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A Review of The Industrialization of Building Projects With a Focus on The Logistics Phase

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ABSTRACT: The building industry is of significant interest due to its unique characteristics compared to other industries, including the allocation of substantial capital and resources. However, its productivity rate remains relatively low. One potential way to improve and increase productivity in the building industry is by adopting and implementing more technological solutions, including industrialization. Successful implementation of industrialization requires, in the first instance, an understanding of the process phases involved in industrialized projects. In this regard, the present research conducts a scoping review (2010–2023) of articles published in Web of Science (WoS) and Google Scholar. A total of 181 articles related to the keywords of the research were identified and evaluated. The findings indicate that the life cycle of industrialized projects can be classified into three main phases: off-site construction, logistics, and on-site construction. Focusing on the logistics phase and reviewing the most important research, key management areas for this phase were identified, including scheduling, cost, and space management. Finally, theoretical gaps within the logistics phase were identified, highlighting the lack of attention given to these areas by researchers.

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1- Introduction

The building industry is one of the largest, most decentralized, and highly region-specific sectors in any country. In many nations, it is considered an indicator of economic growth and development, or economic stagnation [1]. Today, Iran's building industry is facing a productivity management crisis [2]. It is crucial to adopt new construction methods in building projects to enhance both the quality and speed of these projects [3]. One significant approach in this regard is industrialization [4]. Building industrialization refers to the continuous construction and implementation of buildings, where components and modules are produced in a modular and prefabricated manner, with quality control applied at all stages of the process [5].

Given the growth of the country's population and the increasing demand for housing, the use of industrial construction systems to improve the quality of building industrialization has become unavoidable [6]. However, reports indicate limited attention to industrialization in Iran's building projects, with some of the most significant challenges outlined below.

The rate of industrialization in Iran's building sector is currently less than 5%, while it should ideally reach 40%. Industrialization can improve building quality and reduce housing costs. The lack of new technologies, limited capital, entrenched traditional practices, national restrictions, and the availability of cheap energy are some of the reasons why industrial buildings have not gained popularity and are lagging behind. Additionally, insufficient attention to urban design and its impact on the industrialization of buildings is another contributing factor to this stagnation [7]. Currently, there is no shortage of technical and scientific knowledge, and these technologies are available to experts. The real issue is the lack of infrastructure for industrial production. Iran is in the transition phase from traditional construction methods to industrialization [8]. The construction industry in Iran is moving towards industrialization and the use of new technologies [9] Iran, like many other countries, is moving towards development and industrialization in its industries, with government support playing a significant role in this process [10]. Samadi (1400) also states that the use of off-site manufacturing in Iran is very low compared to leading countries in this field, such as China [11].

On the other hand, studies show that the effectiveness of industrialization is limited [12]. Industrialization remains in its infancy due to challenges in its implementation [13]. Other researchers have identified key limiting factors that significantly impact industrialized projects, one of the most notable being the mismatch between production plans and site

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conditions [14]. Deviations from the modular construction schedule can undermine the benefits of industrialization and hinder its widespread adoption [15].

The lack of housing and the need to accelerate construction methods, including industrialization (which is a macro-level necessity), alongside the allocation of a significant portion of the country's resources and capital to building projects, highlight the need for improvement at the macro level. Specifically, planning to enhance the logistics process of industrialization is essential for advancing industrialization in Iran's construction industry.

In response to the challenges mentioned above, and to ensure the successful implementation of industrialized projects, it is necessary to understand the processes that occur throughout the life cycle of such projects. Given that no comprehensive research has yet addressed this issue, the current study aims to identify the stages of the life cycle of industrialized projects through a review of the most reliable databases.

2- Theoretical foundations of research

In the field of industrialization, there are many specialized keywords. For the sake of clarity in conducting the research, the definitions of these keywords are first presented in Table 1. Subsequently, Figure 1, created by the researcher based on the aforementioned definitions, illustrates the scope of industrialization, which is highlighted in blue. This highlighted scope forms the basis of the keyword search conducted in the database and search engine.

This study aims to investigate the industrialization of buildings and its related examples. Examples of industrialization are concepts that are used to achieve the goal of industrialization of buildings, which are resource efficiency, increasing speed, and improving and standardizing the level of quality. These examples are mentioned in 11th book of the National Building Regulations. Some of these examples, such as prefabrication, are carried out both on-site (onsite prefabrication) and offsite (offsite prefabrication). Other examples, such as Factory Construction and Mobile Onsite Factories/ Container Factories, are also carried out at the project site, according to the definitions given in Table 1. In the present study, only that part of industrialization and its examples that are carried out outside the project site and in controlled factory conditions are addressed so that the concept of the logistics phase is meaningful. As a result, only the part highlighted in blue in Figure 1 is the scope of the study.

Figure 1 is drawn based on the information in Table 1 to improve the audience's understanding of the scope of research that has been sought.

Table 1. Definitions of keywords. (Continued)

Row	keywords	Definition	Reference
1	Industry 4.0	I4.0 is recognized as the reference point for the fourth industrial revolution, with terms such as smart factory, smart production, and smart manufacturing used to define it in a broader sense. It also encompasses technologies such as cloud computing, cybersecurity, big data analytics, and service orientation. The main contribution of I4.0 is to facilitate the computerization and interconnection of industries, leading to the creation of an automated and flexible production chain, as well as providing a variety of services and new business models for the value chain. As it is adopted across industries, I4.0 is also inspiring the construction industry, which requires more efficient production chains and business models. This evolution has been termed "Construction 4.0," representing the digitization of the construction industry.	[16]
2	Construction 4.0	It is defined as a transformative framework in which three types of transformations occur: industrialized manufacturing and construction, cyber-physical systems, and digital technologies. Some examples of digital technologies include Building Information Modeling (BIM), Common Data Environment (CDE), Unmanned Aerial Systems, Cloud-based Project Management, Augmented Reality/Virtual Reality (AR/VR), Artificial Intelligence, Cybersecurity, Big Data, blockchain analysis, and laser scanning.	[17]

Table 1. Definitions of keywords. (Continued)

