

BRIDGING THE GAP BETWEEN THEORY AND PRACTICE: A CONSTRUCTABILITY MANAGEMENT FRAMEWORK FOR THE PROJECT LIFECYCLE

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To my beloved Family, Husband and Friends

It always seems impossible until it is done.

Nelson Mandela

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RESUMO

A construtibilidade é o processo de integrar com sucesso a experiência e a especialização da construção nas fases preliminares, para otimizar e melhorar os resultados finais. A construtibilidade tornou-se essencial para o sucesso dos projetos no setor moderno da construção, marcado por prazos apertados, situações complexas envolvendo partes interessadas e demandas financeiras crescentes. Entretanto, existe uma significativa desconexão entre o apoio teórico à construtibilidade e sua aplicação prática ao longo do ciclo de vida dos projetos. Embora a integração precoce e contínua dos princípios de construtibilidade seja enfatizada na literatura acadêmica e nos padrões da indústria, muitas organizações não têm procedimentos definidos que possibilitem a implementação plena desta abordagem. Como consequência, as escolhas de projeto frequentemente negligenciam limitações construtivas, resultando em erros, alterações de última hora e aumentos nos custos.

Ao desenvolver uma Estrutura de Gestão da Construtibilidade estruturada que facilita a implementação metódica dos princípios de construtibilidade em todas as fases de um projeto de construção, esta dissertação de mestrado busca reduzir a lacuna entre teoria e prática. O estudo foi realizado com uma abordagem multifásica. Inicialmente, foi realizada uma revisão bibliográfica aprofundada, destacando estruturas reconhecidas de gestão de projetos de construção, incluindo o RIBA Plan of Work, o Guia PMBOK do PMI e o Front-End Planning (FEP). Essa revisão destacou as deficiências na forma como a construtibilidade é abordada nos fluxos de trabalho tradicionais e ajudou a identificar as melhores práticas atuais.

Após a pesquisa bibliográfica, foi realizada uma investigação empírica por meio de dois inquéritos com profissionais da construção de diferentes empresas. Os resultados revelaram que 41% dos participantes nunca tinham aplicado formalmente a construtibilidade, apesar de mais de 80% deles terem conhecimento sobre o conceito. Obstáculos comuns incluem o envolvimento tardio de empreiteiros, a falta de procedimentos estabelecidos e a resistência organizacional às mudanças.

Aqueles que adotaram precocemente a construtibilidade, seja por meio de revisões de projeto, uso do BIM ou cooperação interdisciplinar, relataram melhor coordenação e menos erros. Um fluxo estruturado foi criada com base nessas observações para mapear o processo de construtibilidade. Ainda, o fluxo desenvolvido foi aprimorado e validado com o auxílio dum especialista em construtibilidade. Finalmente, o fluxo estabelecido oferece procedimentos, recursos e pontos de verificação para cada fase do projeto.

A estrutura desenvolvida pode auxiliar as equipes e gestores a superar métodos ad hoc, promovendo práticas proativas e consistentes de construtibilidade. Pressupõe-se que, sua adoção pode potencializar um melhor desempenho dos projetos, redução de riscos e aprimoramento do trabalho em equipe.

PALAVRAS-CHAVE: Construtibilidade, Ciclo de Vida do Projeto, Gestão da Construção, Desenvolvimento de Estrutura, Melhores Práticas

ABSTRACT

Constructability is the process of successfully incorporating construction expertise and experience into a project's planning and design stages to enhance final results. Constructability has become crucial to project success in the modern construction sector, which is marked by tight deadlines, intricate stakeholder situations, and mounting financial demands. Nonetheless, a significant disconnect exists between constructability's theoretical support and application throughout the project lifecycle. Although early and ongoing integration of constructability principles is emphasised in academic literature and industry standards, many organisations lack defined procedures to enable this approach. Because of this, design choices frequently overlook construction limitations, which results in mistakes, last-minute modifications, and cost overruns.

By creating a structured Constructability Management Framework that facilitates the methodical implementation of constructability principles throughout all stages of a construction project, this master's dissertation seeks to close the gap between theory and practice. The study was carried out with a multi-phase approach. A thorough literature review was conducted first, emphasising well-known construction project management frameworks including the RIBA Plan of Work, the PMI PMBOK Guide, and Front-End Planning (FEP). This review highlighted shortcomings in how constructability is handled in traditional project workflows and assisted in identifying current best practices.

