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# An Extensive Content Analysis of Constructability for Transportation Projects

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**Abstract**
Constructability is considered an effective management tool to optimize a project development process and meet the project's objectives. Constructability implementation aims at integrating construction knowledge, resources, technology, and experience into the engineering and design phases of construction projects. Constructability, if applied properly, can optimize the quality of design plans, cost and schedule estimates, and the utilized construction methods. Many researchers and industry practitioners investigated constructability over the past decades. Constructability issues and concepts, benefits, implementation strategies, and approaches and tools have been extensively investigated. However, there are few studies, if any, that have conducted a thorough literature review of constructability-related literature. To address this knowledge gap, this paper intends to analyze and synthesize previous research efforts as well as industry practitioners' efforts regarding constructability implementation across transportation projects. The authors collected and conducted a content analysis for 191 documents related to constructability implementation, in transportation projects, in the last 30 years. These documents include both journal articles and technical reports. The content analysis intends to reevaluate the conceptualization of constructability by providing a comprehensive set of trends in constructability concepts and barriers. This study contributes to both construction body of knowledge and practices by synthesizing essential issues and recommendations in constructability implementation across transportation projects.

## 1 INTRODUCTION

The construction industry contributes directly to 4.1% of the Gross Domestic Product (GDP) in the U.S. (U.S. Department of Commerce–Bureau of Economic Analysis 2019). In recent years, the construction industry has faced a challenge to overcome the global financial recession and to deliver transportation projects of better quality (Kifokeris and Xenidis 2017). The number of claims and disputes recorded during the development of transportation projects are a main concern to both owners and contractors. Ogburn and El-adaway (2014) documented that a total of $5 billion are registered annually as construction claims and disputes. In the U.S., construction claims develop either by contractors, for any additional unlawful extra cost, or by the owner for any additional cost incurred as a result of unacceptable contractor performance (Ogburn and El-adaway 2014). In both cases, the extra amount of cost and time added to the project is registered as change orders. According to Borad et al. (2004), change orders account for cost and time overruns across transportation projects. Further, researchers found that typical reasons for cost growth involve lack of communication and coordination, shortage of experienced personnel, and improper planning and construction (Ogburn and El-adaway 2014; Stamatiadis et al. 2014). Fisher and Tatum (1997) correlated the inability of projects to meet performance objectives to the disintegration between design and construction. There is a need for investigating and developing management concepts that assist in reducing the gap between various project participants and promoting more integration.

Constructability considered as an effective management tool to optimize project development and meet its objectives (Ford et al. 2004; Stamatiadis et al. 2017). According to Anderson et al. (1999) and Anderson et al. (2000), constructability aims at integrating construction knowledge, resources, technology, and experience into the engineering and design phases of projects. The ASCE (1991) indicated that

constructability optimizes the quality of project documents, the reliable cost and schedule estimates, and the utilized construction method. Specifically, Russel et al. (1994) divided the benefits into two main categories; qualitative and quantitative benefits. Qualitatively, constructability benefits construction projects in terms of cost, time, and quality, in the sense that it fosters collaboration and removes project constraints (Kifokeris and Xenidis 2017). In addition, reduced disputes, better understanding of project goals, enhanced communication, safety and accessibility, and risk control processes, are examples of other qualitative benefits. Quantitatively, Anderson et al. (1997) argued that every single dollar spent on constructability could result in $25 savings to the project. Similarly, Douglas (2008) indicated that the cost benefits of constructability reaches 10:1 Return on Investment (ROI), while the ASCE (1991) argued that it reaches up to 10-20 times the implementation cost. Stamatiadis et al. (2017) found that incorporating constructability into a construction project eliminates 1.25% of the anticipated change orders, which accounts for almost $170,000 savings on owner's expenses.

A wide range of studies investigated constructability benefits. However, a systematic analysis of constructability of transportation projects is limited. Specifically, constructability was discussed in parts, but a comprehensive content analysis has not been conducted. The main objective of this paper is to analyze previous research efforts as well as industry practitioners' efforts regarding constructability of transportation projects. The research objective was formulated with two main aims: (1) to conduct content analysis of constructability-related literature on transportation projects, and (2) to provide researchers and practitioners with a set of recommendations to overcome existing barriers and issues. The following sections present overview of constructability related literature and content analysis, along with a comprehensive discussion.

