

## A Systematic Review of Prerequisites for Constructability Implementation in Infrastructure Projects

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### Abstract

Success in infrastructure projects requires success in all phases of the project, including design, construction, and operation. One of the necessary actions for developing countries to construct their economic infrastructures, is implementing infrastructure plans. This industry should focus more on the construction process and utilizing creative tools and new concepts for construction development. The reason of it is because of delivering the project with certain quality, in time and with the given budget. Contractors should have new strategies for construction to optimize project completion, and constructability. Accordingly, constructability improvements have become the concern of construction industry practitioners. Considering constructability issues in the early stages of the project enhances identifying design limitations that prevent capabilities of contractors to take part in planning and improving project performance. The purpose of this study is identifying the prerequisites of constructability to resolve the current problems of projects, including inappropriate plans without implementability, poor decision making in design, and lack of sufficient implementation experience in the design engineering team. This study provides a list of prerequisites for constructability implementation in infrastructure projects. Accordingly, it identifies the prerequisites, using Systematic Literature Review (SLR) technique. The NVivo software is used to facilitate the qualitative analyses.

*Keywords:* Constructability Prerequisites; Systematic Literature Review (SLR); Infrastructure Projects.

### 1. Introduction

The construction industry is faced with serious crises, including ineffectiveness, lack of appropriate productivity, and excessive use of energy and raw material all over the world. Nowadays, developing countries, for their economic growth, should pay more attention than ever to infrastructure projects [1]. Such that infrastructure projects are at the centre of their economic activities and the demand for implementing such projects is increasing. So all over the world, governments are providing comprehensive development of their countries, and seeking for more investments for such projects [2].

Constructability is one of the techniques that connect the implementation and construction phases to the design and planning phases. By reducing additional processes and preventing duplications, constructability has reduced final costs of projects and their delivery time. The results obtained from the previous studies indicate that improved constructability leads to simultaneous saving of cost and time and also significant improvement of quality and safety, which are key factors for successful delivery of construction projects. Therefore, the significance of constructability is evident in these projects [3].

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Constructability is a project management technique, which examines construction logic from beginning to end, in order to identify obstacles, restrictions, and potentials. Using constructability in the initial stages of the project and attendance of contractors in the early stages result in improvement of project performance and consequently, reducing costs, time, wastes, delays, duplications, mistakes, and increasing quality of the project and coordination of its stakeholders [4].

Therefore, constructability improvement should be considered as a part of the whole project lifecycle. Thus, paying attention of the construction industry to constructability and identifying its prerequisites can improve project performance. This is exactly what the present study is looking for. The next section reviews the existing literature to remove the research gap.

This study at first reviews the previous studies related to this issue, including infrastructure projects, building projects, duplications, and constructability. Then, research methodology is described that is descriptive-analytic. Finally, considering the analysis and interpretation of data obtained from Systematic Literature Review, constructability prerequisites are categorized in 3 categories of specialized, technical, and content. In the following we will review the related literature

## 2. Literature Review

### 2.1. Background of Constructability

Constructability concept for the first time was introduced in the United States in 1970, as a technique that connects initial planning and design phases of construction to the implementation stage. Research on constructability concept in the United States has been a part of research plan of *Construction Industry Institute* (CII). This institute has conducted extensive research in the field of constructability. These studies are generally about management of employer and contractors systems. In 1979, *Construction Industry Research and Information Association* (CIRIA) conducted some studies on identifying constructability problems in the construction industry of UK. These studies indicated that constructability problems occur in the construction stages due to lack of cooperation of designers and planners [5]. In Australia, some studies were performed about constructability in 1980. The *Construction Industry Institute of Australian* (CIIA) developed constructability concept in the construction industry of Australia, in an approach similar to that of CII [6]. The Construction Industry Institute, as an Australian pioneer in this field, in 1986 [7] defined constructability as “Optimal use of construction experience and knowledge in planning, design, supply, and implementation phases to achieve all objectives of the project.”

Utilizing constructability at the beginning of Engineering, Procurement, and Construction (EPC) contracts leads to reduced costs by 6 to 23 percent, and also significant reduction of lead time. Othman and Ahmad (2011) stated that constructability should be used as soon as possible; because it directly affects project costs. In fact, Russell et al. [8] concluded that integrating the constructability knowledge in the design stage can save lead-time by about 10 percent.

Traditional separation between engineering and construction at the beginning of the project is reduced by collaboration of teams from various areas. This philosophy needs a change in culture, and analyzes the differences and commonalities between engineering and construction. Moreover, it turns this issue into a permanent and irreversible transformation. Today, many companies use constructability, however they don't refer to this name. For these organizations, constructions are just good management of projects [9].

Considering the studies performed in this field, it can be concluded that constructability is effective in reducing time and cost, and improving projects' quality. The necessity of applying this issue is understanding its principles and concepts reviewed in the next section.

### 2.2. Constructability Principles and Concepts

Constructability principles in infrastructure projects have been identified and used in the past years. Many researchers have agreed that project stakeholders know the significance of implementing constructability principles in different phases of the project. Constructability principles have been examined by a number of organizations and many researchers, for more than two decades. Conducted studies on constructability in the UK describe seven concepts and strategies, including design and planning for site requirements, planning for real chain of operations, planning for facilitating and simplifying combinations, more details of standards, details of increasing tolerance, and selecting safe and appropriate materials. CIRIA develops these 7 constructability principles in 16 principles for the construction industry of the UK. Various aspects of the design are stated in these 16 principles; including comprehensiveness, availability, capacity, time, materials, skills, standardization, using machinery, tolerance, operations' chain, communications, safety, and possible losses.