3	Modern Methods of Construction (MMC)	Modern Methods of Construction (MMC) encompass a wide range of advanced construction techniques and systems, both on-site and off-site, offering alternatives to traditional construction, especially in the housing sector. MMC includes innovative techniques, such as on-site fabrication or assembly of specific components.	[18]
		MMC also includes many innovations, particularly in home building and the construction industry in general, most of which are off-site technologies that transfer work from the construction site to the factory. These include modular building, pre-assembly, prefabrication, off-site production, off-site manufacturing, industrialized building, and a variety of other off-site and on-site construction methods.	[19]
		Using advanced technology (mechanical tools, computer systems) in a continuous process helps improve efficiency in terms of standardization, modularization, and mass production.	[20]
4	Industrialization Construction	Industrialization in construction refers to the continuous construction and implementation of buildings, where components and modules are produced in modular and prefabricated forms. These can be controlled in terms of quality at all stages of construction and implementation.	[5]
		One of the ways to increase productivity in construction projects is to use industrialized construction (IC), which is one of the new methods in construction (MMC).	[21]
5	Modular Integrated Construction (MIC)	Modular Integrated Construction (MIC) is an emerging construction approach that involves producing prefabricated modules in an off-site factory, which are then transported to the construction site for assembly.	[22]
6	Industrializaed Building System (IBS)	A forward-thinking prefab building approach utilizes the best construction machinery, technology, resources, and careful project preparation. This is also known as off-site construction (OSC), prefabricated components (Prefab), and modular construction (MC) around the world.	[23]
		This method of construction can be built and transported in a controlled environment using industrial manufacturing techniques, then installed on-site with minimal staff involvement. In Malaysia, Industrialized Building Systems (IBS) is defined as a construction method where project components are fabricated off-site, then brought to the site and installed with minimal effort.	[24]
7	Offsite Construction (OSC)	Off-site construction (OSC) introduces a new approach by moving the building construction process from the site to a controlled factory environment.	[25]

Table 1. Definitions of keywords.

8	Offsite Manufacturing (OSM)	Off-site Manufacturing (OSM) is a process in which the majority of traditional site-based construction work is performed in a controlled facility. This allows for the use of advanced manufacturing techniques to pre-fabricate building components, assemblies, and entire buildings in a highly efficient manner.	[18]
		Off-site manufacturing (OSM) refers to the production of components for a structure at a location different from the actual construction site.	[26]
		The off-site manufacturing process (OSM) usually involves pre-assembly or prefabrication of components, which are then installed on-site.	[27]
9	Offsite Production (OSP)	Under the overarching umbrella of MMC are Off-Site Manufacturing (OSM), Prefab, and Off-Site Prefabrication (OSP), which are often used interchangeably in the literature. One of the reasons for using OSP is to address skill shortages, as it may reduce reliance on skilled labor.	[28]
10	Offsite Prefabrication (OSF)	The term "off-site prefabrication" generally refers to all prefabricated products, parts, and MEP services that are not manufactured on-site.	[29]
11	Onsite Prefabrication (OSF)	On-site prefabrication refers to the implementation of prefab techniques on or near the actual construction site, which can be done using temporary or mobile and fully functional on-site factories.	[30]
12	Modular Building (MB)	Modular constructions consist of various parts with standardized dimensions. Modular construction is one of the methods of production and construction outside the workshop. This method covers only components of a building, rather than the entire structure. In the modular method, the parts are produced in a factory, and only transportation and installation remain at the project site, where minimal work is required.	[31]
13	Factory Construction	Any construction site can be considered a complete and complex assembly plant. This means that a new assembly plant is installed and dismantled at the end of the manufacturing period to utilize factory production with high carrying costs. The factory is also moved from one site to another by truck.	[32]
14	Mobile Onsite Factories/ Container Factories	The concept of a "mobile factory on-site" involves the temporary use of small mobile factories or production cells at the construction site. This concept is particularly suitable for situations in the construction industry where long distances and high logistics costs are factors.	[30]

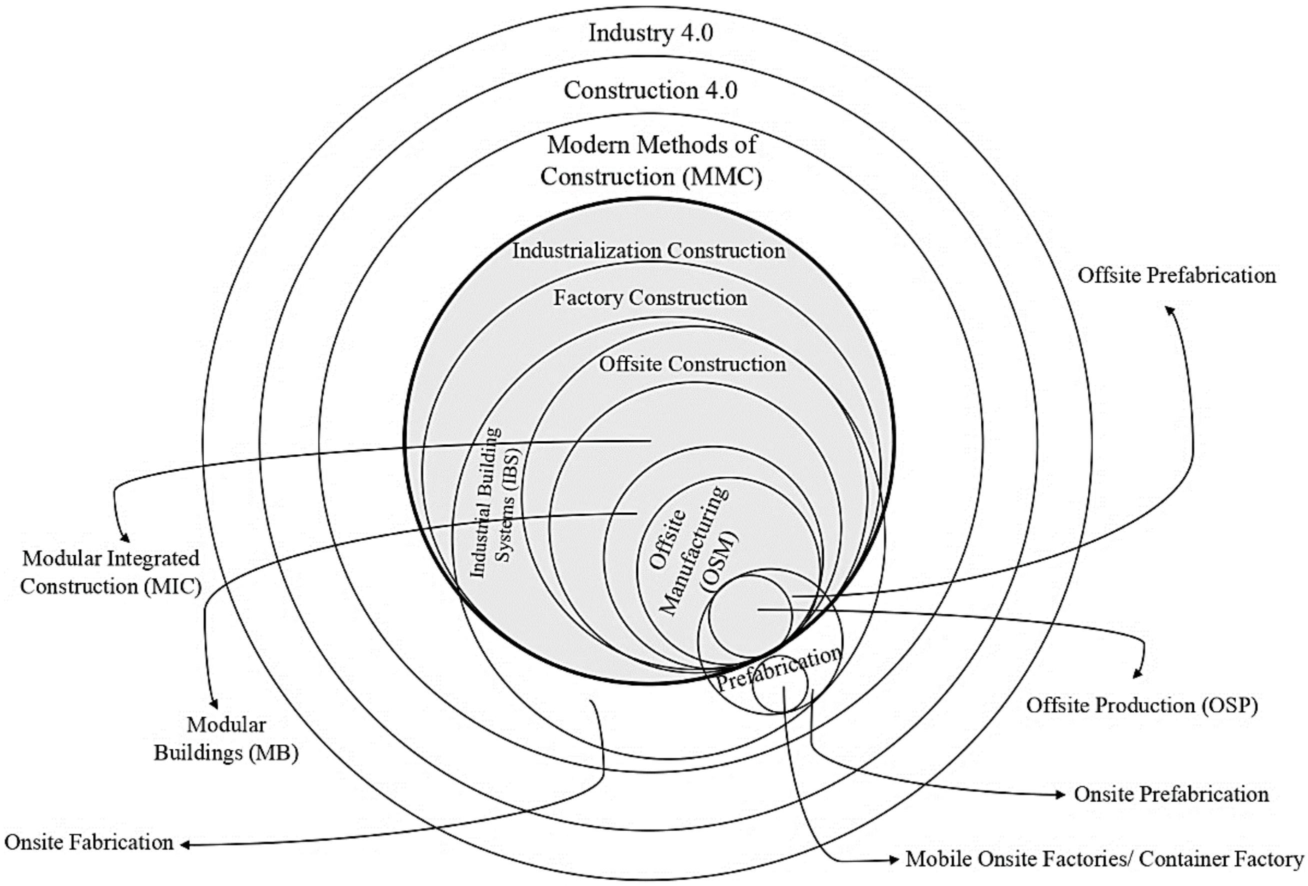


Fig. 1. Scope of the research.