After the literature research, an empirical investigation surveyed construction professionals from several companies twice. The findings revealed that 41% of participants had never formally used constructability, despite over 80% of them being aware of it. Common obstacles include late contractor involvement, a lack of established procedures, and organisational reluctance to change.

Early adopters of constructability, whether via design reviews, the usage of BIM, or interdisciplinary cooperation, claimed improved coordination and fewer mistakes. A structured framework was created based on these observations and verified with the help of experts. The framework offers applicable procedures, resources, and checkpoints for every project stage.

The finished framework assists teams in overcoming ad hoc methods by promoting proactive, consistent constructability practices. Adoption can result in enhanced project performance, decreased risks, and better teamwork.

KEYWORDS: Constructability, Project Lifecycle, Construction Management, Framework Development, Best Practices

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SYMBOLS, ACRONYMS, ABBREVIATIONS

\$ - Dollar sign

% - Percentage sign

$\geq$ - Greater than or equal to

$\leq$ - Less than or equal to

$\approx$ - Approximately

→ - Process flow

3D - Three-dimensional

4D - Four-dimensional

5D - Five-dimensional

AASHTO - American Association of State Highway and Transportation Officials

AI - Artificial Intelligence

AR - Augmented Reality

BCA - Building and Construction Authority

BDAS - Buildable Design Appraisal System

BIM - Building Information Modelling

BPMN - Business Process Model and Notation

BS - Buildability Score

CC(s) - Constructability Concept(s)

CD - Concept Design

CICL - Constructability-Integrated Construction Lifecycle

CII - Construction Industry Institute

CIAT - Construction Input Assessment Tool

CIRIA - Construction Industry Research and Information Association

CHC - Commissioning, Handover & Close-Out

CPPMM - Conceptual Product/Process Matrix Model

D - Design

DB - Design-Build

DBB - Design-Bid-Build

DFA - Design for Assembly

DFM - Design for Manufacturability

DG - Decision Gates

ECI - Early Contractor Involvement

EPC - Engineering, Procurement , Construction

FEED - Front-End Engineering Design

FEL - Front-End Loading

FEP - Front-End Planning

FEPT - Front-End Planning Tool

FM - Facilities Management / Facility Manager

HSE - Health, Safety and Environment

IFC - Issued-for-Construction

IPD - Integrated Project Delivery

ISO - International Organization for Standardization

KPI - Key Performance Indicator

LPS - Last Planner System

MC - Mobilisation & Construction

MEP - Mechanical, Electrical & Plumbing

MMC - Modern Methods of Construction

MOM - Minutes of Meeting

MPB - Master Planning & Briefing

N/A - Not available

O&M - Operations & Maintenance

OPEX - Operational Expenditure

P6 - Primavera P6

PDRI - Project Definition Rating Index

PEP - Project Execution Plan

PM - Project Manager/Project Management

PMBOK - Project Management Body of Knowledge

PMI - Project Management Institute

POE - Post Occupancy Evaluation

PPP - Pre-Project Planning

PPP - Public-Private Partnership

QA/QC - Quality Assurance / Quality Control

RFI - Request for Information

RIBA - Royal Institute of British Architects

SD - Strategic Definition

SLR - Systematic Literature Review

SME - Subject Matter Expert

UK - United Kingdom

USA - United States of America

UO - Use & Operation

VE - Value Engineering

VR - Virtual Reality

WBS - Work Breakdown Structure

tech – Technology

1

INTRODUCTION

1.1. RESEARCH BACKGROUND

Constructability has been the subject of much research over the past fifty years, sometimes including the more specific notion of buildability [1]. Buildability is best viewed as a subset of constructability, primarily focusing on how simple and effective it is to construct building components on-site. Constructability, on the other hand, is a more comprehensive, wide-ranging idea that incorporates construction expertise and experience into every phase of project development, from planning and design to procurement and execution [1].

A substantial number of studies on constructability have emerged over time, covering its definitions, guiding ideas, evaluation methods, and approaches to implementation [2],[3],[4],[5],[6]. In both scholarly research and business practice, constructability programs have discussed assessment techniques and instruments to support real-world implementation [7],[8],[9]. To improve project performance by the early and methodical incorporation of construction insights, these efforts have produced both qualitative frameworks and quantitative indicators.