In the United States, CII have developed 17 constructability principles using viewpoints of various project owners and contractors. The most significant difference between CIRIA and CII principles is that CII principles highlight clearly the significant role of project owners in the decision making process. However, CIRIA principles are just

focused on the design phase. Yet constructability principles based on CII are classified into 3 different groups of conceptual planning, design and supply, and operations [10].

CIIA as a pioneer in constructability studies, has introduced 12 principles in Australia. It is superior to other models, as it considers the best time of using these principles in the project lifecycle. These 12 principles include [7]:

1. Integration: Constructability concept should be implemented in an integrated way in the design phase of the project.
2. Construction knowledge: Project design should actively include simultaneous use of knowledge and experience.
3. Team skills: Combining project team and their abilities, experiences, and skills should match the goals of the project.
4. Common objectives: Defining and understanding common objectives lead to improving project implementability.
5. Available resources: Applied technologies in the design section should be compatible with available capabilities and resources.
6. External factors: These factors are effective in project cost and time planning.
7. Schedule: Project detailed schedule should be implementable and project team should be committed to its implementation.
8. Construction methodology: Constructability should be fully considered in project design.
9. Availability: Considering availability of the construction phase in the design stage will enhance project implementability.
10. Specifications: Constructability should be considered in the development of project specifications.
11. Technology: Using modern innovations and methods will result in improved implementation.
12. Feedback: Project evaluation by an experienced team, after its completion, will be useful for improving constructability of similar projects in future.

The constructability concept has been defined from various views and approaches, due to its abstract nature. Previous studies are presented with different perceptual features of construction, which show various interpretations of constructability features. In addition, it categorizes them into 5 groups: integration of construction knowledge and experience with design, using constructability concept in various stages of the project, facilitation in the construction project, achieving the overall project goals and their optimization, and applying resources to achieve better results [11].

An effective and ideal constructability plan begins during the planning phase and continues conceptually to the end of construction. Many problems of constructability result from lack of communication among the employers, architects or designers, and construction companies before starting the project. Architects, engineers and designers are not experts in constructability, due to the nature of their performance. For this reason, as well as the reasons for sharing responsibility, most performance-specific specifications and plans determine the final result and applications. Lack of communication between designers and contractors often affects performance features, covertly or openly, which is somehow justified. Integrating constructability in the design process in the initial phases will reduce construction conflicts and thus project delivery will be more secure [12].

Applying the mentioned concepts can significantly effect on the project implementation stage. These advantages are elaborated in the next section.

### **2.3. Constructability Advantages**

Constructability should be implemented in the initial phases of the project, and it should consider significant objectives in all stages of construction process. This is because of its impact on project costs and creating added value. Based on construction knowledge and experience, contractors can play a significant role in reducing duplications and wastes and increasing project performance during the design phase [10]. According to the conducted studies, better design, increased quality, reduced wastes, and increased productivity are among the most significant advantages of constructability [13].

In the process of project implementation, the employer, consultant, main and sub-contractors, suppliers, and producers play a significant role together. Various organizations are considered as the main stakeholders of a project. The next important step is establishing effective relationships among these stakeholders. In traditional systems, there are various limitations due to the restrictions imposed by contracts. These limitations are particularly prominent for

building contractors with designers and also maintenance contractors, which lead to conflicts. These conflicts can be mitigated with the help of constructability that allows stakeholders to participate in the early stages of the project [14].

So far, constructability has been used consciously or unconsciously in various projects, and it has been evaluated by various researchers and organizations. The building projects' lifecycle is composed of some phases, including defining goals and tasks, planning, design, implementation, and operation. These phases can be summarized in two main stages of pre-implementation and implementation. Using constructability before project implementation will reduce and/or prevent mistakes, delays, and cost overrun through identifying obstacles. In fact, constructability improves construction process of a project through combining knowledge and practice in all stages of the project to achieve the overall project goals [15].

On the other hand, previous studies show that developing constructability results in saving costs and time, and increases quality and safety. According to the study conducted by Russell [16], constructability advantages can be classified into two qualitative and quantitative categories. Qualitative advantages include increasing avoidance of problems, improving access to the site, reducing barriers, enhancing safety, significant reduction of duplications, increasing focus on objectives, increasing commitment of project team members, increasing communications and team cooperation, facilitating construction, reducing maintenance costs, protection of equipment, significant reduction of transportation, and improving productivity. Quantitative advantages include reducing engineering costs, and reducing construction time and costs (labours, materials, equipment).

Many studies investigated constructability implementation and its potential advantages for project owners, contractors, and designers. The most important advantages include reduced project time and cost, increased quality of construction, creating a safe environment in the site, reduced problems and unexpected changes, and increased communication and teamwork [11].

In addition, Arditi et al. (2002) [17] has identified and ranked constructability advantages in the design companies. In this ranking, improving relationships with customers and contractors, less engagement in lawsuits, earning reputation in construction, professional satisfaction, and effective designing have been listed. Considering the advantages of constructability in project improvement, identifying constructability prerequisites in implementing this technique and helping effective performance of projects for reducing time, cost, increasing quality and reducing duplications are very important. Since it seems so far no study has been conducted in the field of identifying constructability prerequisites using an in-depth Systematic Literature Review (SLR), in the following section we will examine this methodology to achieve the objective of this project.