3- Research Methodology

In this research, a scoping review (from 2010 to 2023) was conducted. In this process, all the keywords specified in the color range of Figure 1-including Industrialized Construction, Prefabricated Buildings, Prefabricated Building Management, Offsite Construction Management, Offsite Manufacturing, Offsite Production, Industrial Building Systems (IBS), Modular Integrated Construction (MIC), Modular Buildings (MB), and Factory Construction—were searched in the authoritative Web of Science database. For comprehensiveness, the same search was performed in the Google Scholar search engine.

During the first stage of searching these two database and search engine, some keywords returned a large number of articles, which exceeded the time available to the researcher. However, the most relevant articles are usually displayed within the first 100 search results. Therefore, only the first 100 results were reviewed. In this stage, 1,819 articles were identified. After applying the exit criteria for the first stage (as shown in Figure 1), 228 articles remained.

In the first stage of filtering the articles, some exclusion criteria were defined according to Figure 2, resulting in a reduction of the number of articles from 1819 to 228. For instance, one exclusion criterion was the removal of articles related to the success and failure factors in accepting and implementing industrialization or its examples. This criterion was defined because the number of articles was very large and the researchers had a technological perspective on this review, as the research findings indicate. Among the articles excluded in this category is one titled "Critical success factors for modular integrated construction projects: A 1 review". This research examined the key success factors for projects from 1993 to 2019. These key success factors included good teamwork and effective communication among project participants. Effective supply chain management, precise design, procurement strategy, appropriate contracting, and standardization were identified as additional key success factors [33].

Another exclusion criterion was the removal of articles discussing the benefits and disadvantages of industrialization or its examples. An example of an excluded article in this category is one titled "The Current Use of industrialized construction techniques in France: Benefits, limits, and future expectations". The research findings showed that the advantages of using off-site construction include improved productivity, reduced construction time, enhanced quality, minimized waste, and the mechanization of construction [34].

Another exclusion criterion was the removal of articles

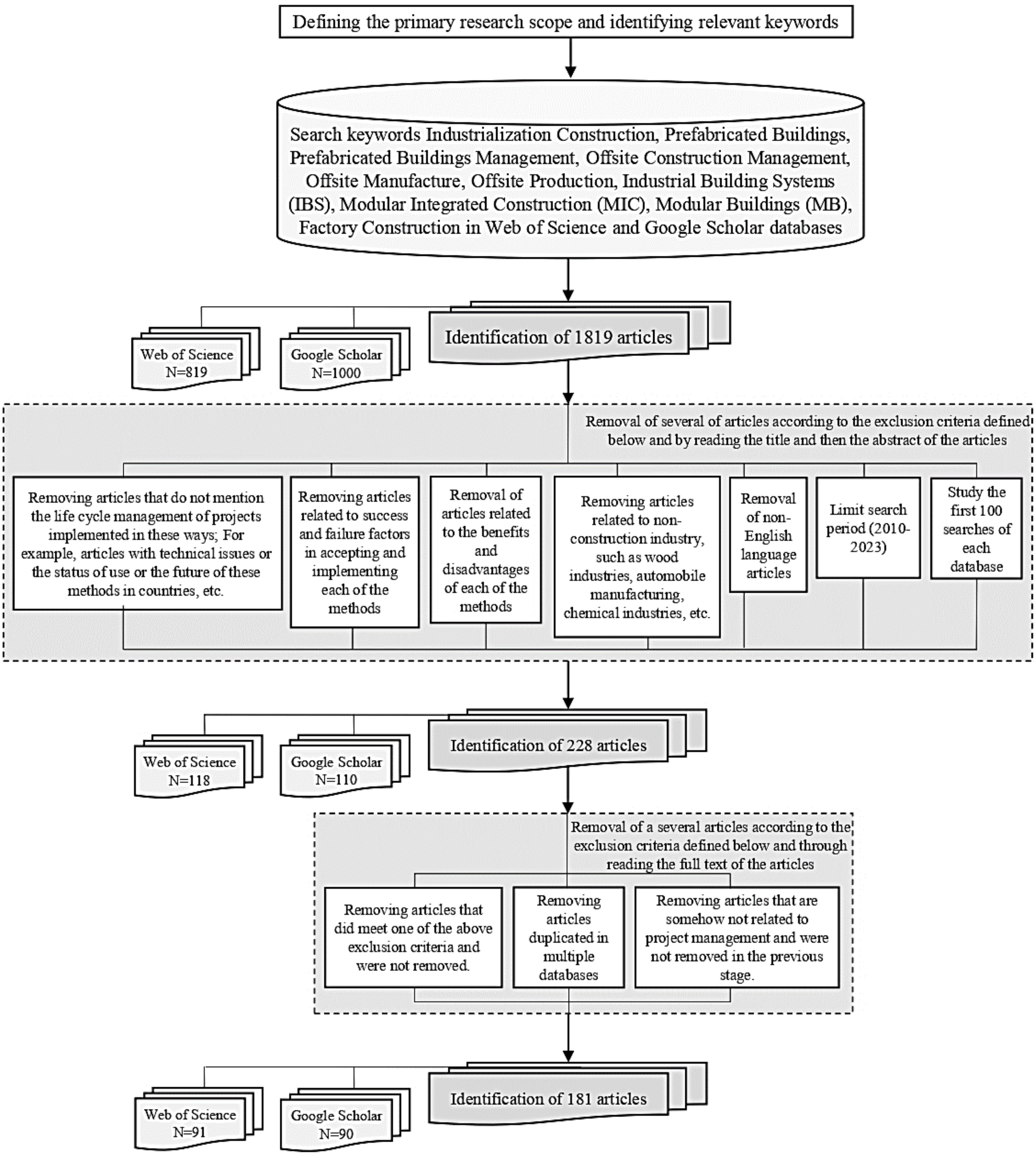


Fig. 2. Research flow chart

related to non-construction industries, such as wood industries, automobile manufacturing, chemical industries, etc. For example, in an article titled "Resource allocation benefits: developing project portfolio management process". This research pertains to the allocation of financial resources in the machining industry [35].

Up to this stage, 228 articles were obtained. Following the second stage of article removal (with the corresponding exit criteria also depicted in the figure), 181 relevant articles were directly studied and evaluated.

Chart 1, which was created by reviewing 181 articles in Web of Science and Google Scholar—in the field of industrialized projects, shows the growing trend of research on industrialization. The lower frequency in 2023, compared to previous years, is due to the fact that the database and search engine were searched only up to October 2023.