To overcome the long-standing gap between design and construction, constructability was developed as a reaction to ongoing inefficiencies in building projects. As demonstrated by a number of studies, including those conducted by the Construction Industry Institute (CII), projects that incorporate constructability early on, especially during front-end planning and design, have fewer change orders, lower costs, and shorter durations [10],[11],[12],[13]. Because of this data, constructability has come to be recognised as a best practice in modern project management [3].

Although constructability is widely acknowledged to have advantages in principle, its application in practice is still uneven. Constructability concepts are still difficult for many projects to use in an organised and methodical manner[6],[8]. Contractor input during the early stages of a project is limited by the tendency of traditional project delivery systems, like design-bid-build, to separate the design and construction phases [5]. Critical construction insights are sometimes overlooked due to this division, leading to problems including inefficient build sequences, design changes, and more rework during construction [14]. More integrated delivery methods, such as Design-Build and Integrated Project Delivery (IPD), have become popular recently [4]. These models seek to involve contractors earlier in the process. Even within these models, constructability procedures are not consistently or methodically used, according to industry surveys and literature. Rather than structured systems, constructability attempts frequently rely on ad hoc practices or personal experience. While some companies, as will be discussed in Chapter 3, for instance, use tools like Building Information Modelling (BIM) for clash detection or perform periodic constructability assessments, these practices are sometimes not standardised across teams or projects.

The increasing complexity of contemporary construction projects emphasises the significance of constructability even more. There is a greater chance than ever of design-construction mismatches and coordination failures due to the growing usage of cutting-edge technology, innovative materials, and distributed multidisciplinary teams, as will be discussed in Chapter 3. At the same time, industry pressure is growing to satisfy sustainability goals, cut waste, and improve efficiency [15],[16]. Constructability encourages choices that lower rework, increase productivity, and improve safety, directly promoting these objectives [14]. Additionally, early constructability integration offers an organised method of making design and construction choices that promote long-term value, as clients' attention shifts from initial capital expenditures to life-cycle performance and overall project cost.

1.2. PROBLEM STATEMENT

When it comes to incorporating constructability into construction projects, there is a significant disconnect between theory and practice. On the one hand, previous studies and theoretical frameworks strongly support the early and ongoing integration of construction knowledge into project planning and design [17]. Applying constructability principles can significantly enhance project outcomes, according to best-practice guidelines. However, real-world implementation within companies is still uneven and dispersed [18]. Constructability issues are frequently addressed too late or not at all in building projects that lack a defined constructability procedure and instead rely on ad hoc metrics or individual experience[19]. Avoidable problems, including design conflicts found during construction, ineffective sequencing, and increased costs as a result of revisions and rework, are caused by this gap.

Current project management models that are employed in organisations do not adequately consider constructability in the phases of a project [3]. While the value of constructability in theory is well established, most companies and project teams do not have a systematic process in place to actually make this happen. Adding to this are the traditional contracting arrangements of separating design and construction, perverse incentives, and a lack of constructability knowledge and training, as will be discussed in Chapter 3. As a result, chances for avoiding mistakes or improving ease of construction are lost, and subsequently, the degree of success of the project may be compromised. The theoretical gap is apparent in writings, as despite the land of studies advocating the potential gain from constructability, there are few sources of guidance on how to bring such recommendations to life throughout all stages of a project environment [3] .

Even well-meaning organisations find it difficult to consistently use constructability, as evidenced by case studies and industry feedback. In light of this, the dissertation clearly aims to answer the following question: How can constructability be structured throughout the project lifecycle to ensure that the well-known advantages (theoretical best practices) are actually achieved in practice? To ensure that no phase overlooks the contribution of construction skills, a uniform framework that incorporates constructability into typical project management phases, from original planning through design and construction to project close-out, must be developed. Without such a framework, there will continue to be a discrepancy between theory and practice, resulting in less than ideal project delivery.

To address the deficiency of an existing solution, this dissertation aims to develop and validate a Constructability Management Framework as presented in Chapter 4. Doing this immediately addresses the theoretical demand for greater integration of constructability knowledge and the practical problems in present project workflows, with the ultimate goal of enhancing the alignment between design choices and construction realities.