### 3. Research Methodology

SLR is a comprehensive review of texts that addresses a clear research question. In this type of review, a systematic and clear method is used for identification, selection and critical evaluation of all related studies and also collecting and analyzing data obtained from available studies [18]. SLR is basically designed for answering a research question based on unbiased assessment of all the previous studies related to that issue. SLR decreases the uncertainty about a topic, identifies issues that there is no sufficient evidences for them, creates a new viewpoint by combining findings obtained from various studies, announces the time that sufficient evidences are available, and reduces the effect of any mistake on a study [19].

Authors present almost the same stages for conducting the SLR approach, some of which can be integrated into others. Accordingly, we state a seven step approach that is usually used in SLR, as presented in the below flowchart.

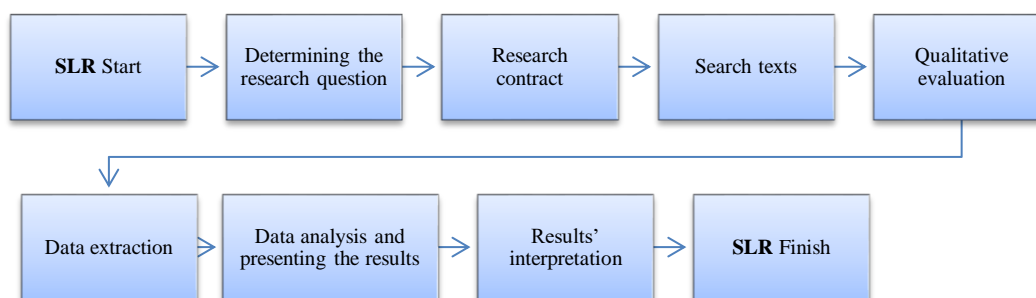


Figure 1. Steps of conducting SLR [20]

At the end, the researcher extracts some codes for data classification in the NVIVO software, which indicate a comprehensive concept of the desired subject. Then data are analyzed accordingly.

## 4. Data Analysis

### 4.1. Determining the Research Question

To begin, a research question with great significance should be set. If the question is rigorous, limited studies will be found and generalizability of the findings will be reduced. On the other hand, if the question is too unlimited, it is likely that practical conclusion even for a single population be difficult [21]. Accordingly, the research question is determined as:

- What are the constructability prerequisites in projects?

### 4.2. Research Contract

The protocol refers to reviewing a transparent plan to orient the SLR, and provides the appropriate strategy to select the preliminary studies. The next section introduces the protocol used to orient the studies of this research. The steps of this protocol are as follows [22]:

- Context

According to the research subject, which is identifying constructability prerequisites, in the last section we examined constructability history, definition, principles, and concepts.

- Research questions

The aim of conducting SLR in this section is determining the following question:

What are the constructability prerequisites in projects?

- Research strategy and data resources

By reviewing the SLR, the closest answers to research questions can be found through reviewing the preliminary studies. To this end, the way shown in the following flowchart has been used.

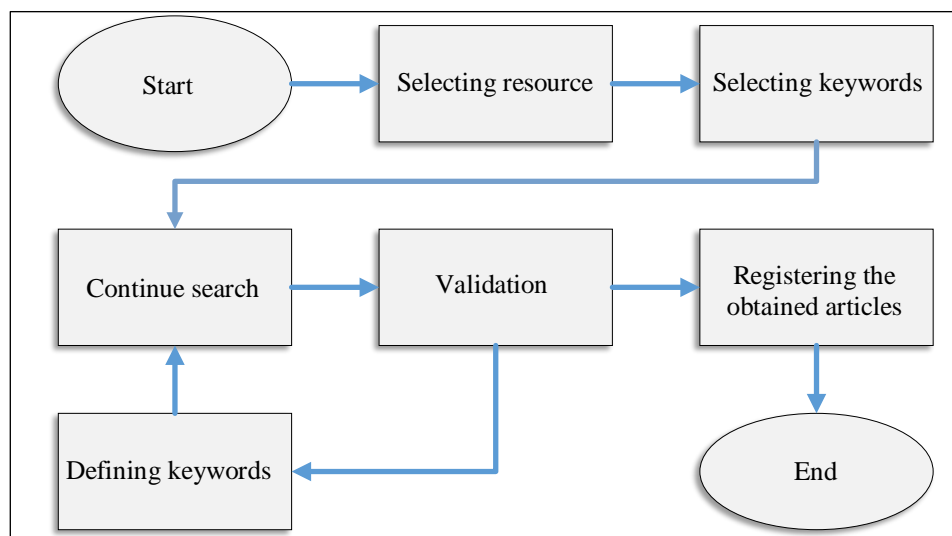


Figure 2. Research strategy

The research findings depend on database and keywords used in the research. The keywords are extracted from the research questions. The keywords to search for are combinations of population and intervention. The following keywords are considered for the question of this research.

Table 1. Determine the constructability keywords

Population	Intervention
“Constructability” OR “Buildability”	“Requirement” OR “Need” OR “Improvement”

In the next stage, in order to identify the best and the most relevant articles, inclusion and exclusion criteria were defined based on research question. These criteria were applied based on title and abstract of studies. In the next step, criteria were considered based on experimental issues such as article’s language, author, population, research plan, sampling method, date of publication, etc.