## 2 LITERATURE REVIEW AND BACKGROUND

The literature on constructability addressed various practicalities and terminologies of its implementation. The Construction Industry Institute (CII) defines constructability as "*the optimum use of construction knowledge and experience in planning, designing, and procurement and field operations to achieve the overall project objective*" (CII, 1986). This definition implies that integrating construction knowledge early into the project development process (PDP) enhances the overall project performance. Similarly, Gransberg and Douglas (2005) and Stamatiadis et al. (2014) agreed that considerable amount of savings could be achieved by bringing contractors to the design process.

Across the industry, constructability advances slowly and lacks for consistent standard processes (CII 1993). A white paper conducted by ASCE in 1991, to evaluate constructability advancement across the industry, concluded that current constructability programs vary dramatically (ASCE 1991). This finding was supported by Anderson et al. (2000) and Gransberg and Douglas (2005). Dunston et al. (1999) related the low and inconsistent application across the industry to the lack of understanding and awareness of constructability issues and concepts among practitioners. To overcome inconsistency, the National Cooperative Highway Research Program (NCHRP Report 390) developed an industry wide constructability implementation framework to guide state departments of transportation (DOTs) (Anderson and Fisher 1997). The American Association of State Highway and Transportation Officials' (AASHTO) sub-committee construction members supported the findings of the NCHRP 390 report, and provided a best practice guide to direct practitioners during implementation (AASHTO 2000). In 2002, an industry wide survey found that constructability is gaining approval in the industry, and that various new methods and techniques are used, but the issues and barriers of implementation still existed and need to be properly addressed (ASCE 2002).

The main issue associated with constructability implementation is the inability of reviewers to obtain early construction inputs in a timely manner. Gibson et al. (1996) correlated this issue to the inability of agencies to integrate construction knowledge into the design process, especially if the traditional design -bid-build (DBB) delivery method is utilized. To overcome such an issue, state DOTs have deployed alternative contracting methods, such as design-build (D-B) and construction-manager-general-contractor (CM/GC), as well as alternative technical concepts (ATCs). ATCs enable agencies from accessing construction knowledge early during the project and design development. However, the NCHRP Synthesis 455 found that ATCs are hindered in highway projects due to the perceived difficulty of allocating contractors to revise decisions made during the environmental permitting process to receive NEPA approval to proceed. This prevents DOTs from performing innovating approaches after the NEPA permit is approved. State DOTs, in most, lack of flexible decision-making frameworks suitable for all contracting methods, and consider all

environmental requirements, which hinder state DOTs from properly evaluating the benefits obtained by incorporating constructability and industry inputs into their projects.

## 3 RESEARCH METHODOLOGY

This paper adopts a three steps methodology to examine constructability. Step 1 involves collecting all constructability related documents. Step 2 involves sorting out the documents that are directly related to transportation projects by applying an inclusion and exclusion criteria. Step 3 commences with a comprehensive content analysis over the collected documents to examine, identify, and prioritize common constructability concepts and issues. The research concludes by presenting a group of practices and procedures recommended for transportation agencies to implement their constructability processes.

### 3.1 Documents Collection

The main purpose of step 1 is to collect all documents related to the research objectives. The collection process targeted all scientific journals that researchers used extensively in the construction engineering and management field. Journals' selection was guided by the ranking provided by UPR (2011) and Wing (1997) for construction management journals. In addition, the research targeted all technical reports that were developed by industry practitioners, including existing guidelines and standards related to constructability of transportation projects. In total, 270 documents initially collected from the reviewed sources. The collected documents were then refined using an inclusion and exclusion criteria discussed in the next section.

### 3.2 Inclusion and Exclusion Criteria

The main purpose of step 2 is to select only the documents that are directly related to the research scope for further investigation. The inclusion and exclusion criteria adopted for this research paper include:

- The document must address at least one out of six aspect of constructability: constructability issues, tools, benefits, concepts, timing, and/or recommendations.
- The document must be related to transportation projects only.

The result from this step provided with a total of 191 documents for further analysis.