1.3. RESEARCH OBJECTIVES

Given the identified issue, a well-defined primary goal and multiple supplementary subsidiary goals were the dissertation's compass. These goals established the outcomes that the dissertation sought to accomplish and guided the scope of the work:

- a) The main goal is to create a thorough Constructability Management Framework for the project lifecycle that unites theory and practice and gives project teams a methodical way to incorporate constructability concepts into each stage of a building project.
- b) Secondary Goals: The following secondary goals were set to achieve the main objective:
 - Literature Synthesis: To lay the theoretical foundation for constructability, thoroughly examine the content of existing research, industry norms and project management frameworks. This entails finding best practices and conceptual models from earlier research and analysing how constructability is addressed by contemporary frameworks (such as Front-End Planning [20] , PMBOK [21], and RIBA Plan of Work [15]).
 - Existing Practice Assessment: Conduct comprehensive research to examine constructability-related existing industrial practices. This entails surveying construction professionals and organisations to determine the degree of constructability awareness, how and when constructability is currently being applied in projects, and what tools or approaches are being used. Finding common practices and identifying any gaps or inconsistencies in practical execution are the goals.
 - Gap Analysis: To conduct a gap analysis, contrast the information obtained from industry (practice) with the insights from literature (theory). This analysis will point out specific instances where current project management procedures fall short of best practices or where constructability is not successfully incorporated into practice. It will also assist in identifying the obstacles and difficulties that lead to these disparities.
 - Development of a Framework: Create a systematic Constructability Management Framework based on the gap analysis results. From project initiation and design through procurement, construction, and project close-out, the framework should provide precise procedures, roles, and resources for incorporating constructability into every project lifecycle phase. It will address the flaws in present procedures while referencing best practices found in the literature.
 - Validation and Improvement: Verify the suggested framework by asking professionals in the field and academia for their opinions. If at all possible, use instructive case studies. This step ensures that the framework is useful, comprehensive, and flexible. The input will be utilised to improve the framework and create implementation suggestions to provide a workable tool that companies can use to enhance their constructability practices.

By achieving these goals, the study methodically moves from comprehending the theoretical principles and real-world applications to developing a solution that bridges the gap between them. Reaching these goals guarantees that, in addition to diagnosing constructability problems in project management, the dissertation will provide a tangible, verified framework as its contribution to the field. The ultimate goal of this framework is to improve the standard of constructability integration in the construction sector by acting as a reference for future studies and a guide for practitioners.

1.4. METHODOLOGY

1.4.1. INTRODUCTION

A structured methodology is used in this study to provide a thorough comprehension of constructability in relation to construction project management. The approach is divided into eight distinct sections, each meticulously addressing a particular stage of the research process. The method starts with a thorough literature study to establish a strong theoretical framework, identify important knowledge gaps, and indicate areas that need more research. Following the selection of relevant companies, thorough data collection is conducted using thoughtfully crafted surveys that gather quantitative and qualitative information directly from specialists in the field about their present constructability methods. These surveys were developed and improved with the help of a specialised focus group of academic and industry professionals, guaranteeing their efficacy, relevance, and clarity.

After the data is collected, it is thoroughly analysed to identify trends, patterns, and important gaps in the constructability implementation. Building on these realisations, a useful constructability framework is created within recognised project management standards, offering precise procedures and industry best practices to improve constructability integration throughout all project stages. Through expert assessment, this framework is thoroughly confirmed and improved to guarantee its usefulness in real-world situations. Lastly, thorough documentation of every research finding is provided, along with specific recommendations.

The synthesis of the project lifecycle phase structure emerged through a systematic comparison and combination of insights drawn from both theoretical frameworks, namely, Front End Planning, PMI's PMBOK and the RIBA Plan of Work, and empirical data collected through surveys, focus group discussions and personal experience, using the autoethnography method [22].

The organised methodological stages are graphically depicted in Figure 1.1, making the study's phases and logical flow evident.

