

## **Presenting a framework for AIoT-based supply chains in the construction industry**

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### **Abstract**

The digital transformation of construction enables engineers to harness the power of technology-based data to help make more accurate decisions. IoT sensors collect details about temperature, fluid levels, vibrations, etc. Similarly, using artificial intelligence along with the Internet of Things provides high analytical power to evaluate the big data resulting from the Internet of Things. Therefore, understanding the dimensions of supply chains based on these technologies can help to facilitate and empower supply chain processes in this key industry. This research presents a framework by identifying the dimensions and key components of success in the supply chain based on the artificial intelligence of things (AIoT). This framework identifies key areas of the smart construction supply chain. Properly understanding this framework can be a valuable guide for the optimal implementation of smart supply chain processes.

**Keywords:** construction industry, artificial intelligence of things (AIoT), Internet of Things, supply chain based on AIoT

### **1- Introduction**

With the time, new and fresh concepts have been formed in different fields, each of which has created changes and effects in human life, with the growth of the use of the Internet and digital tools, the Internet of Things was first proposed by Kevin Ashton. In this sense, everything, including objects, has a digital identity for itself and allows central computers that are connected to them to organize and manage them. The Internet of Things is one of the new and popular technologies in civil engineering, thanks to which the way engineering projects are carried out will change completely, the digital transformation in construction enables engineers to use the power of technology-based data. Use to help make more accurate decisions (Aliahmadi & Nozari, 2022).

In general, the applications of the Internet of Things and other transformative technologies such as artificial intelligence are among the newest and most up-to-date solutions in the construction industry, which by providing the possibility of significant data mining and information processing, cause a significant development of civil infrastructure and improve the quality of the structure. In general, IOT or Internet of Things in the construction industry includes sensors or sensors and the communication between them that connects different parts of a structure with a network connection (Nozari et al., 2023). This information, which includes a large amount of data, is collected and analyzed to be used in future decisions for a structure. For this purpose, the Internet of Things links physical items such as machines, equipment, tools,

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and even consumables with digital information and processes. By equipping physical items with sensors, data can be automatically recorded and transferred to the software system (Nahr et al. 2021, Nozari et al., 2021). The software guides the projects, which causes engineering measures to be carried out with urgency and in the shortest time, and even helps to predict future events and also better documentation of past activities.

Various methods have been proposed to solve the problems that have existed in the building since ancient times, but with the Internet of Things and smart systems such as artificial intelligence, this has been facilitated. Because in a smart building by placing various sensors and connecting various equipment such as water and energy meters, lighting, security, heating and cooling systems, air conditioning, etc., which are equipped with relevant sensors and data analysis. The results obtained from the equipment are helped by the application software to improve the performance of the building (Koe et al., 2023).

The construction industry is now poised to experience fundamental changes that will lead to increased productivity, safety, improved processes, and the use of new tools. The Internet of Things (IoT) enables cost-effective communication through simple and low-power sensors. Artificial intelligence also gives high analytical power to the data obtained from the Internet of Things. Technologies such as blockchain also contribute to data transparency and data security (Chenet et al., 2023)7]. As these technologies are expanding, their effects on the transformation of the construction industry are becoming more significant. IoT allows all stakeholders of a project to know in real time what is happening at every stage of the project from the planning phase to construction. Another use of IoT is to use it in the operation phase to know the performance of the building. Also, by using smart learning tools, data can be checked and the best decisions can be made (Aliahmadi et al., 2013).

The construction industry is heavily influenced by deadlines and targets. Falling behind schedule in a project leads to additional costs, so activities should be carried out as much as possible according to the schedule. IoT leads to increased productivity through greater efficiency and readiness (Tortorella et al., 2023). IoT allows more time to interact with project owners and provide new ideas to improve project delivery and customer satisfaction. Sufficient materials and materials must always be available for the project to run smoothly. However, the late supply of materials can be attributed to poor timing due to human error. Material supply can be improved by IoT and appropriate sensors (Maqbool et al., 2023).

By using these revolutionary technologies, you can easily track the location of any materials and equipment at any time. Therefore, there is no need to entrust the inspection of the workshop to a security organization. With the use of the Internet of Things and artificial intelligence, the world of business is changing rapidly. The Internet of Things is gathering a significant amount of data from many sources. On the other hand, collecting, processing, and analyzing data received from countless devices is a very difficult task. Artificial intelligence adds this capability to the Internet of Things. Therefore, the simultaneous use of this technology which is called artificial intelligence of things (AIoT), can add many capabilities to the construction industry.