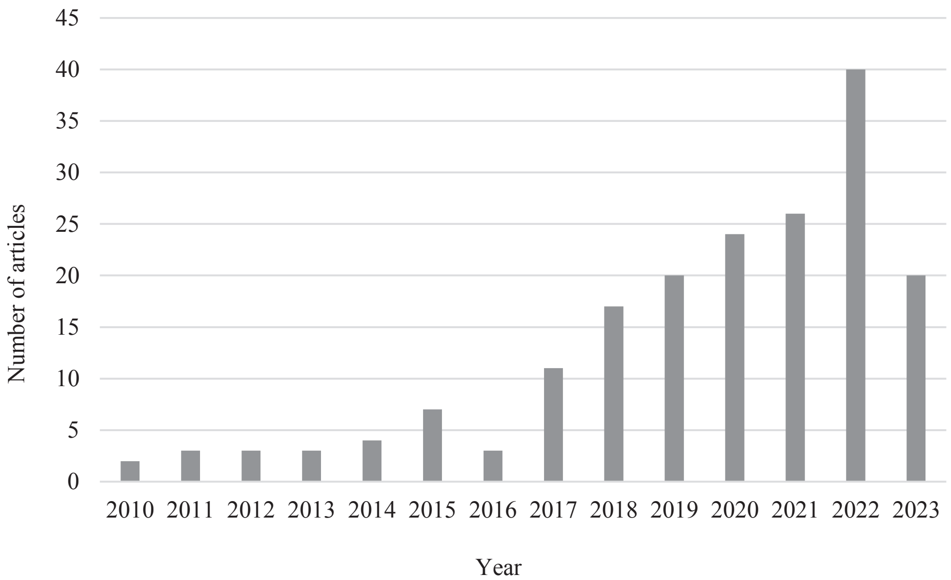


Chart 1. Frequency of articles published each year (2010-2023)

4- Results

4- 1- The main phases of industrialized projects

Industrialized projects go through three main phases in terms of the location of the project, including off-site construction, logistics, and on-site construction [36]. Other researchers have referred to these three main phases by different titles, prefab factory, prefab logistics, and onsite assembly [37]. Off-site construction refers to the transfer of part of the building construction process from the workshop to a controlled factory environment [25] and on-site construction refers to the construction activities that are carried out in the workshop or construction project site.

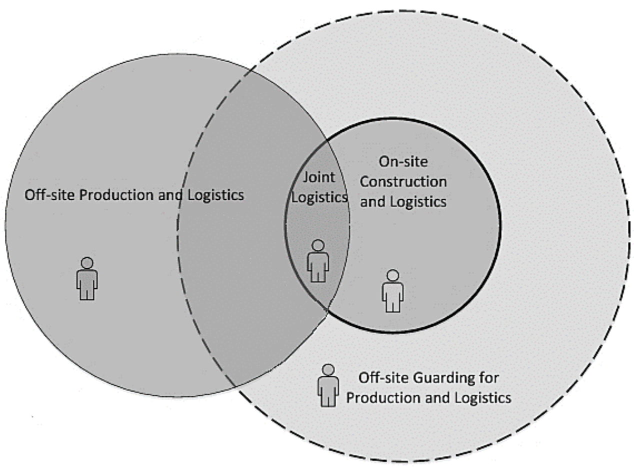


Fig. 3. The main phases of industrialized projects [36].

During the review of the 181 articles and the categorization of each article into a specific phase of the life cycle of an industrialized project, the three main phases were further divided into more detailed subsections, as shown in Figure 4. Additionally, the numbers listed under each phase indicate the number of related articles evaluated in this review.

In some phases, such as converting raw materials into components, the technical field is more prominent, while in other phases, such as site management or erection, the management field takes precedence. As shown in Figure 4, most research has been conducted in the phases of automation and robotics production, transportation, site management, and erection, respectively.

4- 2- Technologies used in industrialized projects

There are several problems that can limit the effectiveness of industrialization. Currently, issues arise at various stages of the lifecycle of industrialized projects, which in turn lead to construction conflicts and increased costs [12] . In response to these challenges, digital technologies can help mitigate these issues [14].The planning, scheduling, and execution of prefab components are critical to the timely delivery of prefab modules in industrialization, and technologies can facilitate these processes [50]. It seems that transformative technologies, with their capabilities, can help address these issues and, as a result, improve the productivity of the construction industry. The use of technology is mentioned in the majority of the 181 reviewed articles. Among the transformative technologies highlighted in these articles, the most commonly used were BIM, IoT, AI, Digital Twin, and RFID technologies. Chart number two illustrates this.

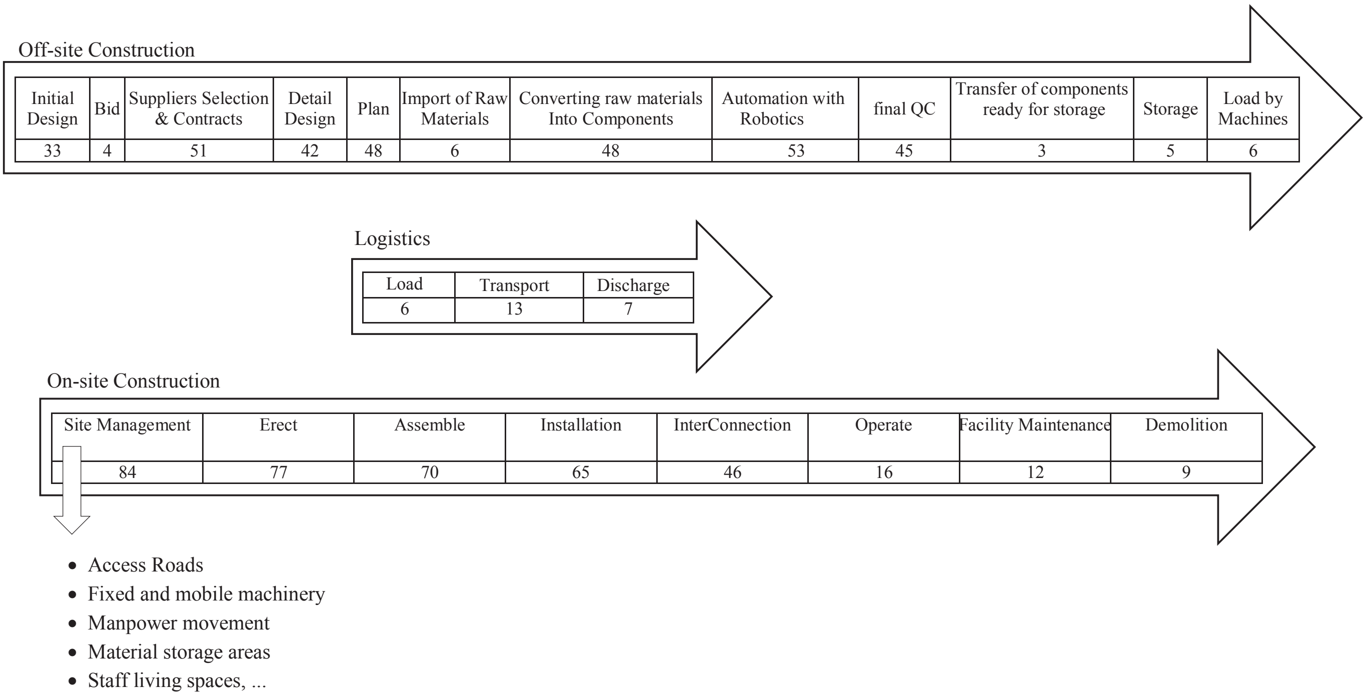


Fig. 4. Division of industrialized project life cycle phases based on the location of project activities.