### 3.3 Content Analysis

Step 3 was carried out using a detailed content analysis over the 191 documents. Content analysis is a technique used by researchers to determine the existence of a specific set of words in a group of documents. Using content analysis, researchers first quantify and evaluate the existence of words and then asses the relationships between them to conclude the messages implied within those words. The findings are presented in terms of frequencies and percentages. Frequencies were obtained directly from the content analysis software (Nvivo Pro 11), and it represents the number of documents interpreted to the constructability aspect under investigation. Percentages represent the frequency of using each aspect divided by the total number of documents selected for analysis (n =191).

## 4 RESULTS AND ANALYSIS

Two main types of documents were considered for analysis; journal articles and technical reports. An initial analysis showed that almost 57% (n=108) of documents were journal-based articles, and nearly 43% (n=85) were technical reports. Journal- based articles are divided into two groups. The first group contains the majority of constructability related articles (86%, n=93) and include the following fifteen journals: Journal of Construction Engineering and Management (JCEM), Journal of the transportation Research Board (TRB), Automation in Construction (AC), Journal of Performance of Constructed Facilities (JPCF), Journal of Management in Engineering (JME), AACE International Transactions (AACEIT), International Journal of Project Management (IJPM), Practice Periodical on Structural Design and Construction (PPSDC), Journal of Legal Affairs and Dispute Resolution in Engineering and Construction (JLADREC), Procedia Engineering (PE), Engineering, Construction and Architectural Management (ECAM), Automation and Robotics in Construction (ARC), International Journal of Quality & Reliability Management (IJQRM), Journal of Computing in Civil Engineering (JCCE), and Journal of Architecture Engineering (JAE). Contrary, the second group contains only 14% (n=15) of journals-based articles, and referred to as "others". Figure 1 illustrates the percentage distribution of articles published in each journal.

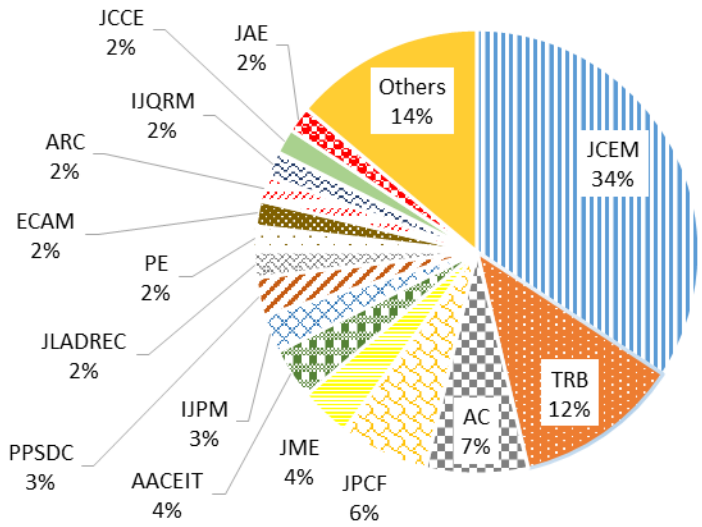

Figure 1: Percentage distribution of journal articles (n=108)

On the other hand, out of the whole set of technical reports (n=85), approximately 42% (n=35) were manuals issued by state DOTs to guide transportation agencies while implementing constructability. A considerable proportion of reports (16%, n=13) represent industry standards that were published by AASHTO and other leading agencies. Another 12% (n=10) represent guidelines issued by the FHWA or the Federal Transit Administration (FTA). Almost 11% (n=9) of technical reports represent national industry efforts published by NCHRP and Transportation Research Board (TRB). Figure 2 summarizes the percentage distribution of the various types of technical reports selected for analysis.