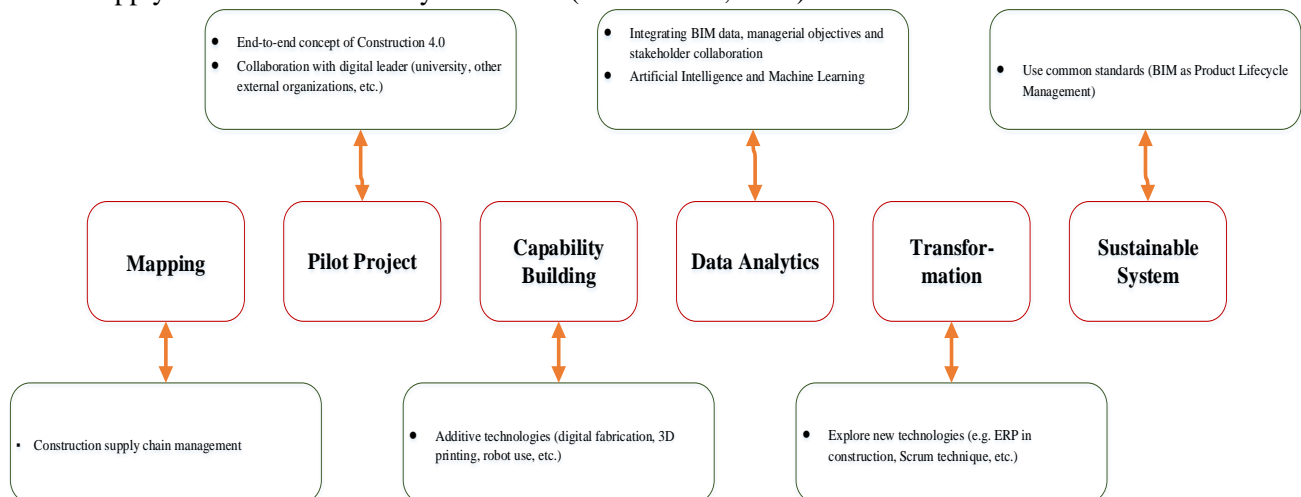
In this research, an effort has been made to examine the dimensions, components, and key indicators of supply chains empowered with these technologies, and provide a conceptual framework that shows the cause-and-effect relationships of effective parameters for the implementation of an AIoT-based supply chain in the construction industry. The main innovation of this paper is the calculation of these parameters and the establishment of cause and effect relationships and their prioritization exclusively in the construction industry, which can help to make all processes smarter in this vital industry. A correct understanding of these relationships and checking their priorities can show an effective guide for the proper implementation of processes in these industries.

The structure of this paper is as follows. In the second part, the literature review is presented. In the third part, the research method is proposed. Analytical results are presented in the fourth part, and finally, the conclusion is presented in the fifth part.

## **2- Literature Review**

The fourth industrial revolution or Industry 4.0, which we are currently implementing in the world, is characterized by the application of information and communication technology in industry. Systems and computers with third revolution technology expanded with network connectivity. This extension provided the possibility of communication with other input and output devices (Osunsanmi et al., 2022). The fourth industrial revolution increases a more comprehensive, comprehensive and comprehensive approach in the field of production and gives business owners the opportunity to control various aspects of production and to improve productivity, production and increase the rate of growth (Rawlins et al., 2022). This is possible with better communication with the digital world. In the concept of Industry 4.0, the two concepts of Internet of Things (IOT) and Industrial Internet of Things (IIOT) are very important. Industrial automation plays a prominent role in the formation of these two concepts (Bose et al., 2022). After the connection between objects in an industrial site is established and a network is created using software, distributed control systems and industrial automation can be connected to each other and receive a connection from cloud computing to a higher level of automation. let's get Connecting industrial automation systems to each other makes the control process easier and applied in a wider range. The possibility of remote communication and movement is also one of its advantages (Lin et al., 2022). Figure 1 shows the concept of construction based on smart technology. Due to the importance of the topic in recent years, many researches have been conducted on the use of these smart technologies in the construction industry. Turner et al. (2020) examined the challenges and opportunities of Industry 4.0 in the construction industry (Turner et al., 2022). Tahmasebinia et al. (2020) examined the development criteria for sustainable construction in Construction Industry 4.0. They showed that more advanced technology in the future could overcome the current limitation of 3D printing and this idea as a common method in house construction (Tahmasebinia et al., 2022). de Almeida Barbosa Franco et al. (2022) showed sustainability in the civil construction sector with the support of Industry 4.0 technologies. The results showed that civil construction with the challenge of reducing the consumption of natural resources, ensuring safe work and optimizing processes, especially manual work is facing However, the inclusion of Industry 4.0 technologies in civil construction allows sensors, robots, modeling and simulation systems, artificial intelligence and drones to increase their productivity, efficiency, safety, strategic management and environment (de Almeida Barbosa Franco et al., 2022).

The use of digital methods in the construction industry has faced significant growth and progress in this century. As the cyber and physical environments have been integrated unprecedentedly with the Internet of Things (IOT). Internet of things and artificial intelligence or their combined technology, i.e. AIoT, have wide applications in various industries (Ghahremani Nahr et al., 2022). Among the sectors where AIoT can have significant effects, we can mention the construction industry, building operation and management, which results in moving towards sustainable development goals. Therefore, considering the significant advantages of AIoT, the use of this technology in various industries, especially the construction industry and its supply chain has been widely welcomed (Nozari et al., 2021).