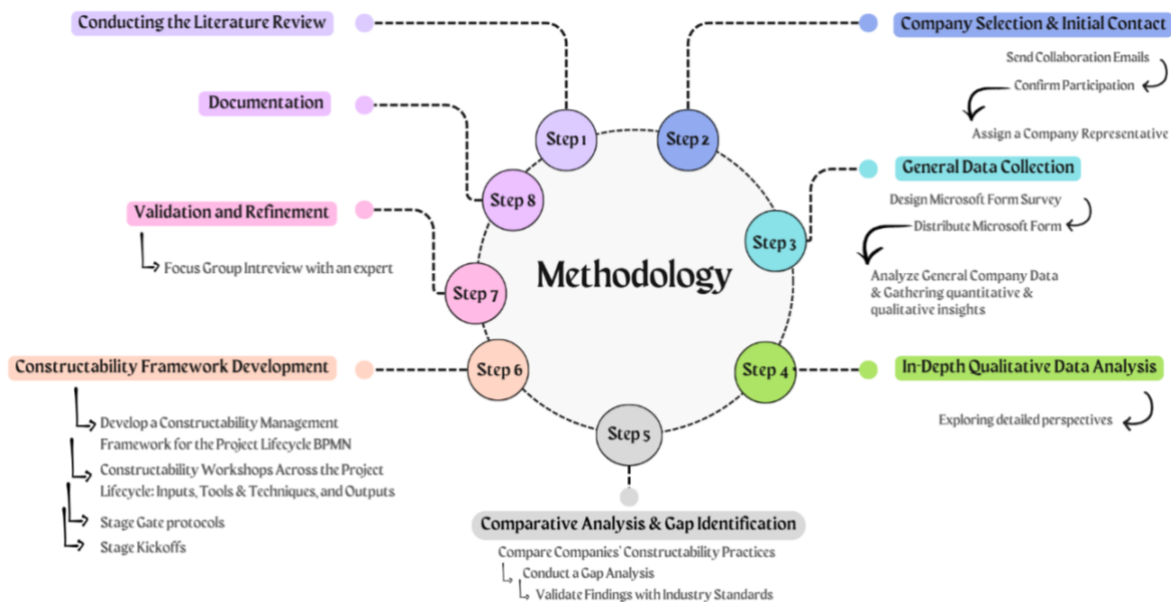


Fig. 1.1 - Methodology Framework: A Step-by-Step Approach to Constructability Research

1.4.2. CONDUCTING THE LITERATURE REVIEW

A thorough literature assessment established the theoretical basis of the study. A non-systematic literature review (non-SLR) was conducted to collect the artefacts [23]. The collection of documents was based on desk research [24]. A thorough study of scientific journals, company reports, and recognised constructability and project management best practices was conducted. In addition to identifying established practices and industry guidelines, the evaluation process also revealed important gaps concerning the real-world use of constructability in project management frameworks. This fundamental stage provided a roadmap for later research stages, guaranteeing conformity with current company practices and theoretical perspectives.

1.4.3. COMPANY SELECTION AND INITIAL CONTACT

At this point, relevant construction and engineering companies were carefully selected based on specific criteria, including their industry experience, the scope of their projects, and demonstrated relevance to constructability practices. Thus, it is a non-probabilistic sample, selected according to convenience [25]. Formal collaboration emails outlining the goals, advantages, and anticipated contributions were sent to prospective participants. Following the acquisition of positive responses, participation was confirmed through follow-up correspondence. Each participating company chose an official representative to oversee the coordination of the following activities, guaranteeing efficient communication and productive involvement. This representative facilitates communication, provides relevant company information, and assists in coordinating the next stages of the research.

1.4.4. GENERAL DATA COLLECTION

Once company participation is secured, general data collection is initiated. Microsoft Forms was used to create and distribute two successive surveys to gather data. To collect fundamental data, the initial survey examined organisational structure, decision-making procedures, project management methodologies, and general constructability principles awareness inside participating firms. Using open-ended and multiple-choice questions, this survey combined quantitative and qualitative components to thoroughly understand the organisations' current procedures. A second, more targeted survey was sent out a week after the first one was finished. The focus of this second survey was on actual constructability issues that professionals actively involved in the planning and execution of construction projects experience. In contrast to traditional surveys, this version included open-ended and scenario-based questions to encourage respondents to think critically and openly about their experiences, providing a comprehensive analysis of the real-world challenges of implementing constructability in projects. This strategy was specifically developed to record deep, qualitative insights on real-world industry difficulties and procedures.

1.4.5. IN-DEPTH QUALITATIVE DATA ANALYSIS

The second survey's qualitative responses were carefully examined for more detailed information. The information offered thorough explanations, personal perspectives, and expert opinions regarding constructability issues that arose in many construction situations. These accounts made it possible to identify recurring themes, particular obstacles to successful constructability integration, and real-world examples of both successful and unsuccessful project outcomes.