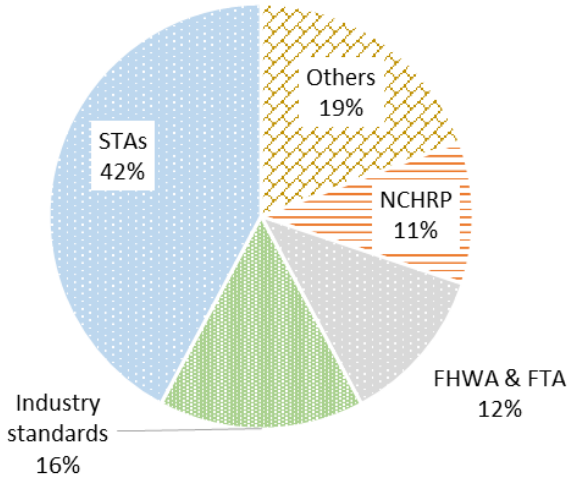

Figure 2: Percentage distribution of technical reports (n=85)

The following sections discuss briefly the typical findings regarding constructability issues, concepts, and recommendations.

### 4.1 Constructability Related Issues

In terms of constructability issues, Stamatiadis et al. (2014) indicated that constructability related issues are dynamic and of variable nature. Khan (2016) further categorized constructability issues into general, owner, designer, and contractor related issues. A similar categorization was adopted for the content analysis purposes of this paper. Table 1 presents the frequencies and percentages of the use of those issues within the reviewed documents.

Table 1: Main Constructability Issues as indicated by the reviewed documents

| Category | Number of documents | Percentage of total | Rank |
|---|---|---|---|
| **General Issues/Barriers** | | | |
| Complacency with status quo | 9 | 4.7% | 6 |
| Discontinuity of project team | 11 | 5.8% | 5 |
| Failure to identify risks, problems and opportunities | 5 | 2.6% | 9 |
| Lack of experienced team members | 12 | 6.3% | 4 |
| Lack of proper communication channels between owner, designer, and contractor | 19 | 10.0% | 3 |
| Lack of proper constructability tools to address issues | 7 | 3.7% | 8 |
| Lack of proper knowledge management systems and databases to document lessons learned and feedback | 9 | 4.7% | 6 |
| Lack of fund and resources for constructability | 30 | 15.7% | 2 |
| Site related issues including Right of Way (ROW), traffic control, utilities, geotechnical and Environmental issues | 104 | 54.5% | 1 |
| This is another program, and design reviews are already conducted | 3 | 1.6% | 10 |
| **Owner Issues/Barriers** | | | |
| Lack of coordination between project disciplines | 11 | 5.8% | 6 |
| Unawareness of constructability concepts | 11 | 5.8% | 6 |
| Lack of commitment on design and construction scopes | 39 | 20.4% | 2 |
| Lack of construction experience personnel among owner representatives | 11 | 5.8% | 6 |
| Lack for proper contract clauses to ensure incentives for participants to encourage innovation among contractors | 11 | 5.8% | 6 |
| No standard development process | 6 | 3.1% | 10 |
| Perception that constructability delays the project | 43 | 22.5% | 1 |
| The extra cost associate with constructability | 16 | 8.4% | 4 |
| The selected project delivery method | 24 | 12.6% | 3 |
| Unreceptive to contractor innovation | 13 | 6.8% | 5 |
| **Designer Issues/Barriers** | | | |
| Construction inputs are requested too late to be of value | 9 | 4.7% | 5 |
| Lack of construction experienced personnel among design professionals | 17 | 8.9% | 2 |
| Lack of knowledge of construction technologies and methods | 10 | 5.2% | 4 |
| Lack of mutual respect between designer and contractor | 13 | 6.8% | 3 |
| Lack of proper feedback systems from the construction | 6 | 3.1% | 6 |
| Lack of awareness of benefits, concepts, and process | 18 | 9.4% | 1 |
| Perception that it increases designer liabilities | 5 | 2.6% | 7 |
| Perception that designers already conducted it | 5 | 2.6% | 7 |
| Setting company goals over project goals | 4 | 2.1% | 9 |
| **Contractor Issues/Barriers** | | | |
| Depend on field personnel to conduct preconstruction reviews | 3 | 1.6% | 7 |
| Lack of involvement in tools and equipment development | 4 | 2.1% | 5 |
| Lack of knowledge of the design philosophy among construction staff | 8 | 4.2% | 3 |
| Adversarial relationships and poor communication skills | 19 | 10.0% | 2 |
| Poor plans, quantities, and specifications package | 74 | 38.7% | 1 |
| Poor timeliness of inputs | 4 | 2.1% | 5 |
| Site responsibilities are not coordinated | 5 | 2.6% | 4 |