**Figure 1.** The concept of construction based on smart technology (Hossain et al., 2019)

## 2-1 AIoT in construction industry supply chain management

The combination of these two technologies ie the artificial intelligence of things brings a unique opportunity to promote learning and personalization at the same time. The combination of artificial intelligence and the Internet of Things can continuously influence and improve decision-making performance (Nozari et al., 2021). Artificial intelligence can enable devices to interpret data by themselves and make decisions in real time without any delay caused by data transmission. In general, the combination of these two technologies can provide many advantages in providing powerful solutions for intelligent automation. Figure 2 shows the basic capabilities of AIoT and their basic effects on big data (Cataldo et al., 2022).



**Figure 2.** Capabilities of AIoT and their effects on big data

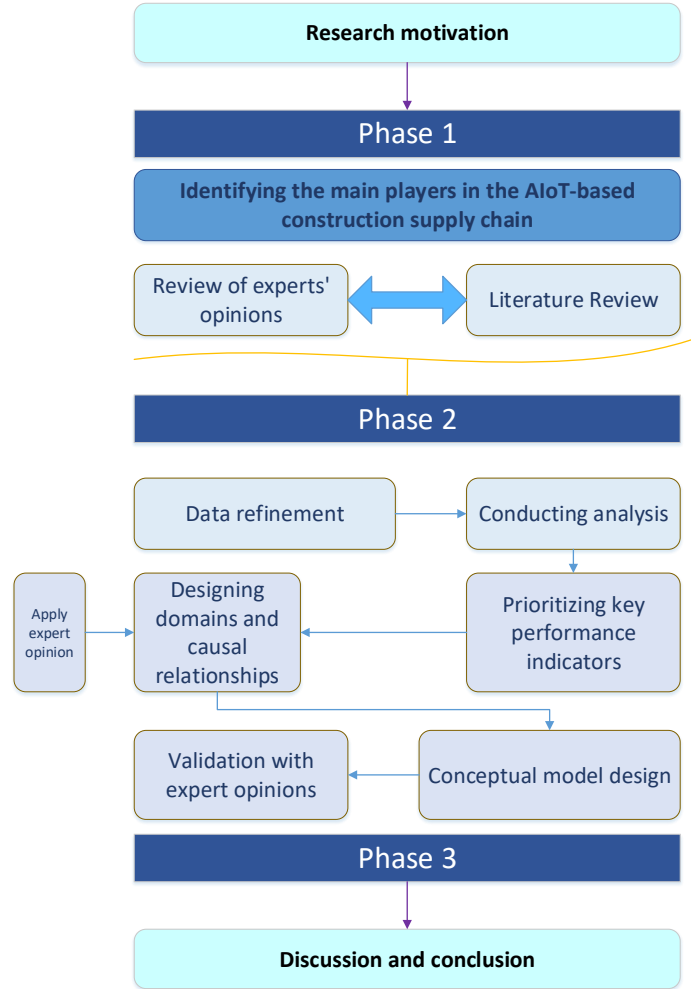
The Internet of Things and artificial intelligence offers a perfect mix of capabilities to organizations, businesses, and industries. Artificial intelligence can optimize the Internet of Things through intelligent decision-making, and the Internet of Things can facilitate the use of artificial intelligence through easier data exchange. Finally, the combination of these two technologies always paves the way for a new era of solutions and experiences, which will undoubtedly have a great impact on transforming businesses and various industries and can create new opportunities (Long et al., 2022).

Increasing productivity, reducing margins, and increasing competition are clear reasons that show that construction companies should turn to AIoT technology and digitization. Today, when data has become an important factor in business, informed decisions are made only on the basis of data. The construction industry is heavily influenced by deadlines and targets (Nozari et al., 2022). Falling behind schedule in a project leads to additional costs, so activities should be carried out as much as possible according to the schedule. AIoT leads to increased productivity through greater efficiency and readiness. With uninterrupted and real-time access to information, you can know the status of each asset, schedule maintenance, and refueling, and turn off unused equipment. In addition, sensors and artificial intelligence analyses can be used to prevent problems and keep customers satisfied. Supply chain management is defined as a gap between theory and practice in construction management (Sun et al., 2022). The implementation of intelligent supply chain management based on AIoT plays a significant role for manufacturers. In a way that is effective in facilitating processes and improving the business environment in different dimensions. Therefore, industries that focus on long-term profitability and sustainability can simultaneously reduce environmental and social risks in their operations by adopting AIoT-based supply chain management and take steps to ensure sustainable operations while providing economic benefits (nozari et al., 2019).

## 3- Research Method

This research is based on a philosophy of interpretive research and critical realism to understand how artificial intelligence technology can affect construction and improvement of supply chain performance. Qualitative data are the two main sources of information for this study. Primary data was collected through semi-structured interviews with 15 subject matter experts. The experts were selected based on their expertise in the subject. Insights were gained from various professional backgrounds. Sampling criteria include the following: (a) familiarity with Internet of Things and artificial intelligence technologies and, accordingly, AIoT, (b) interaction with digital technologies in construction, and (c) professional experience

in the field of business, or technology space. The geographical location of the participants was not limited. Interviewees were contacted through professional contacts and social media contacts. Secondary data was also obtained through literature review in online databases such as Google Scholar and Scencedirect. The analytical framework of the research is shown in Figure 3.