### 4.3. Search and Selection of Texts

The next step includes search and determination of related studies in the existing texts, which may respond the

research question. Make sure that searched texts are compatible with what is stated in contracts. For selection, consider well inclusion and exclusion criteria [21].

Inclusion and exclusion criteria considered for selecting articles, include the following items:

Inclusion criteria:

- Initial studies related to research questions
- Subject of the article should be related to the subject of research question.
- Articles describe constructability.
- Full text of the article is available

Exclusion criteria:

- Removing duplicate studies
- Articles that do not explain advantages of modeling building information.
- Articles that are not in English or Persian.
- Articles that are published in the websites of companies

The results show total number of found articles with any keywords in. No result was obtained through search with "Constructability Requirement" and "Constructability Needs" keywords, so "constructability Improvement" keyword was used in searches. The reason for using this keyword was lack of articles with "Need" and "Requirement" keywords. So we decided to use "Improvement" keyword, and considered this issue that the necessity of constructability improvement is identifying its needs, and in this way we can identify constructability needs. In the following we will explain it in detail.

At first, the number of articles found in the desired websites was 432, 142, 110, and 10, respectively. Search for the keyword "constructability improvement" was also performed. Then, articles with titles outside the scope of review were removed and 73 articles were identified. Inclusion and exclusion criteria such as article's language, full access to article, book chapters and etc. were applied in the initial search.

**Table 2. Secondary search results constructability articles**

Search Keywords	Google scholar		Sciencedirect		Springerlink		ASCE		Civilica	
	Searched Articles	Selected Articles	Searched Articles	Selected Articles	Searched Articles	Selected Articles	Searched Articles	Selected Articles	Searched Articles	Selected Articles
"Constructability" or "Buildability"	432	33	142	6	13	2	110	15	10	0
"Constructability Improvement"	130	8	6	0	6	1	10	8	0	0
<b>Total</b>	562	41	148	6	19	3	120	23	10	0

In the main search, there were various types of articles, including experimental academic articles, case studies, etc. At this stage, search was conducted based on keywords and studying the abstract of articles obtained from the previous stage. Finally, 51 articles were found.

**Table 3. Secondary search results constructability articles**

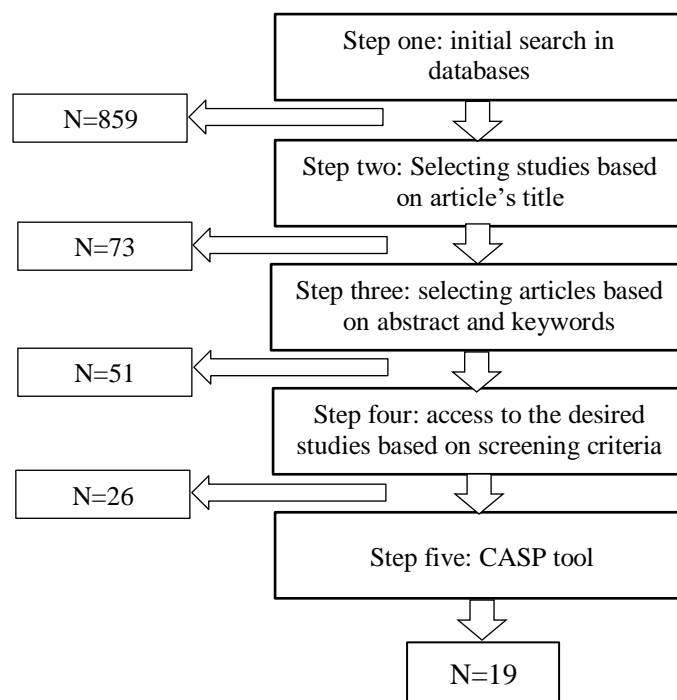
keywords	Google scholar	Sciencedirect	Springerlink	ASCE	Civilica
"Constructability" or "Buildability"	27	5	0	9	0
"Constructability Improvement"	5	0	0	5	0

#### 4.4. Quality Evaluation

- *Step one:* Through searching the determined keywords in the desired databases, 859 articles found.
- *Step two:* By studying the title of articles and reviewing their connection with research question, irrelevant articles were deleted and 73 articles remained.
- *Step three:* The abstract and keywords of the selected articles were examined and cases irrelevant to research question were deleted and 51 articles remained.
- *Step four:* Among the remaining articles, those incompatible with the defined screening criteria were deleted and 26 articles remained.



- *Step five:* Contents of the selected articles were studied and cases didn't gain the required score through CASP, were deleted and finally 19 articles remained.



**Figure 3. Steps of selecting articles**

In fact, CASP pattern tool includes 10 indices similar to a check list, which help the researcher in evaluating accuracy, reliability, and significance of studies. By using this tool, the researcher assigns a score between 1 and 5 to each index, which indicates qualitative rank of the article from very good to very poor, and classifies the articles. Since in this method, inclusion and exclusion criteria depend on the type of study and the opinion of researcher, this scoring is reliable.

The scores are very good (5), good (4), medium (3), poor (2), very poor (1). Generally, their qualitative score is also classified based on a 50 score scale, as very good (41-50), good (31-40), medium (21-30), poor (11-20), and very poor (0-10). According to this classification and based on the table, poor and very poor articles were deleted. Consequently, from 26 articles, 19 articles were evaluated for more analysis and achieving the answer of the question. Finally after careful examination, NVIVO QSR software was used for classifying the findings.