1.4.6. COMPARATIVE ANALYSIS AND GAP IDENTIFICATION

At this stage, all participating companies' survey results were systematically compared to fully determine common trends, unique practices, strengths, errors, and important gaps in how constructability is currently being implemented. A detailed overview of each company's constructability approach was made possible by the analysis, which looked at both the quantitative data from the first survey and the rich qualitative narratives from the second survey. A thorough comparison between the organisations stated actual practices and industry project management frameworks was conducted to identify specific deviations and areas that did not adhere to established best practices. This thorough analysis offered a solid and fact-based basis for later developing an extensive and useful constructability framework designed especially to rectify noted weaknesses and improve project results. A key aspect of this phase involves conducting a gap analysis, in which discrepancies between current company practices and established industry best practices are assessed. BPMN (Business Process Model and Notation) is utilised to map out workflows and visualise inefficiencies [26]. Additionally, findings are benchmarked against globally recognised frameworks such as FEP, PMI, RIBA, and CII to determine how well companies align with industry standards [20],[15],[21],[27].

1.4.7. CONSTRUCTABILITY FRAMEWORK DEVELOPMENT

Building on the findings from a comparative analysis and gap analysis, using the autoethnography method [22], a structured constructability framework was developed, integrating project management frameworks like Front-End Planning (FEP), PMI and RIBA Plan of Work stages [20],[21],[15]. This framework serves as a structured guideline for companies, ensuring that constructability principles are embedded at every project stage. Specific checkpoints at various project phases are defined, clearly outlining roles, responsibilities, and necessary interventions. Additionally, best practices from high-performing companies are incorporated to enhance the framework's usability. To improve decision-making, expedite project execution, and improve overall project results through increased constructability, the goal of this framework is to provide a practical tool that companies can adopt to improve constructability and decision-making throughout their projects systematically.

1.4.8. VALIDATION AND REFINEMENT

A focus group interview with an expert in construction production and management of construction projects was conducted to validate the suggested constructability framework thoroughly [28]. By conducting a thorough assessment of the framework's usefulness, relevance, and comprehensiveness in actual project contexts. The professional validation stage's input was carefully recorded and integrated into the framework. The framework's resilience was guaranteed by necessary improvements and modifications, which also improved its applicability and practical significance in workplace environments.

1.4.9. DOCUMENTATION AND FINAL RECOMMENDATIONS

All results, analytical conclusions, and verified framework elements were methodically recorded after the validation and refinement stages. Clear presentations of the results of the literature study, thorough survey analysis, comparative findings, qualitative insights, and the completed constructability framework were all included in the extensive documentation. To further improve the usefulness and accessibility of the information provided, supporting visual aids like diagrams and comparative tables were incorporated into the documentation to guarantee clarity and ease of understanding.

The dissertation generated a thorough Constructability Management Framework in the Project Lifecycle that offers a methodical way to improve constructability during project planning and execution. Visual representations such as BPMN diagrams, Constructability Workshops Across the Project Lifecycle: Inputs, Tools & Techniques, and Outputs, stage kick-offs, and stage gate protocols significantly enhance clarity and usability. These final proposals sought to systematically incorporate constructability concepts into all project management phases to improve overall project outcomes, reduce common constructability concerns, and improve project efficiency.

1.5. STRUCTURE OF THE DISSERTATION

This dissertation is structured into four main chapters. Chapter 1 introduces the research topic, presenting the background, problem statement, research objectives, and a step-by-step explanation of the adopted methodology. Chapter 2 offers an extensive literature review, focusing first on major project management frameworks, namely Front-End Planning (FEP), the RIBA Plan of Work, and the PMBOK Guide, and then delving deeply into the concept of constructability. It provides a holistic overview of constructability, covering its core concepts and principles, its role throughout the building lifecycle, and the distinct contributions of designers, contractors, and owners. It also analyses practical tools, barriers to implementation, the influence of contractual frameworks, integration with risk management, and the need for organisational commitment and operational skills. Chapter 3 presents the data analysis and discussion, based on two comprehensive surveys targeting professionals across the construction industry. The findings explore how constructability is currently practised, highlight challenges and inconsistencies, and identify opportunities for improvement, supported by both quantitative metrics and rich qualitative insights. Chapter 4 proposes a Constructability-Integrated Construction Lifecycle (CICL), which synthesises literature and field data into a structured framework. It includes detailed Business Process Model and Notation (BPMN) diagrams, stage-specific constructability workshops, clearly defined inputs, tools and techniques, outputs, stage kick-offs, and stage-gate review protocols. The dissertation concludes with practical recommendations for industry implementation and directions for future research to further close the gap between constructability theory and practice.