**Figure 3.** Research methodology

As shown in Figure 3, the conceptual framework will be presented in three stages. These stages include data collection, framework design, and finally validation.

In this research, to prioritize the key performance indicators, the hierarchical analysis method based on fuzzy AHP has been used. It is called Russ Mikhailov and it is a non-linear fuzzy decision-making method. In this method, it is assumed that fuzzy pairwise comparisons are triangular fuzzy numbers. The deterministic vector of weight (priority)  $w = (w_1, w_2, \dots, w_n)$  is extracted in such a way that the priority rate is almost within the range of basic fuzzy judgments. In other words, the weights are determined so that equation (1) holds.

$$l_{ij} \leq \frac{w_i}{w_j} \leq u_{ij} \quad (1)$$

Each deterministic weight vector ( $w$ ) with a degree applies to the above fuzzy inequalities, which is measurable through the linear membership function of relation (2) (in terms of the unknown rate):

$$\mu_{ij} \left( \frac{w_i}{w_j} \right) = \begin{cases} \frac{(w_i / w_j) - l_{ij}}{m_{ij} - l_{ij}} & \frac{w_i}{w_j} \leq m_{ij} \\ \frac{u_{ij} - (w_i / w_j)}{u_{ij} - m_{ij}} & \frac{w_i}{w_j} \geq m_{ij} \end{cases} \quad (2)$$

Considering the specific form of the membership functions, the fuzzy prioritization problem becomes a nonlinear optimization problem in the form of Equation (3).

$\max \lambda$

*Subject to :*

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0$$

$$(u_{ij} - m_{ij})\lambda w_j + w_j - u_{ij} w_j \leq 0 \quad (3)$$

$$i = 1, 2, \dots, n-1, \quad j = 2, 3, \dots, n, \quad j > i$$

$$\sum_{k=1}^n w_k = 1, \quad w_k > 0, \quad k = 1, 2, \dots, n$$

Considering the non-linearity of relation (3), it is obvious that it is not possible to solve it without using software. Therefore, Lingo software was used to solve the models created in this research. Positive optimal values for the  $\lambda$  index indicate that all weight ratios are fully applied in the initial judgment, but if this index is negative, it can be understood that the fuzzy judgments are highly inconsistent and the weight ratios are approximately being applied.

#### 4- Conceptual framework

Beyond general discussions about the potential or requirements of AIoT in supply chain management in construction, which seems to have been the main focus in the literature of this industry, deeper analyzes are currently underway to derive specific requirements and implementation conditions for Special programs are required. For example, an asset tokenization program for crowdfunding development projects by private investors will have different requirements than an IoT and AI-based off-site component supply tracking program or smart contract by a public customer. This encourages and facilitates early adopters of the technology. Along with different organizational characteristics (e.g. public/private clients, investors, contractors and SMEs), this research should consider different supply chain characteristics of different sectors (e.g. building, civil, energy and infrastructure). For this reason, in this research, the data were first analyzed through thematic content analysis and were grouped in the form of SWOT analysis along with the secondary data. SWOT analysis is a business management tool that can be used to evaluate new technologies or directions.

In this regard, the data extracted from the literature was analyzed using experts' opinions, and the refined data was used for SWOT analysis. These data are shown in four sections, strengths, weaknesses, opportunities and threats in Table 1.

**Table . SWOT analysis for AIoT-based construction supply chain**

<b>Strengths</b>	<b>Weaknesses</b>
<ul style="list-style-type: none"> <li>-Increased data traceability</li> <li>-Increased data transparency</li> <li>-Smooth handover of data</li> <li>-Data interoperability</li> <li>-Clear and time-stamped accountability chain</li> <li>-Immutability and tamper-less ledger of transactions</li> <li>-Able to skip the intermediaries (middlemen)</li> </ul>	<ul style="list-style-type: none"> <li>-Robust data validation (proof-of-stake) systems are necessary</li> <li>-Private blockchains cannot communicate with each other</li> <li>-Lack of awareness at senior management level</li> <li>-Lack of skilled human resources</li> <li>-Lack of understanding of requirements for different application opportunities</li> <li>-Lack of legal foundations/regulations</li> <li>-Lack of industry standards for blockchain</li> <li>-Insufficient evidence on the business case</li> </ul>
<b>Opportunities</b>	<b>Threats</b>
<ul style="list-style-type: none"> <li>-Large and public clients will be the primary beneficiaries of the technology</li> <li>-The trust layer just above the Internet for digital transactions</li> <li>-Stronger government involvement to legitimize the implementation and usefulness</li> <li>-Faster financing and allocation of payments in projects</li> <li>-Protected IP rights</li> <li>-Increased capital movement and investments</li> <li>-New business model enablement</li> <li>-True sharing economy</li> </ul>	<ul style="list-style-type: none"> <li>-Energy management and use</li> <li>-Powerful organizations and governments trying to dominate and control the blockchain environment</li> <li>-Lack of governance in P2P transactions</li> <li>-Lack of involvement from professional institutions in policy-making</li> <li>-Traditional culture and lack of innovativeness</li> <li>-The existing digital difference between large organizations and SMEs may worsen</li> </ul>