Table 2. Examples of articles published in stages with the highest number of articles. (Continued)

Stage	Title	Abstract	Reference
Automation with Robotics	A Framework of Indicators for Assessing Construction Automation and Robotics in the Sustainability Context	Providing a framework of sustainability indicators (social, economic, environmental, and technical performance) for the evaluation of construction automation and robotics (CAR)	[38]
	The future of construction automation: Technological disruption and the upcoming ubiquity of robotics	A review of the applications of robots and automation in future construction	[39]
	TOWARDS AUTOMATION AND ROBOTICS IN INDUSTRIALISED BUILDING SYSTEM (IBS): A LITERATURE REVIEW	A review of the use of robotics and automation in IBS, along with the factors affecting the adoption of IBS	[40]
Transport	Real-Time Optimization of Precast Concrete Component Transportation and Storage	*Providing a dynamic optimization method for the transportation and storage of prefabricated components based on scheduling and real-time tracking *Deriving the actual schedule from 4D-BIM and tracking the position of prefabricated components during the entire transportation process through a tracking system that integrates the Global Navigation Satellite System (GNSS) and RFID	[41]
	Damage detection for prefabricated building modules during transportation	Providing a framework to identify defects and failures of prefabricated parts during transportation through step-by-step transportation tracking	[42]
	A multi-objective optimization model for prefabricated construction integrating production, transportation, and assembly	Presenting a scheduling optimization model for the relationship between production, transportation, and assembly of prefabricated construction, followed by testing the model in two case studies	[43]

Table 2. Examples of articles published in stages with the highest number of articles.

Site Management	4D-Based Workspace Conflict Detection in Prefabricated Building Constructions	Identification of 4D interactions on the site (space-time) between machines and workers in the prefabricated project using Navisworks SDK	[44]
	Utilization of 3D Visualization of Mobile Crane Operations for Modular Construction On-Site Assembly	Using 3D simulation to determine the optimal movement of mobile cranes for lifting and assembling activities	[45]
	Virtual prototyping- and transfer learning-enabled module detection for modular integrated construction	Simulating and reporting the movement process of machines carrying the modules on-site and how the modules are moved and installed in MIC (Modular Integrated Construction)	[46]
Erect	Digital Twin-Based Safety Risk Coupling of Prefabricated Building Hoisting	Presenting a Digital Twin-based Elevator Safety Risk Management Framework by integrating IoT, BIM, the Apriori Algorithm, and Complex Networks, with implementation in the construction of a large-scale prefab building	[47]
	Simulating and optimizing precast wall lifting in prefabricated building construction	Identifying ways to improve in-service lift performance for prefabricated buildings using Discrete Event Simulation (DES), Elimination, Combination, Rearrangement, and Simplification (ECRS) techniques, and intelligent optimization tools	[48]
	A Framework for Prefabricated Component Hoisting Management Systems Based on Digital Twin Technology	Using BIM and IoT to create a Digital Twin model for prefab building elevator control, followed by the use of Dijkstra's algorithm to perform elevator path planning based on BIM data. Additionally, Long Range Radio (LoRa) technology was used to collect and transmit data to monitor the lift status.	[49]

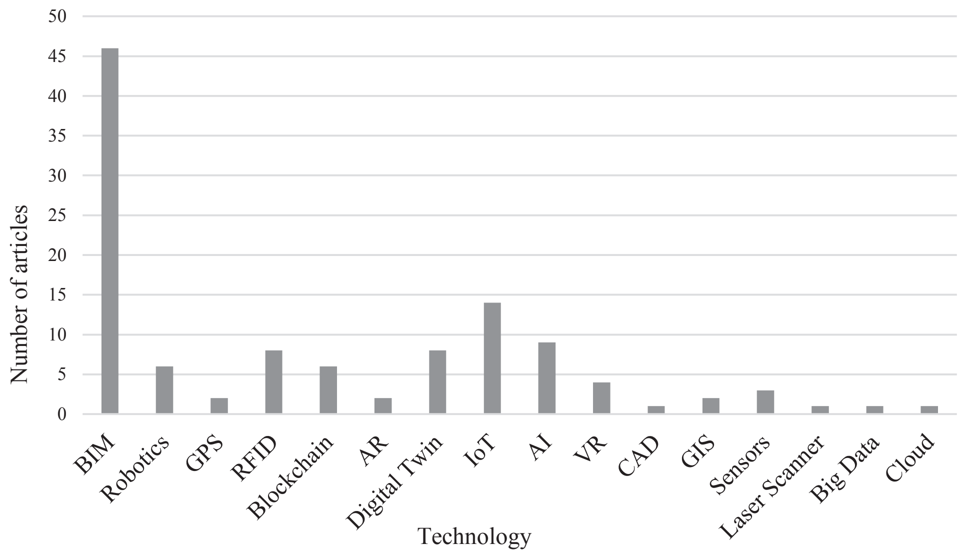


Chart 2. Frequency of use of transformative technologies in articles

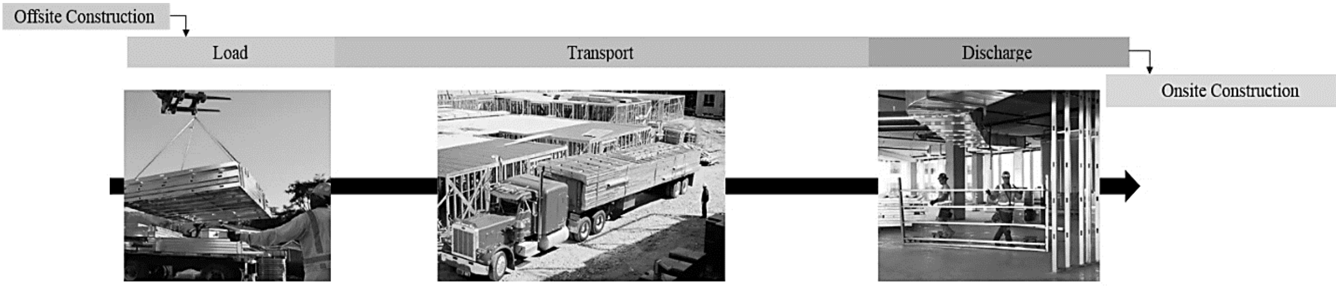


Fig. 5. Connections between the three main phases of industrialized projects.