The majority of documents addressed general constructability issues. As indicated in table 1, site related barriers such as traffic control, Right of Way (ROW), utilities, and environmental issues, are the main factors (55%, n=104) that hinder constructability. Among general issues, a small proportion of documents mentioned that constructability is hindered by lack of proper funds and resources (16%, n=30), followed by improper communication channels between owner, designer, and contractor (10%, n=19), in-experienced team members (6.3%, n=12), discontinuity of project team (6%, n=11), and improper knowledge management systems to utilize lessons learned (5%, n=9). Similarly, complacency with status quo, lack of proper constructability tools, failure to identify risks and opportunities, and that constructability is just another program where design reviews are already conducted, were mentioned less frequently as general issues among the reviewed documents.

Regarding owner related issues, the perception of owners that constructability delays the project schedule is the most common issue (23%, n=43) associated with owners of transportation projects. Lack of commitment to design and construction scopes is the second main issue (20.5%, n=39) that hinders constructability, followed by the selected project delivery method (13%, n=24). The selected project delivery method controls contractors' involvement during the design phase that permits or prevents early construction inputs. Generally, three main delivery methods are utilized by transportation agencies: Design-Bid-Build (DBB), Design-Build (DB), and Construction Manager/General Contractor (CM/GC) (Tran and Molenaar 2015). Consequently, DB and CM/GC delivery methods allow the incorporation of contractors 'perspectives into the design process, while DBB delivery method has limited input from contractors. The main philosophy of DBB is that, the design has to be 100% completed before the construction gets started, and before the contractor gets procured into the project. The issue of unreceptiveness to contractors' innovation is less frequently mentioned in the reviewed documents (7%, n=13). Similarly, lack of coordination among project disciplines, unawareness of constructability concepts, shortage of construction experienced personnel among owner staff, and improper incentive clauses are mentioned as owner related issues in 6% (n=11) of the reviewed documents. Only 3% (n=6) of documents indicated that lack of a standard constructability review processes (CRPs) hinders its implementation.

In term of designers-related issues, lack of awareness of constructability benefits, concepts and procedures is the main issue (9.5%, n=18) that hinders its implementation among design professionals. Lack of awareness is associated with considerable shortage of construction experienced personnel (9%, n=17) among design teams. Failure to obtain mutual respect between designers and contractors is an issue for conducting an effective constructability review (7%, n=13). A small proportion of documents mentioned that constructability is hindered by lack of knowledge of the main construction methods (5%, n=10), late requisition of construction inputs (4.7%, n=9), improper feedback from construction (3%, n=6), the perception that constructability increases designers' liabilities (3%, n=5), the perception that designers already conducting it through design review process (3%, n=5), and setting the company's goals over the project goals (2%, n=4).

Lastly, poor quality of construction documents, including plans, specifications, and estimates is the main issue (39%, n=74) that hinders constructability implementation among construction professionals. Adversarial relationships and poor communication skills also have a considerable impact on constructability (10%, n=19) as concluded by the content analysis results. A small proportion of documents (4%, n=8) mentioned that lack of knowledge of design philosophy among construction professionals hinders constructability, followed by uncoordinated site responsibilities (3%, n=5), poor timelessness of inputs from design (2%, n=4), lack of involvement in tools and equipment development among construction professionals (2%, n=4), and dependency on construction personnel to conduct preconstruction reviews (1.6%, n=3). In summary, the constructability issues often involve the need to increase the level of awareness of constructability benefits among owners, designers, and contractors, while considering those issues in the early project phases.

**4.2 Constructability Concepts**

The CII published a guide for constructability implementation across the entire project development process, and included a comprehensive list of 23 essential concepts (CII, 1993). The list covered most concepts presented in the literature and included a wide variety of principles, such as integration, construction experience, teams, resources, construction methods, specifications, and innovation. The

concepts identified by the CII are applicable for all kinds of projects, and mainly addressed the requirements for a successful constructability program implementation. Typically, the concepts are spanned over three main project phases: planning, design and procurement, and field operation. The same categorization system of the CII was used by various researchers, including: Ford et al. (2004) and Kifokeris and Xenidis (2017). Therefore, this paper utilized the same categorization, provided by the CII, for content analysis purposes to evaluate the advancement and trends of constructability concepts and principles across the reviewed literature. Table 2 shows the percentage distribution of the use of the 23 concepts in the reviewed documents.