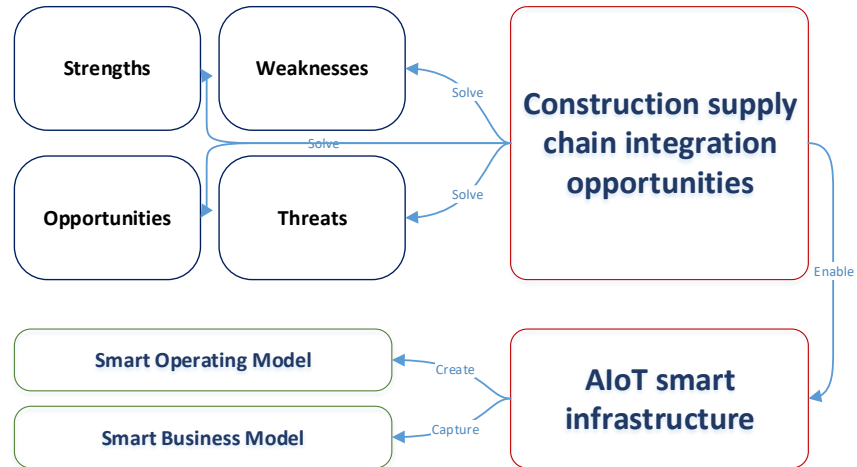
The refined table of SWOT analysis by experts overlaps with the analyzes made by some researchers.

Based on the findings from the SWOT analysis, the preparation of AIoT-based construction supply chains requires strong conceptualization and development of operational processes aligned with stakeholder roles and responsibilities regarding potential use cases that can transform the construction industry through integrated digital commerce.

Automation in the construction supply chain increases the speed of the processes significantly. With the development of the Internet of Things and the formation of smart construction, the need to implement a smart supply chain in these future businesses is strongly felt. In a smart construction, all procedures need to be done intelligently. The Internet of Things plays a very prominent role in the supply chain. With the advancement of the Internet of Things, supply chains are also becoming more modern and capable. Of course, the existence of various challenges in the supply of basic goods in an active construction shows that chain services still need to evolve and improve. Anticipating needs in advance will improve services. Information technology, Internet of things and data processing are among the topics that make the processes of goods supply and logistics to improve more.

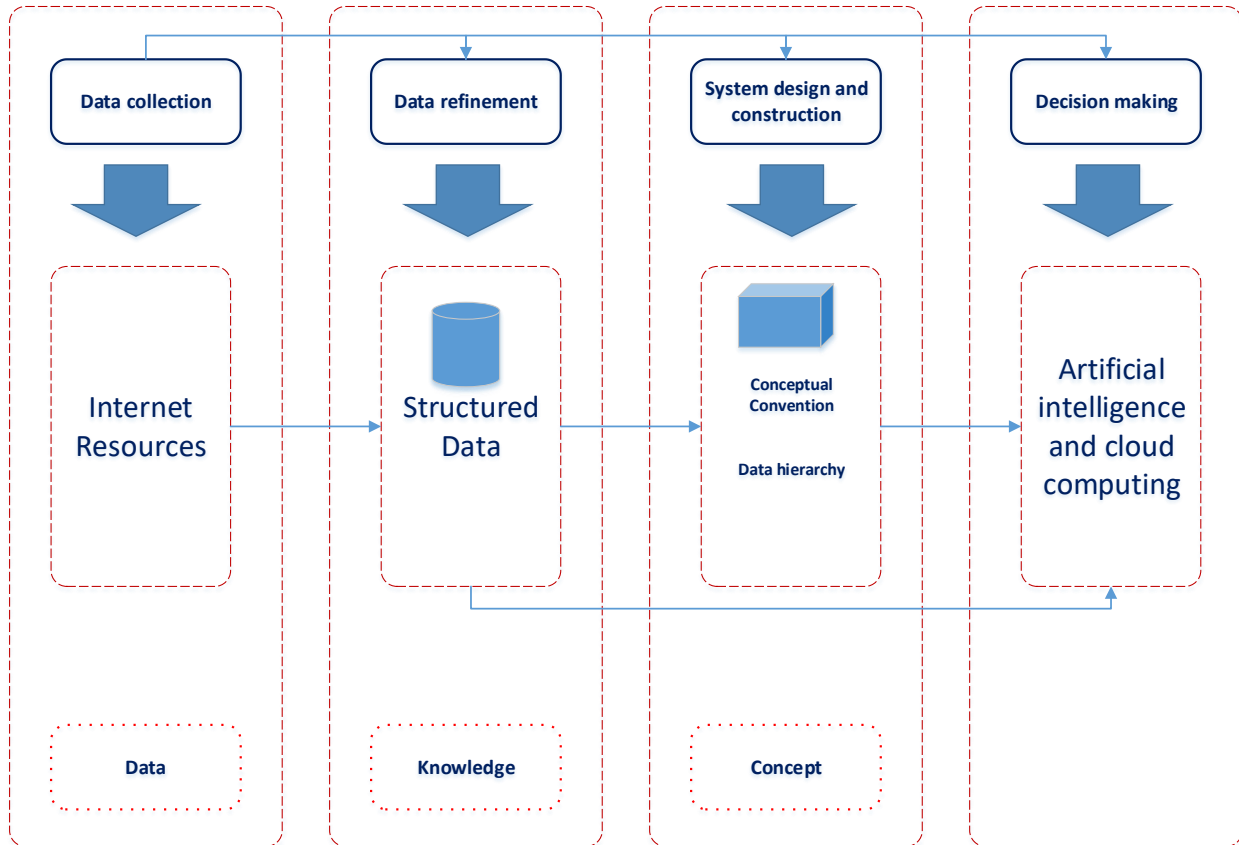
These findings from the literature and review of expert opinions prompt us to incorporate AIoT principles into the consideration of digital solutions for construction supply chains.