**4.5. Data Extraction**

The basis of extracting components, can be answering the following questions:

- Is the article addresses constructability significance and improvement?
- Are the goals of the article clearly stated?
- Has the article referred to the answers to the research questions?

According to these criteria, data were extracted in the designed forms and duplicated articles were deleted. During the initial and secondary analysis, by examining title, abstract, conclusion, and desired text of the article, the answers to the research question were examined more precisely. The extracted data are presented in the following table.

**Table 4. Extract constructability data**

Row	References	Constructability requirements
1	[23]	1. The necessity of communication and coordination among designers and engineers 2. Reviewing the design process 3. Increasing understanding of engineers about the project 4. Familiarity with construction techniques
2	[24]	1. Familiarity with new methods of construction 2. Familiarity of contractors with modern technologies 3. Relationships among all project stakeholders 4. Sharing knowledge and experience of all members of the project team 5. Using a strong support program

3	[25]	<ol style="list-style-type: none"> <li>1. Communication and coordination in the project</li> <li>2. Mutual cooperation and respect among project team members</li> <li>3. Using team work skills</li> </ol>
4	[26]	<ol style="list-style-type: none"> <li>1. Presenting feedback to designers</li> <li>2. Using experiences of contractors in the design phase</li> <li>3. Participation of contractors in the review process</li> <li>4. Communications among project stakeholders</li> <li>5. Cooperation of project team members</li> <li>6. Cost allocation for constructability implementation</li> <li>7. Commitment to create clear and high quality designs</li> <li>8. Using design standards</li> <li>9. Using previous lessons learned</li> </ol>
5	[27]	<ol style="list-style-type: none"> <li>1. Integration of project team members</li> <li>2. Awareness of construction knowledge</li> <li>3. Visualizing project environment before the construction phase</li> <li>4. Reviewing project design</li> <li>5. Having a correct program to achieve project objectives</li> <li>6. Improving documentation of project documents</li> </ol>
6	[28]	<ol style="list-style-type: none"> <li>1. Considering and familiarity with construction knowledge in the initial stages of the project</li> <li>2. Awareness and knowledge of designers about project site and construction methods</li> <li>3. Integrating knowledge and experience of team members</li> <li>4. Improving communications and cooperation</li> </ol>
7	[29]	<ol style="list-style-type: none"> <li>1. Using lessons learned from previous studies</li> <li>2. Design standardization</li> <li>3. Using knowledge and experience of project stakeholders in the initial stages of the project</li> <li>4. Using documentation methods</li> <li>5. Using development tools and equipment</li> </ol>
8	[30]	<ol style="list-style-type: none"> <li>1. Integration of project team and increasing communications</li> <li>2. Cooperation of design and construction teams</li> <li>3. Having experience and knowledge by project members</li> <li>4. Using knowledge management</li> <li>5. Using appropriate contracts for the presence of contractors from the beginning of the project</li> <li>6. Increasing communications of project stakeholders</li> <li>7. Finding, maintaining, and reusing experimental knowledge about constructability and improving knowledge management in the company</li> <li>8. Familiarity with technical knowledge about the project</li> <li>9. Improving understanding of project environment</li> <li>10. Project visualization</li> <li>11. Careful understanding of project objectives</li> <li>12. Understanding employer needs</li> </ol>
9	[31]	<ol style="list-style-type: none"> <li>1. Communication with construction agents during the design phase</li> <li>2. Sharing experiences and knowledge of contractors with designers for better performance</li> <li>3. Early participation of contractors in the project</li> <li>4. Integration</li> <li>5. Effective team building</li> </ol>
10	[32]	<ol style="list-style-type: none"> <li>1. Full data collection from project site</li> <li>2. Using simplified and improved designs</li> <li>3. Visualizing project environment and any physical interventions</li> <li>4. Synchronization of available skills and resources by technologies used in the design</li> <li>5. Presenting full and clear information about the previous plan, from the beginning of construction</li> <li>6. Considering design and construction standards</li> </ol>
11	[33]	<ol style="list-style-type: none"> <li>1. Participation of stakeholders in the constructability activities</li> <li>2. Using innovative construction methods</li> <li>3. Using lessons learned</li> <li>4. Using coordination sessions</li> <li>5. Understanding constructability concepts</li> <li>6. Using competent staff</li> <li>7. Participation of construction team from the beginning of the project</li> <li>8. Exchanging informations and experiences of previous projects</li> <li>9. Increasing communications and coordination among team members</li> </ol>