After identifying four frequently mentioned technologies in the reviewed articles, several papers that have utilized these technologies are referenced. One of these papers, titled " Digital Twin-Based Safety Risk Coupling of Prefabricated Building Hoisting", proposes a digital twin-based safety risk management framework for lifts by integrating BIM, IoT, and the Apriori artificial intelligence algorithm, which has been implemented in the construction of a large-scale prefabricated building project [51]. The other article titled "Modular Structure Construction Progress Scenario: A Case Study of an Emergency Hospital to Address the COVID-19 Pandemic" reports on the use of big data, cloud, IoT, AI, 5G, and BIM technologies in the construction of a hospital in China, showcasing modular construction methods that were utilized during the COVID-19 pandemic to meet the urgent need for hospitals for COVID-19 patients [52].

In the continuation of the review, all three phases of off-site construction, logistics, and on-site construction were evaluated in more detail.

4- 3- Logistics phase of industrialized projects

During the review of 181 articles from Web of Science and Google Scholar, in the field of industrialized projects, it was found that the articles can be categorized into either off-site construction or on-site construction. However, there are phases in the lifecycle of these projects that do not strictly fall into either category, which are referred to as the transition from off-site to on-site construction. This section, marked in green in Figure 5, is part of the supply chain process and the logistics of industrialized projects. It shares characteristics with both off-site and on-site construction activities. If construction activities are divided into three separate categories based on location, the connection loop between factory and on-site activities is not clearly defined. Figure 5 illustrates the connections between these three parts. Defined. Figure 5 expresses the connections between these three parts.

By studying the text of the 118 final articles and categorizing each article into a phase of the industrial project lifecycle, as illustrated in Figure 4 drawn by the researcher, 25 articles were related to the logistics phase of the projects. This means that the content of these articles pertains to either the module loading stage, the transportation of modules, or the unloading of modules at the project site. For example, one of the 118 articles had the title "Using BIM in the safety risk management of modular construction [53]", which relates to the use of BIM for construction site management, and indicates that it is related to the onsite construction phase and thus does not pertain to the logistics phase. Another article titled "Planning and controlling design in engineered-to-order prefabricated building systems [51]" was analyzed. The paper presents a model for planning and controlling the design process in companies that design, manufacture, and assemble engineered-to-order (ETO) prefabricated building systems, and it was determined that it belongs to the offsite construction phase, and is not related to logistics. In total, only 25 articles were categorized under the logistics phase.

In total, 26 articles related to the logistics phase were identified among the 181 filtered articles. The evaluation of these articles revealed that research has been scattered across the three main logistics steps of industrialized projects: loading prefabricated modules, transporting modules from the factory to the site, and unloading modules at the project site. However, from a project management perspective, no comprehensive research has been found that integrates all three steps in an integrated manner. The logistics phase in industrial construction refers to the loading, transportation, and finally unloading at the project site. The logistics phase is directly related to issues such as transportation vehicles, traffic, weather conditions, routing, and more [54]. Modular components from factories are often large and require careful handling when being transported across public roads and during on-site assembly [55]. This challenge is compounded in urban construction sites, where storage space is limited, making warehouses crucial for temporary storage [56].

The unique and complex production processes involved in modular construction, along with the need for tailor-made, project-specific products, set these supply chains apart from those in other sectors. As a result, they are often studied independently due to their distinct logistics requirements [57].

A summary of the 26 articles is provided in Table 3.

Table 3. Classification of 26 identified articles. (Continued)

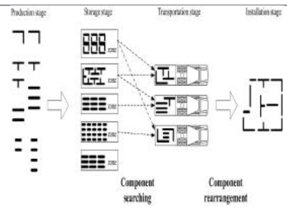
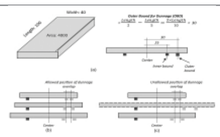
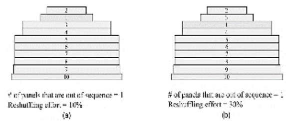
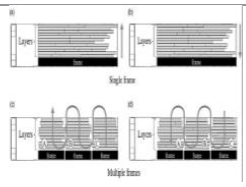
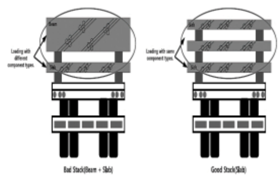
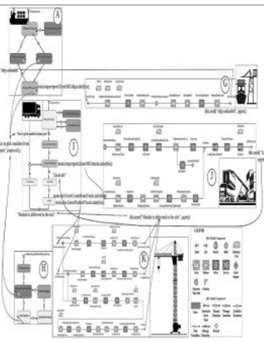
Row	Title (Reference)	Abstract	Management Area	Images extracted from articles	Disruptive Technology
1	Precast Storage and Transportation Planning via Component Zoning Optimization [58]	Providing a model for optimal decision-making during the loading and transportation of modules by mapping the direction and size of the modules on-site, then determining how to store (both inside and outside the factory) and load the modules based on their orientation at the site	space		
2	Automated Generation of Precast Concrete Slab Stacks for Transportation in Offsite Construction Projects [59]	Identifying considerations for computer-aided truck-back stacking of precast concrete slabs	space		
3	Empirical Study of Identifying Logistical Problems in Prefabricated Interior Wall Panel Construction [60]	Presenting a model to optimize the loading of modules onto transport vehicles using data obtained from interviews	space		
4	Methodology to estimate logistics costs for vertically transported prefabricated wall panels [61]	Proposing an optimal method for generating loading plans and assessing site conditions using algorithms, then testing the method in a case study comparing logistics costs for three different framework options, considering site conditions	cost		**Genetic Algorithm**
5	Automated Components–Vehicle Allocation Planning for Precast Concrete Projects [62]	Integrating factory, transportation, and site information, where a construction manager must plan for the allocation of prefabricated components to vehicles, including the type of component loading, planning to reduce the number of vehicles, adjusting arrival times at the site, and choosing the appropriate type of vehicle	time		
6	Optimized multimodal logistics planning of modular integrated construction using hybrid multi-agent and metamodeling [63]	Providing a comprehensive model that significantly impacts key performance metrics (KPMs) such as project duration, total costs, and carbon emissions. A meta-modeling approach is then used to find the optimal logistics and construction decisions (number of trucks, dispatch times, ship capacity, inventory, and resource planning) by combining Discrete Event Simulation (DES) and Agent-Based Simulation (ABS) in a case study	time cost		**DES**

Table 3. Classification of 26 identified articles. (Continued)