The framework presented in Figure 4 shows how these AIoT-enabled technologies lead to value creation through new operating models and mechanisms to capture value through new business models.



**Figure 4.** A Framework for construction supply chain integration using AIoT

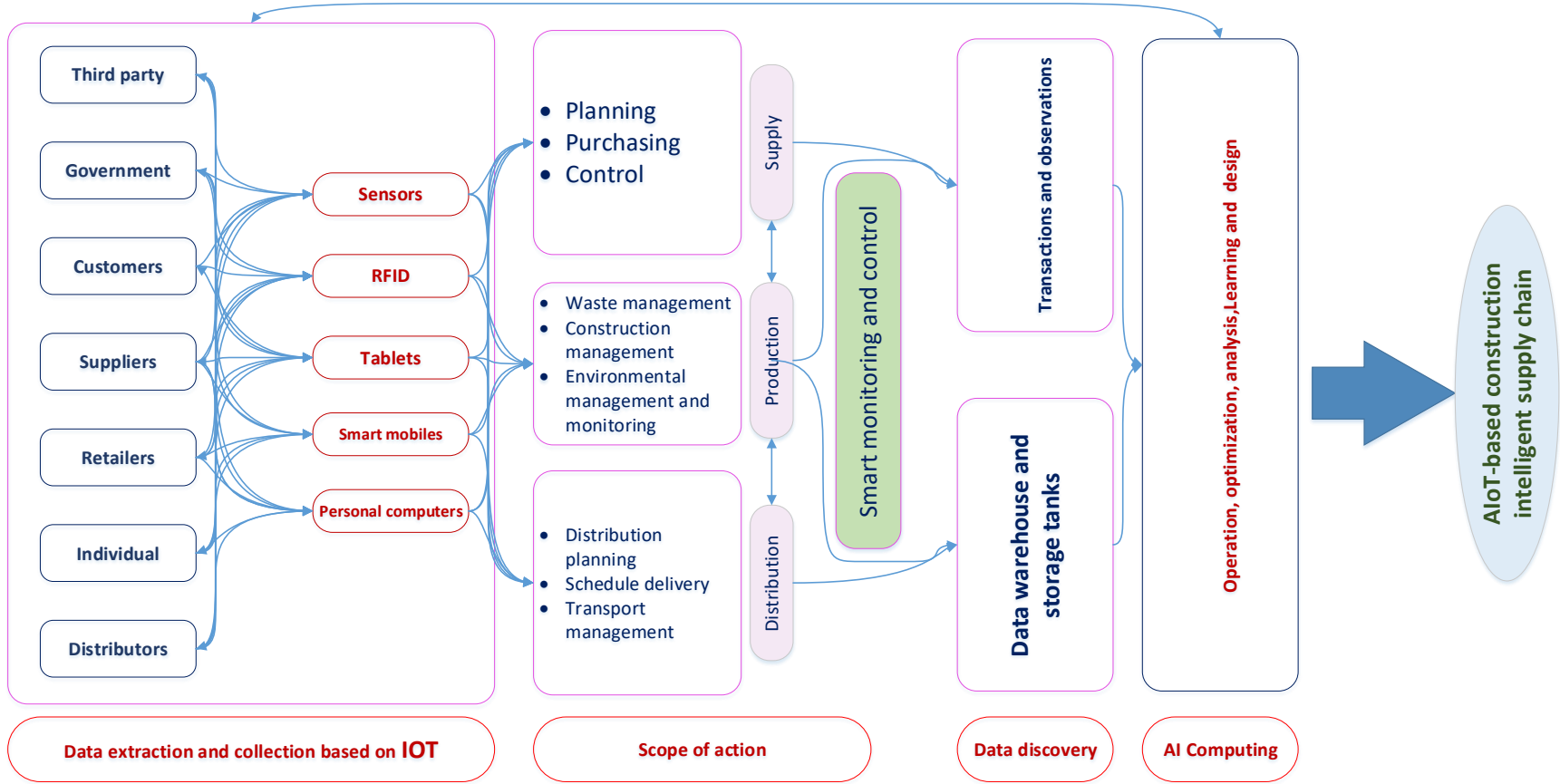
Causal and effect analysis of effective elements with emphasis on SWOT based on the opinions of experts shows us that we can examine and analyze the opportunities in two technical sectors as well as the ecosystem of the construction industry. Weaknesses can be found in the structural sectors, people and principles and relationships. opportunities can be found in the new functions that these transformative technologies create for the construction industry. First, given the growth and development of transformative technologies, cross-comparison with other industries and sectors is needed to understand the technological boundaries and determine the blockchain implementations that can be used in the construction industry. These steps can provide a basis from which cross-industry benchmarking and identification of best practices can be used. Ownership can be registered for many types of assets such as buildings, leading to increased trust between parties. Similarly, identifying projects or asset information/key document types that need to be digitized throughout the project lifecycle includes AIoT technologies that can be used to track key project or asset information and ownership history of key project lifecycle information/documents. Finally, there are threats in the sectors related to competitors and information breaches. The structure of data input and analysis in AIoT-based supply chain in construction systems is shown in Figure 5. This structure in the presented analytical framework shows the initial layer of information entry based on SWOT detail analysis.