12	[34]	<ol style="list-style-type: none"> <li>1. Communication of employer, consultant engineer, designer, and contractor</li> <li>2. Knowledge interaction</li> <li>3. Increasing communications and coordination among all project stakeholders</li> <li>4. Attention of designers to constructability</li> <li>5. Reviewing the design and construction process</li> <li>6. Understanding project information and its environment</li> <li>7. Paying special attention to the design phase</li> <li>8. Increasing integration of project phases</li> <li>9. Increasing knowledge about construction methods</li> <li>10. Using experiences of construction contractors in the design phase</li> <li>11. Using guidelines of constructability implementation</li> <li>12. Enhancing cooperation among project team</li> <li>13. Reviewing designs to reduce errors</li> <li>14. Increasing discussion and exchange of ideas among designers and other team members</li> <li>15. Improving project documents management</li> <li>16. Paying attention to the design phase</li> </ol>
13	[35]	<ol style="list-style-type: none"> <li>1. Finding and transferring lessons learned and experiences of previous projects</li> <li>2. Participation of contractors in the design phase</li> <li>3. Awareness of constructability advantages</li> <li>4. Using team building and participation skills</li> <li>5. Mutual respect between contractor and designer</li> <li>6. Communication skills among team members</li> <li>7. Integration of project stakeholders</li> </ol>
14	[36]	<ol style="list-style-type: none"> <li>1. Knowledge about constructability concepts</li> <li>2. The desire to allocate costs for constructability implementation in the initial phases of the project</li> <li>3. Teambuilding and strong participation among members</li> </ol>
15	[37]	<ol style="list-style-type: none"> <li>1. Familiarity of designers with details of construction</li> <li>2. Coordination and communication among project stakeholders</li> <li>3. Cooperation among architects and civil engineers</li> <li>4. Familiarity with construction methods</li> <li>5. Awareness of designers about construction rules</li> <li>6. Understanding the situation and conditions of project site</li> </ol>
16	[38]	<ol style="list-style-type: none"> <li>1. Coordination and communication among employer, designers, and contractors</li> <li>2. Using modern construction methods</li> <li>3. Awareness of project stakeholders about constructability</li> <li>4. Using advanced information technologies</li> <li>5. Coordination of design documents and working environment</li> </ol>
17	[39]	<ol style="list-style-type: none"> <li>1. Communication skills all over the project</li> <li>2. Coordination among project team members</li> <li>3. Interaction among team members and adoption of computer models</li> <li>4. Clarity of design information</li> </ol>
18	[40]	<ol style="list-style-type: none"> <li>1. Communication among project stakeholders</li> <li>2. Transferring experiences of contractors to engineers during the design process</li> <li>3. Understanding advantages of constructability implementation</li> <li>4. Using experts</li> <li>5. Considering constructability techniques as a part of the project</li> <li>6. Official commitment of members to constructability</li> <li>7. Participation of contractors from the beginning of the project and design phase, accompanied with designer and employer</li> <li>8. Priority to use new construction contracts than the traditional</li> </ol>
19	[41]	<ol style="list-style-type: none"> <li>1. Entrance of contractors to the design team</li> <li>2. Appropriate attention to the construction methods in the design phase</li> <li>3. Awareness of new methods of construction</li> <li>4. Using team building and team work skills</li> <li>5. Improving data collection methods</li> <li>6. Identifying limitations and barriers</li> <li>7. Developing programs</li> <li>8. The possibility of evaluating design options</li> <li>9. Considering environmental factors (technology, economic, social, ...)</li> <li>10. Improving information and communication</li> </ol>

		<ol style="list-style-type: none"> <li>11. Improving creativity and innovation</li> <li>12. Matching technology with available skills and resources</li> <li>13. Increasing integration of components</li> <li>14. Considering standards</li> <li>15. Using information technology</li> </ol>
20	[42]	<ol style="list-style-type: none"> <li>1. Increased integrity of construction</li> <li>2. increased team collaboration and coordination</li> <li>3. effective use of labor and materials and capital</li> <li>4. using new technologies</li> <li>5. improved relations and communication</li> <li>6. improving executive changes</li> <li>7. better planning</li> <li>8. improved relationships between the design and construction units</li> <li>9. integrating knowledge and experience</li> <li>10. the use of new ideas</li> <li>11. integrating construction knowledge in the project delivery process</li> <li>12. resolving deviations in the design phase</li> </ol>
21	[43]	<ol style="list-style-type: none"> <li>1. increasing design quality</li> <li>2. improving design and construction changes</li> <li>3. increasing communication and coordination among all project stakeholders</li> <li>4. exchanging information and ideas between the design and construction teams</li> <li>5. resolving productivity wastes at the design stage through optimizing data transfer and exchange among all activities</li> </ol>

#### 4.6. Data Analysis

At this stage, all of the items extracted from the articles were classified in similar groups. Each category was considered in a specific subgroup, which is presented in the following table.