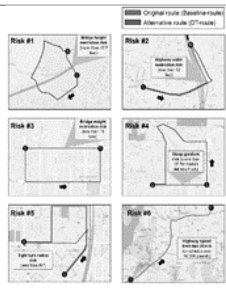
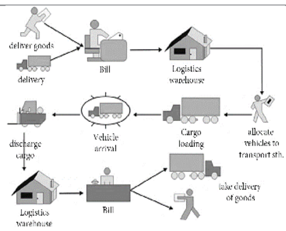
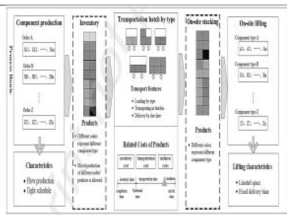
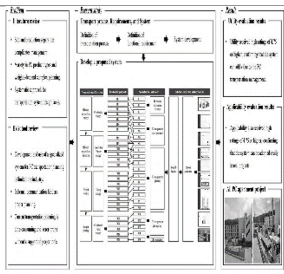
7	Digital Twin for Supply Chain Coordination in Modular Construction [15]	Developing a Digital Twin framework (using BIM, IoT, and GIS) for real-time logistics simulation, capable of identifying potential logistics risks and the exact time of module arrivals on-site, tested in a case project	time		**Digital Twin BIM IoT GIS**
8	Prefabricated construction enabled by the Internet-of-Things [64]	Providing a BIM platform based on the Internet of Things and testing it on a project in Hong Kong. This platform tracks the movement of machines carrying modules using GPS and RFID, plans transportation and delivery times, produces an information repository for transportation planners, and installs RFID tags for operators and logistics drivers	time communication /information	 	**BIM IoT GPS RFID**
9	Optimization Algorithm of Logistics Transportation Cost of Prefabricated Building Components for Project Management [65]	Presenting a logistics cost optimization algorithm related to the transportation of prefabricated components, focusing on the total cost, which is affected by the waiting time for unloading modules, transportation costs, and penalties	cost		**Genetic Algorithm**
10	JUST-IN-TIME MANAGEMENT OF PRECAST CONCRETE COMPONENTS [66]	Conducting interviews with precast concrete suppliers about just-in-time delivery of components, factoring in storage space issues and traffic restrictions	cost time		
11	A multi-objective optimization model for prefabricated construction integrating production, transportation, and assembly [43]	Presenting a scheduling optimization model that relates production, transportation, and prefabricated assembly, followed by testing the model in two case studies	time space		**Genetic Algorithm**
12	MODULAR CONSTRUCTION SYSTEM SIMULATION INCORPORATING OFF-SHORE FABRICATION AND MULTI-MODE TRANSPORTATION [67]	Investigating the combined effect of different modes of transport (trucks, ships, rail) on logistics planning, considering unloading point capacity, time availability, site arrival dates, and installation delays. The study includes simulation based on Symphony software, evaluating various scenarios in a case study in Alberta	space time		
13	Cloud-based information system for automated precast concrete transportation planning [68]	Proposing a cloud-based information system for automatic transportation planning of prefabricated components, identifying 26 functional requirements, and designing the system through testing in a case study	communication /information		**Cloud**

Table 3. Classification of 26 identified articles. (Continued)

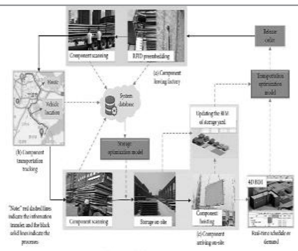
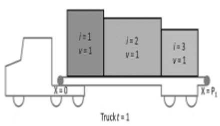
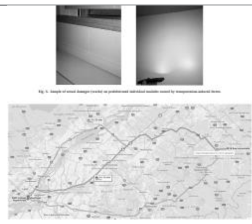
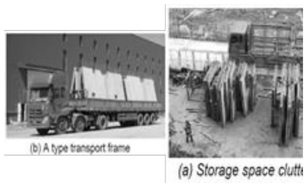
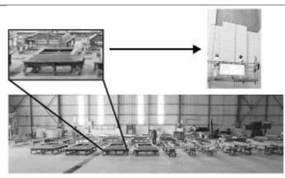
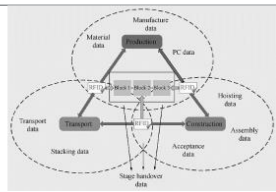
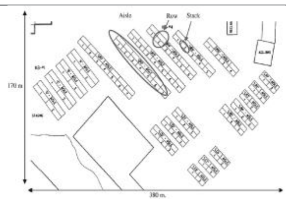
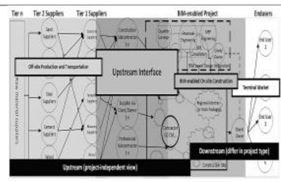
14	Real-Time Optimization of Precast Concrete Component Transportation and Storage [69]	Presenting a dynamic optimization method for the transportation and storage of prefabricated components based on real-time scheduling and tracking. The actual schedule is extracted from BIM-4D, and component positions are tracked during transportation using a system that integrates Global Navigation Satellite System (GNSS) and RFID	time		**BIM RFID**
15	Lead time and quality-driven transport strategies for the wood supply chain [70]	Drawing inspiration from the wood industry, simulating various transportation strategies using DES in management research	time quality		
16	Integrated scheduling optimization of production and transportation for precast components with a delivery time window [71]	Providing an optimal scheduling method for the production, transportation, and unloading of components, using a genetic algorithm to solve the model, and validating it with real organizational data	time		**Genetic Algorithm**
17	Minimizing transportation cost of prefabricated modules in modular construction projects [72]	Formulating and developing an optimal model to minimize the total costs of transportation and storage of prefabricated modules in modular building projects, with successful results in a case study for a healthcare building	cost		**Genetic Algorithm**
18	Damage detection for prefabricated building modules during transportation [42]	Providing a framework to identify defects and failures of prefabricated components during transportation through step-by-step tracking of the transportation process	quality		**Sensors**
19	RESEARCH ON TRANSPORTATION SAFETY OF PREFABRICATED BUILDING COMPONENTS BASED ON SPAABC [73]	Presenting a model to ensure the safety of transporting prefabricated components, categorizing risk factors related to transportation preparation, transport, and storage. The model identifies ten risk indicators, such as transportation operators, transport plans, and stabilization measures for prefabricated components	security risk		
20	Analyzing the benefits of RFID technology for cost-sharing in construction supply chains: A case study on prefabricated precast components [73]	Calculating the benefits of each part of the supply chain against the costs of the component tracking system based on RFID, addressing issues like missing components and delays in delivery, as observed in a case study of prefabricated concrete walls	cost time		**RFID**
21	Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling [74]	Developing a logistic control and planning model for unloading and storing modules at the site using BIM 4D modeling, followed by the development and testing of the proposed model on the trusses of a steel manufacturing company	space		**BIM**

Table 3. Classification of 26 identified articles. (Continued)