Table 2: Constructability concepts based on the reviewed documents

| Concept No. | Category | Number of documents | Percentage of total | Rank |
|---|---|---|---|---|
| | **Planning Phase Concepts** | | | |
| *CC (1)* | Constructability Programs are made integral part of project planning execution plans | 24 | 12.6% | 5 |
| *CC (2)* | A project team shall be formed to take consideration of constructability issues through all project phases | 10 | 5.2% | 16 |
| *CC (3)* | Project planning actively involves construction knowledge and experience | 11 | 5.8% | 13 |
| *CC (4)* | The construction method shall take into account the type and number of contracts required for the project | 9 | 4.7% | 18 |
| *CC (5)* | Overall project schedules are construction sensitive | 15 | 7.9% | 10 |
| *CC (6)* | Basic Design approaches consider major construction methods | 26 | 13.6% | 4 |
| *CC (7)* | Site layout should be studied carefully so that construction, operation, and maintenance can be performed efficiently | 14 | 7.3% | 11 |
| | **Design and Procurement Phases Concepts** | | | |
| *CC (8)* | Design and procurement schedules are construction sensitive | 20 | 10.5% | 7 |
| *CC (9)* | The use of Advance information technologies to overcome the problem of fragmentation | 18 | 9.4% | 9 |
| *CC (10)* | Designs are configured to enable efficient construction | 23 | 12.1% | 6 |
| *CC (11)* | Design elements are standardized | 78 | 40.8% | 1 |
| *CC (12)* | Simplification of the project technical specifications | 13 | 6.8% | 12 |
| *CC (13)* | Modularization, Preassemblies are prepared to facilitate prefabrication | 49 | 25.7% | 2 |
| *CC (14)* | Designs promote construction accessibility of personnel, material and equipment | 19 | 9.9% | 8 |
| *CC (15)* | Designs facilitate construction under adverse weather conditions | 27 | 14.1% | 3 |
| | **Field Operation Phase Concepts** | | | |
| *CC (16)* | Innovative definitive sequencing of field tasks | 8 | 4.2% | 20 |
| *CC (17)* | Innovative uses of temporary construction materials/systems | 10 | 5.2% | 16 |
| *CC (18)* | Innovative uses of hand tools | 7 | 3.7% | 22 |
| *CC (19)* | Innovative uses of construction equipment | 8 | 4.2% | 20 |
| *CC (20)* | Constructor optional preassembly | 11 | 5.8% | 13 |
| *CC (21)* | Innovative temporary facilities directly supportive of field methods | 11 | 5.8% | 13 |

| | | | | |
|---|---|---|---|---|
| *CC (22)* | Post-bid constructor preferences related to the layout, design and selection of materials | 5 | 2.6% | 23 |
| *CC (23)* | Evaluation, documentation, and feedback of issues of constructability should be maintained during the PDP | 9 | 4.7% | 18 |

As indicated in Table 2, the concepts of the design and procurement phases are commonly addressed while conducting constructability reviews. Among the design and procurement concepts, design standardization was used most frequently (41%, n=78), followed by modularization to facilitate prefabrication (26%, n=49), and designs that facilitate construction in adverse weather conditions (14%, n=27). Design configuration to enable efficient construction was used less frequently (12%, n=23), as well as, construction-sensitive design and procurement schedules (10.5%, n=20), designs promote construction accessibility of personnel, material and equipment (10%, n=19), the use of information technologies to promote integration (9%, n=18), and simplified specifications (7%, n=13).

Under the planning phase concepts, basic design approaches that consider the proposed construction methods, along with integrating constructability programs into the project development process, were used most frequently, with percentages near to 14% (n=26) and 13% (n=24), respectively. Construction-sensitive scheduling is emphasized with a smaller proportion closing to 8% (n=15) among the reviewed documents, followed by efficiently performing construction, operation, and maintenance (7%, n=14), involving construction experienced personnel in the planning process (6%, n=11), consideration of constructability issues through all project phases (5%, n=10), and considering the number and type of contracts while selecting a construction method (4.7%, n=9).