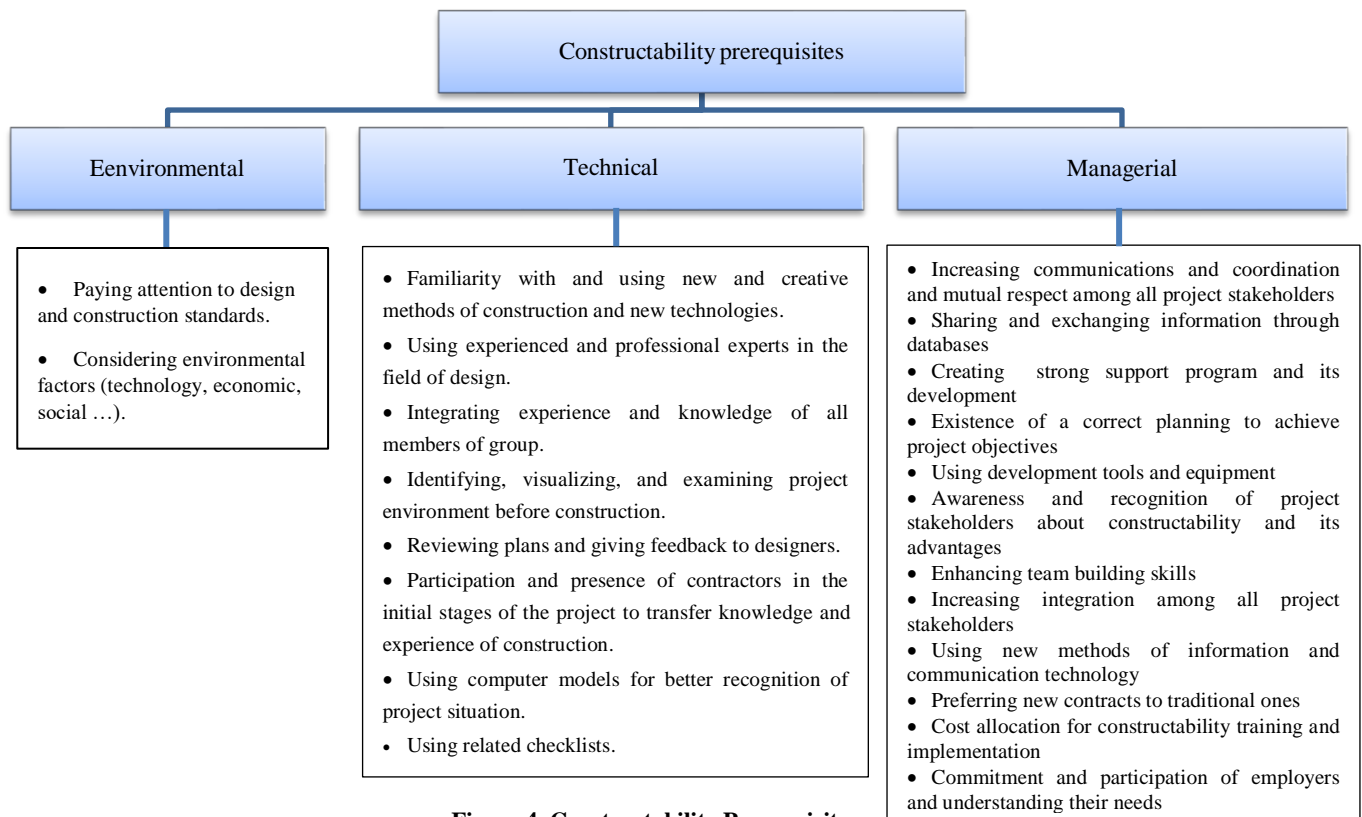
**Table 5. Extract constructability prerequisites codes**

Factors	Constructability prerequisites codes	Resources
managerial	Increasing communications, integration, coordination, and mutual respect among all project stakeholders	[24 – 34, 37, 39, 40, 42, 43]
	Sharing and exchanging information through database, documenting previous projects and lessons learned, and fast and easy access to them by all of team members	[24, 26 -35, 38, 39, 41, 43]
	Creating a strong support program and its development	[24]
	Existence of a correct planning to achieve project objectives	[27, 41]
	Using development tools and equipment	[29]
	Knowledge of project stakeholders about constructability and its advantage	[27, 34-36, 38, 40]
	Enhancing team building skills	[25, 31, 35, 36, 41]
	Increasing integration among all project stakeholders	[30, 33, 34, 35, 38, 39]
	Using new methods of information and communication technology	[38, 41, 42]
	Preferring new contracts to traditional ones	[30, 40]
	Allocating cost for constructability training and implementation	[26, 33, 34, 36]
	Commitment and participation of employers and understanding their needs	[33, 40]
	Technical	Familiarity with and using new and creative methods of construction and new technologies
Using experts experienced in the field of designing		[26, 30, 33, 37, 40]
Integrating knowledge and experience of all team members		[28, 30, 42]
Identifying, visualizing, and reviewing the project environment before construction		[28, 34, 37]
Reviewing plans and presenting feedback to designers		[23, 26, 27, 32, 34, 41]
Participation and presence of contractors in the initial stages of the project to transfer construction knowledge and experience		[23, 26, 28,29, 31, 34, 35, 40, 41]
Using computer models for better identification of project situation		[23, 25, 27, 30, 32]
Using related check lists	[41]	
Environmental	Paying attention to design and construction standards	[26, 29, 32, 37, 41]
	Considering environmental factors (technology, economic, and social, ...)	[41]

#### 4.7. Presenting and Interpreting the Results

By studying the selected articles, we found that each article refers to a number of constructability needs. Generally, we classified the findings through reviewing constructability needs and their improvement, and we considered similar items as one. According to what is obtained from reviews, we can classify constructability needs in three groups of managerial, technical, and environmental ones. By observing the results we find that content factors, including organization structure, management factors, and decision making, require the most attention to identify constructability prerequisites and to provide the related solutions to resolve them. Most of the constructability prerequisites originate from inside of an organization and depend on decisions of senior managers.

In this regard, awareness of managers about the significance of constructability and identifying its needs are very important. Because understanding these needs by organization stakeholders leads to finding effective solutions to improve constructability of projects. Then, professional and technical factors are important, such that professional knowledge of construction factors, using new methods of construction, using appropriate plans with the project situation, and understanding and visualization of project before construction have been identified as significant prerequisites of constructability. If these prerequisites are realized, they will result in reducing errors, wastes, duplications, and delays. Employing professional and experienced staff in this field accompanied with new methods of information and communication technologies, help improving constructability. Finally, there are some external factors, which are effective on the growth or decline of the organization, such as cultural, environmental, and social factors and other rules and standards of design and construction, which can be classified under the group of context factors. Identifying these needs leads to finding solutions to resolve them. According to the findings and their classification, the following figure presents constructability prerequisites in the form of three factors of content, professional, and context.