22	Integrating off-site and on-site panelized construction schedules using fleet dispatching [75]	Proposing a framework for truck dispatch scheduling using DES and GPS, considering separate scheduling for on-site and off-site operations	time		**GPS**
23	The quality traceability system for prefabricated buildings using blockchain: An integrated framework [76]	Providing a tracking system for the quality of prefabricated components using blockchain, considering factors like traffic plans, lifting equipment, vehicle types, routes, racks, and loading/unloading needs during transportation	quality		**Blockchain**
24	Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS [77]	Proposing an automated system using RFID and GPS to address issues such as late deliveries, double movement of components, and incorrect installation, leading to delays in the entire project schedule and increased labor costs. The system is tested in a case study.	time cost		**RFID** **GPS**
25	Research on the Selection of Logistics Suppliers in the Process of Housing Industrialization [78]	Presenting a logistics supplier performance evaluation model by collecting data from 10 logistics companies in industrialized building projects	human resource		
26	Off-Site Guarding: Look-Ahead Supply Scheduling for Risk Indication With BIM [36]	Examining the reorganization of the supply chain resulting from the use of BIM, followed by solving the risk control problem by using off-site guarding as a link between off-site production and on-site logistics. A predictive schedule for material delivery to the site is proposed and evaluated in a case study	risk time		**BIM**

As shown in Chart 3, there is a clear lack of research in management areas such as safety, supervision, stakeholder involvement, and the relationship between off-site and on-site construction. Additionally, there is insufficient focus on issues like communication between parts suppliers and project agents, claims, and other related cases. This gap in the research suggests that the supply chain of industrialized projects has been underexplored. Most existing research tends to focus on timing issues [36, 41, 43, 59, 62-64, 67, 70, 75, 77, 79] and cost [61, 63, 72, 77, 80], which are not comprehensive enough to address the broader scope of the supply chain.

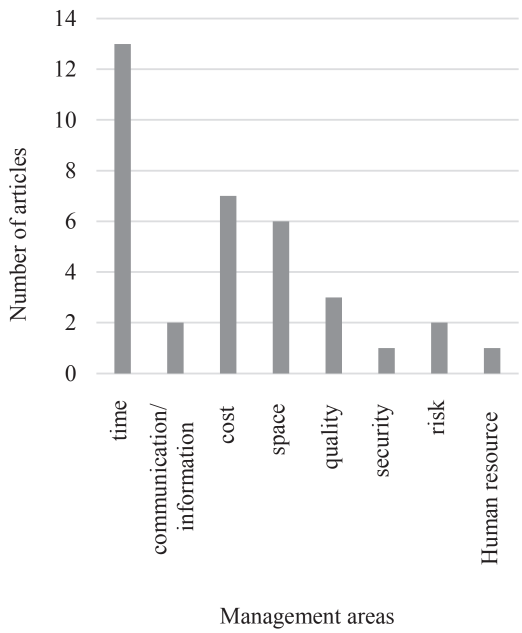


Chart 3. Management areas of 26 extracted articles.

4- 4- Summarizing articles in the field of logistics to identify theoretical gaps

Table 4 provides a classification of articles to highlight these research gaps.

5- Discussion and Conclusion

Given the underdeveloped state of industrialization in Iran's construction industry, there is a need for a detailed identification of the stages in the lifecycle of industrialized

Table 4. Comparative comparison of articles in the field of logistics of industrialized projects.

Row	**Logistics phase**			**Research scale**			**Target variable**								**Other Target variable**			**Technology capability**							
	load	transfer	discharge	Intra-project	intra-organizational	inter-organizational	reduce time	Reduce cost	Improve the use of space	Improve quality	Risk management	Facilitate communication	Increased safety	Resource management	Stakeholder identification	Reduce claims	Facilitate monitoring	Instant tracking of parts	modeling	Optimization	Production of information repository	Chinese scenario for decision making	Identification and positioning	Simulation	**Animating elements**
1	*			*					*											*					
2	*				*				*											*		*			
3	*			*					*																
4	*			*				*												*		*			
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6	*			*			*	*																	*
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8		*	*	*			*					*						*			*				
9		*		*				*												*					
10			*			*	*		*																
11		*		*			*		*											*					
12		*	*	*					*													*		*	
13		*		*								*									*				
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25			*			*								*											
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sum	6	13	12																						
				18	5	2																			
							13	7	6	3	2	2	1	1	0	0	0								
																		7	6	8	3	4	5	1	**3**

*Dark areas in each color spectrum indicate a lack of research.

projects, from a project management perspective. This research, based on a review of 181 articles, identified the three main phases of construction: off-site construction, logistics, and on-site construction. Each phase was further divided into sub-sectors. The most important and widely used technologies in these phases were also identified, including BIM, IoT, AI, and RFID. This finding aligns with the research by Wang and colleagues (2019), who conducted a review of studies in the area of off-site construction supply chains. They stated that the main research approaches include genetic algorithms, RFID, and BIM [81].

Key management areas for the logistics phase were identified, including scheduling, cost, and space management.

Based on the gaps identified in Table 4, the following topics are suggested for future research.

One of the identified gaps is the lack of research concerning the identification of stakeholders involved in the logistics phase of industrialization projects and the evaluation of communication channels among them. Successful implementation of these projects requires the identification of key stakeholders and the relationships between them. It is through stakeholder identification that sustainability goals in such projects, which have become highly relevant in recent years, can be achieved.

Following stakeholder identification, examining the causes of disputes and claims between stakeholders in the logistics phase of industrialization projects is another research gap that arises. Disputes can occur in any project, but given the distinct nature of industrialization projects, they may be more different and complex.

Implementing monitoring and management mechanisms for the logistics phase of industrialization projects is another area for future research that could have significant practical implications. This suggestion becomes particularly important when transporting modules over long distances from various cities or even countries. For example, mechanisms such as RFID and sensors can help track the modules, providing information on their health status and location, as well as identifying shorter or better routes for transportation; for instance, a 20-meter module may not be able to pass under a bridge of a certain height, which must be managed beforehand.

Simulation and optimization of the transportation phase of prefabricated modules to prevent and reduce damage during long-distance transportation is another research topic that is suggested for future researchers; delays in module transportation can lead to delays in module installation and ultimately project completion, which is cost-prohibitive. Additionally, modules may get damaged during transit and have to be returned to the warehouse, incurring significant production and storage costs.

Another proposed research area is the identification of challenges and suggestions for improving coordination between off-site and on-site construction, focusing on the logistics communication link. Considering the unknown aspects of industrialization projects and the absence of a logistics phase in traditional projects, there are many known and unknown challenges in these projects that require identification.

Examining financing mechanisms for the transportation processes of industrialization projects is also among the proposed research topics. The importance of timely financing stems from the fact that these projects, due to a substantial portion of work being done in factories during the production and transportation phases of the modules, exhibit very different cash flow patterns compared to traditional projects. It appears that current regulations concerning payments are inadequate, pointing to the necessity of exploring various financing mechanisms.

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