A small proportion of the reviewed documents addressed field operation concepts. Only 6% (n=11) of the reviewed documents encouraged contractor to innovatively use temporary facilities and preassemblies. All other concepts are used with percentages less than 6%. The content analysis results indicate that research, in general, address constructability during pre-construction phases, with less focus on construction and post-construction phases. The combined cost of the project during planning, design and construction phases does not exceed 50% of the total lifecycle cost of the project, whereas the other 50% are acquired during post construction phase (Dunston and Williamson 1999). Therefore, agencies may need to consider reorganizing their constructability programs to effectively and efficiently integrate the needs and requirements of both construction and post-construction phases.

### 4.3 Recommendations for Constructability Implementation

Through a comprehensive content analysis process, the research team analyzed constructability optimization efforts and recommended a group of procedures to enhance its implementation across transportation projects. The results of content analysis indicated that most documents (92%, n=176) recommend site visits early in the project for successful initiation of constructability programs. A smaller proportion of documents encourage the use of status quo to optimize design schedules reliability (8%, n=16), post-construction reviews (6%, n=12), and better selection of construction materials (7%, n=13). Table 3 summarizes the main recommendations as concluded from the content analysis process.

Table 3: Recommendations to optimize constructability implementation

| Category | Number of documents | Percentage of total | Rank |
|---|---|---|---|
| Conduct site visits early in the project development | 176 | 92.1% | 1 |
| The use of more integrated delivery methods | 156 | 81.7% | 2 |
| Develop comprehensive knowledge management systems includes lessons learned, and feedback channels | 139 | 72.8% | 3 |
| Create a comprehensive formal constructability review program | 113 | 59.1% | 4 |
| Incorporate construction knowledge early in the project development | 107 | 56.0% | 5 |
| Implement a wide organizational change to increase the awareness of constructability benefits | 97 | 50.8% | 6 |

| | | | |
|---|---|---|---|
| Develop and provide efficient decision support models to evaluate the effectiveness of a constructability program | 78 | 40.8% | 7 |
| Inclusion of contract clauses to fund external parties involve in the review and to foster their innovation | 78 | 40.8% | 8 |
| Establish a multidisciplinary team that is different than the design team to oversees constructability and it shall be continuous over the whole project development process | 46 | 24.1% | 9 |
| Marinating status quo to control design schedules | 16 | 8.4% | 10 |
| Proper selection of construction materials | 13 | 6.8% | 11 |
| Conduct constructability audit at project completion, and post construction reviews | 12 | 6.3% | 12 |

## 5 CONCLUSION

A comprehensive review and content analysis of 191 documents related to the constructability of transportation projects were conducted. The content analysis showed that the majority of research efforts have addressed constructability issues and concepts. In total, 36 issues and 23 concepts were identified and evaluated. Constructability related issues were divided into general, owner, designer, and contractor related issues. Most efforts focused on general issues associated with constructability of transportation projects. On the other hand, constructability concepts are classified into three main groups: planning, design and procurement, and field operation concepts. This paper concludes that transportation agencies need to adopt formal constructability review processes to overcome challenges in constructability implementation across the entire project development process. This formal review process should be administrated by a champion that administers a multidisciplinary team to conduct the reviews. An organizational change to increase the level of awareness of constructability issues, concepts, and benefits among owner, design, and construction professionals is essential for continuous improvement. Using the findings of this research, future research needs to focus on measuring the costs/benefits of constructability implementation, as well as, developing a more flexible and practical frameworks to incorporate constructability reviews into the various transportation project development processes. Further examination of constructability issues and concepts is needed for construction and post construction phases.

## 6 REFERENCES


American Association of State Highway and Transportation Officials. (2000). *Constructability Review Best Practices Guide*, AASHTO Subcommittee on Construction, USA.

ASCE (American Society of Civil Engineers) Construction Management Committee of the Construction Division. (1991). “Constructability and constructability programs: White Paper.” *Journal of Construction Engineering and Management*, 117(1), 67-89.

Anderson, S. D. and Fisher, D. J. (1997). NCHRP Report 390: Constructability Review Process for Transportation Facilities. *Transportation Research Board*, Washington, D.C.

