources, enhancing performance, and improving quality. This can lead to significant scheduling challenges. Integrating Integrated Project Delivery (IPD) with modern technologies like the Internet of Things (IoT) can address these challenges, contributing to project success and sustainable development.

The study aims to create a framework for using IPD and IoT together in supply chain management, particularly in the context of sustainable development. It was conducted in three phases:

Phase I: Identifying effective parameters from the integration of IPD and IoT in the construction supply chain.

Phase II: Using the fuzzy SWARA method to calculate the importance of each criterion and sub-criterion.

Phase III: Prioritizing objectives using the fuzzy ARAS method and proposing solutions.

In the first phase, the study identifies key parameters and categorizes them into main and sub-criteria, validated by experts. The second phase involved determining the relative importance of these criteria with economic factors ranking highest, followed by project management, technical factors, growth and development factors, and support factors. Economic factors, particularly sustainable financing for the electronic supply chain, were found to be the most influential. In the final phase, the fuzzy ARAS method was used to prioritize the objectives. The results highlighted that project cost, time savings, and operational efficiency were the most critical factors, with operational efficiency and project cost ranking first and second in terms of desirability.The findings suggest that improving efficiency and quality in construction projects requires attention to economic stability, management, technical issues, and project support. Despite advances in technology and modern construction management methods globally, Iran's construction industry still largely relies on traditional supply chain management, missing out on significant benefits from IoT and IPD. Successful implementation of these technologies in Iran will require years of effort, detailed planning, and substantial investment.

Despite developing technologies and modern construction management methods in developed and developing countries, Iran's construction industry still largely relies on traditional supply chain management methods, missing significant advancements in IoT and IPD. Nevertheless, successful and proper implementation of IoT and IPD technologies in supply chain management requires years of effort by experts and substantial long-term investment. Detailed and practical planning and implementation in organizations and companies are essential to achieve these goals. The following steps outline the implementation of a combined IPD and IoT model in the Iranian construction industry's supply chain management:

- Propose the initial idea within the company or organization.
- Hold meetings with supply chain management directors.
- Present the topic to the organization and meet with the CEO.
- Conduct studies and consultations on IPD and IoT.
- Develop a plan to organize conferences within the organization.
- Engage senior managers and identify the benefits of lean thinking for integrating IPD and IoT in the supply chain, gaining their support.
- Establish an IPD and IoT planning committee and find experienced and knowledgeable individuals.
- Formulate organizational or company goals and strategies.
- Form planning committees to estimate time, cost, and quality aspects.
- Organize seminars to familiarize organization members with the combined model.
- Establish planning and supply chain sub-departments.
- Implement a pilot project after ensuring readiness.
- Hold a seminar within the organization to review the project's results.
- After achieving favorable results from the pilot project, revise existing processes based on IPD and IoT in supply chain management.
- Develop organizational guidelines.
- Train individuals based on their specialization and related work areas.
- Prepare technical infrastructure and facilitate data exchange between companies.
- Establish a department within the organization and its subsidiaries.

Below are suggestions for future research:

- Evaluation and comparison of the estimation of initial costs necessary for the implementation phase of IoT technology in supply chain management based on lean thinking from two micro and macro perspectives.
- Evaluating the applicability and feasibility of employing an Internet of Things technology combining cloud computing with IPD approaches in construction supply chain management.
- Inspection of required standards and checking whether the current regulations comply to facilitate better IoT and IPD integration with construction industry supply chain management.

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