#### 5. Discussion

According to what has been said so far, applying constructability at the early stages of the project can significantly reduce the risk of investment in projects [44]. Reducing investment risk due to applying constructability at the early stages of the project is significant. The role of constructability throughout the process should not be overlooked, because as the project performance increases, the decision making power, the influence of designers and stakeholders of the project decreases, and the costs increase dramatically. Therefore, to achieve the goals of the project, constructability studies should be conducted at the beginning of the project. This issue helps identifying the obstacles to its implementation in order to reduce wastes and prevent mistakes, delays, duplications, and consequently reduce time and cost [36]. Lack of proper communication among the employers, contractors, and designers before beginning the project and in during its implementation causes many constructability problems [45].

The most significant prerequisites for constructability include increased communication and integration and sharing and exchange of project information across all its practitioners. In fact, with the rapid growth of technology, global competition, and projects' complexities, it is important to collect and transfer various information, skills, and experiences and integrate them into one work unit [44]. In fact, with increased communication and coordination people understand each other's priorities, which results in describing new ideas and using advanced methods. On the other hand, it is more effective to resolve the problems through performance feedback. The members understand conflicts, which this is considered as an opportunity to resolve the problem. It also reduces stress during the project lifecycle and leads to mutual trust and respect among project members [13].

Another prerequisite for constructability identified through SLR in this study is the awareness and knowledge of project practitioners about constructability and understanding its benefits and also integrating the experience and knowledge of all project members. Management's commitment to use constructability techniques and having the relevant experience helps identifying and resolving constructability prerequisites. Finally, the early presence of the contractors from beginning of the project and the design stage is necessary to improve project constructability. As found through SLR, the presence of the contractors while designing, offers the designers a good execution perspective. This issue is one of the most significant factors of reducing duplications, enhancing the quality of projects, and most importantly, it helps the projects to be constructible [46].

Factors such as not knowing the details of design of a project, incorrect estimation of time and cost, lack of coordination and communication among project practitioners, lack of using team building and participation skills, unspecified responsibilities and tasks of practitioners, lack of sufficient knowledge of construction, lack of using modern construction methods, lack of realistic planning, and insufficient feasibility studies, lack of awareness of employers about the advantages of team work and poor thinking system and participatory decision making are identified as constructability prerequisites and emphasize the necessity of using constructability [15].

Many problems of projects, such as increased time and cost, increased duplications and wastes, increased changes during project implementation, lack of design integration, and poor implementation system of project, are due to lack of information exchange and useful and effective communication in the design and construction phases, and ignoring the effects of design decisions in constructability of the plan. This issue indicates that by integrating constructability in the design phase at the early stages of the project, there will be less construction conflicts and thus safer project delivery [47].

According to the above, it is necessary to identify the prerequisites for constructability in infrastructure projects. Conducting constructability studies at the beginning of the project reduces duplications and increases productivity of projects.

## 6. Conclusion

This study has been conducted to identify the prerequisites for constructability and is important in improving productivity and performance of infrastructure projects.

Given the current problems of construction projects and wastes, duplications, conflicts among stakeholders, high cost and time, and lack of proper productivity, project practitioners should pay more attention to the significance of constructability and its implementation. The interaction among planning, design and engineering and construction improves constructability; which results in significant saving of time and cost. Many of constructability problems arise from lack of coordination and cooperation among project practitioners. This issue can be addressed by integrating design and construction and increasing communication among project stakeholders in order to achieve the common goals determined for the project.

Considering the findings of this study, the needs for constructability are categorized into three groups of content factors, professional factors, and contextual factors. Looking at the results, we find that the factor that should be considered more than others to identify the prerequisites for constructability is the content factor. Knowing that the content factor comprises most of the management decisions, therefore, the most intra-organizational prerequisites for constructability of this factor involve management decisions. Accordingly, most of the prerequisites for constructability that are internal to the organization depend on the decisions of managers of the organization. Thus, it is necessary that managers be aware of the significance of constructability and identify its needs. Being aware of the significance of these needs will help identifying and considering the appropriate and effective solutions to improve them. For example, the use of experts and new methods of information and communication as one of the solutions to improve the prerequisites for constructability help enhancing the function of this concept.

Considering what has been said and the need to identify the significance of prerequisites for constructability in infrastructure projects and reducing duplications and increasing productivity, it is hoped that practitioners in the construction industry, particularly managers, be aware of these prerequisites to be able to improve the projects' constructability. It is suggested to find solutions for constructability implementation, particularly a functional

framework for implementing this issue in construction projects, considering the conditions governing the construction industry. Moreover, some suggestions are presented for infrastructure projects' success and improvement and providing constructability prerequisites in these projects according to the obtained results, including:

- More coordination between design engineers and executives;
- Holding training sessions for managers and employers' knowledge about the benefits of constructability implementation;
- Early presence of all project practitioners from beginning of the project;
- The significance of knowledge management and its improvement in organizations;
- Promotion of teamwork culture and team- building skills;
- Increasing communications and integration;

Finally, it is suggested that future studies address identifying the constructability prerequisites and the processes required for its proper implementation.

## 7. Conflicts of Interest

The authors declare no conflict of interest.

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