Anderson, S., Fisher, D., and Rahman, S. (1999). “Constructability Issues for Highway Projects.” *Journal of Management in Engineering*, 15(3), 60-68.

Anderson, S. D., Fisher, D. J., and Rahman, S. P. (2000).”Integrating Constructability into Project Development: A Process Approach.” *Journal of Construction Engineering and Management*, 126(2), 81-88.

Bordat, C., McCullouch, B., Labi, S. and Sinha, K. (2004). *FHWA/IN/JTRP-2004/7: An Analysis of Cost Overruns and Time Delays of INDOT*. Purdue University, West Lafayette, IN. Brochner, Jan, Bjork and Bo-Christer (2008). “Where to submit? Journal choice by construction management authors.” *Construction Management and Economics*, 26(7), 739-749.

CII (Construction Industry Institute). (1986). *Constructability: A primer*. University of Texas at Austin, Austin, TX.

CII (Construction Industry Institute). (1993). *Constructability Implementation Guide*. University of Texas at Austin, Austin, TX.

Douglas, E. (2008). "Schedule Constructability Review." *AACE International Transactions*.

Dunston, P. S. and Williamson, C. E. (1999). "Incorporating Maintainability in Constructability Review Process." *Journal of Management in Engineering*, 15(5), 56-60.

Dunston, P., Gambatese, J., and McManus, J. (2005). "Assessing State Transportation Agency Constructability Implementation." *Journal of Construction Engineering and Management*, 131(5), 569-578.

Fischer, M., and Tatum, C. B. (1997). "Characteristics of Design-Relevant Constructability Knowledge." *Journal of Construction Engineering and Management*, 123(3), 253-260.

Ford, D., Anderson, S., Damron, A., de Las Casas, R., Gokmen, N. and Kuennen, S. (2004). "Managing Constructability Reviews to Reduce Highway Project Durations." *Journal of Construction Engineering and Management*, 130(1), 33-42.

Gibson, G., McGinnis, C., Flanigan, W., and Wood, J. (1996). "Constructability in Public Sector." *Journal of Construction Engineering and Management*, 122(3), 274-280.

Gransberg, D. D. and Douglas, E. E. (2005). "Implementing Project Constructability." *AACE International Transactions*.

Khan, S. (2016). "Application of Design Structure Matrix (DSM) for Managing Projects on the Basis of Constructability." *Civil Engineering and Architecture*, 4(3), 91-111.

Kifokeris, D. and Xenidis Y. (2017). "Constructability: Outline of Past, Present, and Future Research." *Journal of Construction Engineering and Management*, 143(8), 1-13.

Ogburn, M. and El-adaway I. (2014). "Biddability, Constructability, Operability, and Environmental Checklist: Potential Role in Reducing Conflicts, Claims, and Disputes." *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 6(1).

UPR (Universidad de Puerto Rico). (2011). *"List of Journals Related to Construction Engineering and Management, Civil Infrastructure, and Engineering Education."* Universidad de Puerto Rico, Rio Piedras, PR.

U.S. Department of Commerce–Bureau of Economic Analysis. (2019)."GDP-by-industry data." *⟨http://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=q&5102=1⟩* (April. 20, 2019).

Russell, J., Gugel, J. and Radtke, M. (1994). "Comparative Analysis of Three Constructability Approaches." *Journal of Construction Engineering and Management*, 120(1), 180-195.

Stamatiadis, N., Goodrum, P. Shocklee, E., and Wang, C. (2014). "Quantitative Analysis of State Transportation Agency's Experience with Constructability Reviews." *Journal of Construction Engineering and Management*, 140 (2), 1–9.

Stamatiadis, N., Sturgill, R. and Amiridis, K. (2017). "Benefits from Constructability Reviews." World Conference on Transportation Research, *Transportation Research Procedia*, Shanghai, 2889-2897.

Tran, D., and Molenaar, K. (2015). "Risk-Based Project Delivery Selection Model for Highway Design and Construction." *Journal of Construction Engineering Management*, 141(12), 1-9.

Wing, C. K. (1997). "The ranking of construction management Journals." *Construction Management and Economics*, 1997(15), 387-398.