**Figure 5.** Structure of data entry in AIoT-based supply chain in construction industry

Our literature analysis and review of expert opinions show that stakeholder collaboration in a construction supply chain is an outstanding feature to bring positive results to urban construction systems. However, several factors can prevent supply chain coordination and information visibility, and it often comes down to companies' attitudes and openness about how they understand and adapt to a data-rich world. Developing a digital mindset takes effort, and extensive research concludes that leaders with a digital mindset can lead organizations to greater success and create a flexible workforce in this digital age. They presented a conceptual framework for AIoT-based supply chains, four domains of data collection and extraction, analysis domain, data management, and analysis and decision making. These domains are similar to previous research in other industries.

The conceptual framework for AIoT-based supply chains in the construction industry is presented in figure 6. This conceptual framework tries to show the cause and effect relationships of the involved elements in the domains proposed by the experts. As seen in Figure 5, there are causal relationships or the main architecture of an intelligent supply chain in 4 main layers. Coordinated and timely communication of these technologies creates optimal growth of all processes.



**Figure 6.** Conceptual framework of AIoT-based intelligent construction supply chain

After the development, the presented framework was reviewed by the research experts and edited with their additional comments. Finally, with the consent of all the people in the focus group, this framework was approved and validated. Also, this framework has a relative overlap with many other researches in the field of ozone, which shows the validity of the model.

This framework can simplify the design of construction supply chains that have complex and security-critical supply and production processes. The framework could also consider the use of smart contracts to automate payments for a publicly funded construction project. In the form of smart contracts, you can benefit from blockchain technology along with Internet of Things and artificial intelligence technologies. AIoT can significantly reduce costs by simplifying processes and reducing manual involvement, thus increasing collaboration between project participants.

According to the review of the literature on the subject, the most important indicators of success in the supply chain of the construction industry based on AIoT can be extracted. In this research, these indicators have been evaluated and refined with the opinions of active experts in the field of the construction industry. The most important key performance indicators for developing a powerful framework are shown in Table 2.

**Table 2.** Key performance indicators for AIoT-based supply chain in the construction industry

Increase operational resilience (W1)
Reducing waste in materials and materials(W2)
Reducing the cost of inventory(W3)
Purchase Order Tracking(W4)
Supplier On-time Delivery(W5)
Constant monitoring and safety(W6)

The process of ranking key performance indicators in this research is divided into two main parts:

- 1) Determining the matrix of pairwise comparisons based on the integration of experts' opinions.
- 2) Using mathematical modeling to rank and obtain the weight of the factors in the research model.

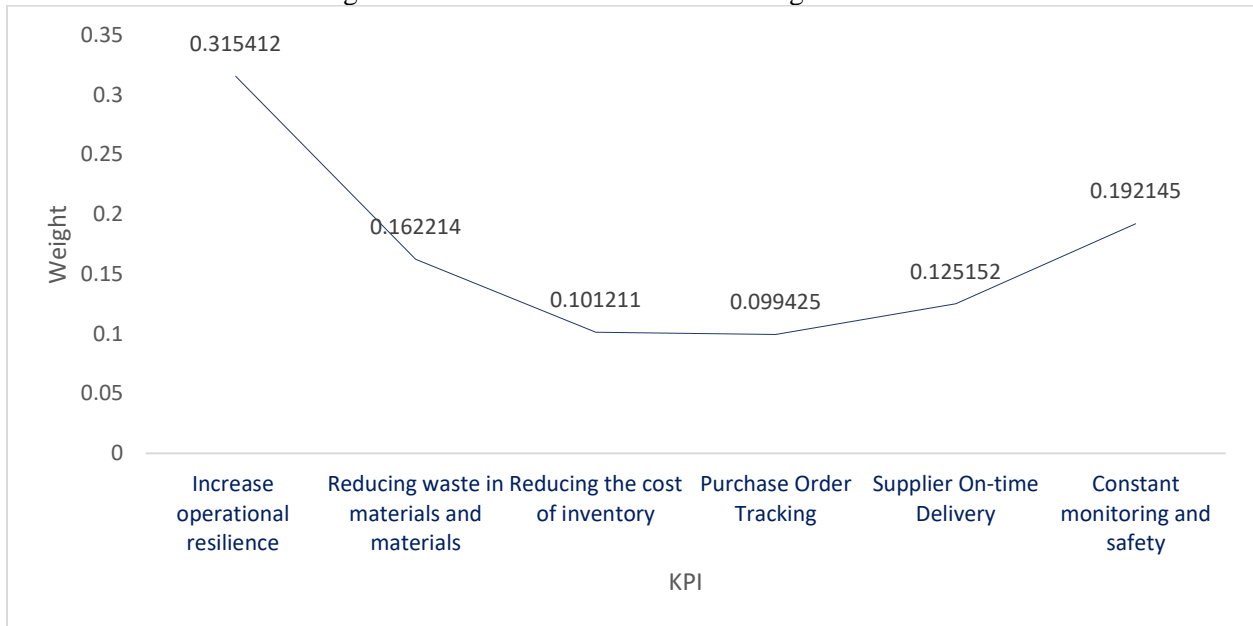
In order to prioritize the 6 final indicators extracted in this research, fuzzy questionnaires using language variables were sent to 15 experts and university professors. These experts were selected from people active in construction companies and had at least 5 years of experience in the field of construction and were familiar with the concepts related to technology development, and academic people also had related research records. 14 questionnaires were completed and received. These paired comparison tables are shown in Table (3). This table is used for calculations using the Mikhailov method.

**Table 3.** Pairwise comparison matrix for key performance indicators in the AIoT-based supply chain in the construction industry

	W1	W2	W3	W4	W5	W6
W1	-	-	-	-	-	-

W2	(1.25,2.5,3.5)	-	-	-	-	-
W3	(2.1,2.7,3.8)	(1.25,2.2,3)	-	-	-	-
W4	(2.2,3.5,4.8)	(1.5,2.5,3.1)	(2,3.5,4.1)	-	-	-
W5	(2,3,4.1)	(2.1,2.75,4)	(1.25,2.25,3.35)	(1.2,2.3,3.2)	-	-
W6	(3.21,3.78,4.25)	(3.1,3.75,4)	(1.2,2.35,4.1)	(1.4,2.54,4.21)	(1.2,3.1,3.98)	-

By putting the data obtained from table (3) in the non-linear model (3) and solving the model using Lingo software, the weight and rank of each of the key performance indicators can be obtained. The results of calculations related to solving the nonlinear model are shown in Figure 7.



**Figure 7.** Normal weight of key performance indicators of AIoT-based supply chain in the construction industry

As seen in Figure (7), increasing operational resilience is one of the most important performance Euclidean indicators in the AIoT-based supply chain in the construction industry.

## 5- Conclusion

The technological revolution in supply chain logistics is experiencing a transformative wave of new innovations and challenges. With today's fast-paced digital technologies, customers expect faster ordering and delivery of goods, and as a result, organizations looking to implement new technologies to deliver services faster and more efficiently. Considering the expansion of technology and the smartening of the Internet of Things and their help in better meeting the goals, their study and investigation in the field of supply chain is important. The Internet of Things technology, along with the artificial intelligence that makes up the AIoT technology, has recently attracted the attention of the construction industry, like many other industries. As a transformative technology, this technology also has its strengths, great opportunities, carries some weaknesses and serious threats. For this purpose, in this research, an effort was made to examine the concept of AIoT as one of the most important transformative technologies in the current era, and to present its effective dimensions and components in order to properly understand and implement this technology in the construction industry.

Therefore, using primary and secondary data, this research project aimed to understand the current issues related to the creation of AIoT-based construction supply chains and developed a conceptual framework for preparing such supply chains for blockchain in the construction industry. The findings are mostly in agreement with the recent literature on the implementation of transformative technologies in the construction industry and supply chain management in general. In addition, the presented conceptual framework was also validated by active experts in the field of study. In addition, potential research areas for further development of AIoT implementation in the construction industry were announced. More research is needed to better understand the specific roles and responsibilities of stakeholders (eg, governments, policy makers, customers, large and small organizations, suppliers, and end users) to overcome identified technology threats and weaknesses. Moreover, to understand and operationalize AIoT strengths and opportunities for the industry, careful analysis is required.

Along with that, more conceptual discussions, use cases of this transformative technology and experiments around it and understanding the opportunities are needed to better understand the implementation of the technology in the construction industry. This study has shown that these technologies cannot be fully utilized in the construction industry without the necessary adaptations and transformations in business models, procurement arrangements and upgrading of industry skills. These step-by-step changes are necessary to achieve success in the project life cycle. Beyond the hype and mainstream discourse, the general public needs to be educated about the benefits and functionality of blockchain technology. People need to be informed about the potential limitations and issues of AIoT to make it an efficient user-driven data-driven platform. In addition, to reduce resources as a possible barrier to its adoption, intensive progressive planning is needed to prepare enough skilled people to implement the process. Strong regulations are needed to protect users from unskilled providers, fraud and liability.

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