2

LITERATURE REVIEW

2.1. INTRODUCTION

Successful infrastructure and construction projects are increasingly dependent on the methodical fusion of execution management, strategic planning, and direct construction expertise [29],[21],[6]. The industry has embraced various approaches to enhance predictability, efficiency, and performance in response to the difficulties presented by increasing project complexity, regulatory requirements, and stakeholder expectations. Two fundamental and complementary ideas, project management frameworks and constructability, are at the heart of these initiatives. By concentrating on three internationally accepted frameworks, the Front-End Planning (FEP) model from the Construction Industry Institute, the Royal Institute of British Architects' (RIBA) Plan of Work, and the Project Management Institute's PMBOK Guide, this literature review explores these interconnected fields [21],[20],[15],[30].

These frameworks show several but related methods for planning and overseeing building projects. With its five process groups, Initiating, Planning, Executing, Monitoring and Controlling, and Closing, and ten knowledge areas, the PMBOK Guide offers a process-based framework for all sectors[21],[30]. Many projects that need strict control and formal governance use it because it provides a scalable and adaptable approach for controlling scope, time, cost, quality, and risk. In contrast, the RIBA Plan of Work provides a stage-based lifecycle designed especially for the construction and architectural industries [15]. From strategy definition to building use, it emphasises stakeholder participation, design creation, and strategic briefing in eight stages [15]. Similarly, the Construction Industry Institute (CII) strongly advocates the Front-End Planning (FEP) framework, which focuses on establishing project goals and coordinating stakeholder expectations before the start of detailed design[31]. It evaluates preparedness and enhances decision-making in the early stages of a project, particularly in complicated or capital-intensive projects, by using structured methods such as the Project Definition Rating Index (PDRI) [32].

These frameworks have different origins and areas of emphasis, but they all aim to increase performance, clarity, and coordination across the project life cycle. Most importantly, they all offer platforms for constructability integration, which is the methodical application of construction knowledge to planning, design, procurement, and execution [3]. A unifying factor that connects early strategic purpose with on-site reality is constructability[3]. When properly applied, it lowers rework, improves safety, enhances building quality, and results in a more economical use of resources[18],[9]. Within each of the three frameworks, this integration is made easier by tools like Constructability Review Checklists, Guidelines, Building Information Modelling (BIM), and workflow-enabled platforms (like Front End Planning Tool (FEPT)) [3],[33],[12],[11],[15],[17].

According to the literature, constructability is a strategic process that should be integrated into every project stage. The early and ongoing involvement of important stakeholders, especially owners, contractors, and designers, is crucial to the efficacy of constructability since their cooperation guarantees that project plans are both ambitious and realistically achievable [34]. In actual use, there have been quantifiable advantages to these frameworks' conformity with constructability principles [8]. Projects that use integrated management systems, constructability evaluations, and formal front-end planning and project lifecycle stage perform better than those that only use conventional, sequential delivery techniques, according to empirical research and case studies [13] [27]. For instance, constructability is enhanced through integrated design reviews during RIBA Stage 2, which improve spatial coordination and minimise design conflicts; through early contractor involvement during FEP, which promotes scope clarity and proactive risk mitigation; and through robust change control and monitoring procedures aligned with the PMBOK, which help manage complexity and prevent scope creep during construction [34],[13],[15],[35].

This analysis highlights the interconnections of constructability and project management frameworks in high-performing project environments. Together, they facilitate the shift from disconnected project delivery to comprehensive, lifecycle-based management. This literature review offers a basis for comprehending how these frameworks interact to enhance constructability, lower project risk, and drive value in the built environment by combining academic theory, institutional models, and empirical data.

2.2. PROJECT MANAGEMENT FRAMEWORKS

2.2.1. GENERAL KNOWLEDGE ABOUT PROJECT MANAGEMENT

Project management (PM) is the integration of a variety of techniques, abilities, expertise, and experience to accomplish particular project objectives while fulfilling acceptance standards and adhering to established limitations [36]. A project's final deliverables must meet the precise budget and schedule standards in order to be considered successful [30]. Project management, in contrast to continuous management procedures, results in a measurable product at an established endpoint [21]. This crucial feature sets it apart from general management.

Project managers must therefore require a wide range of skills, which frequently include technical know-how, people skills, and effective knowledge of company practices [21],[30]. A project is a brief, one-of-a-kind undertaking with the goal of achieving predefined outcomes, which might be characterised by outputs, results, or advantages [21]. Usually, a project's success is determined by whether it achieves its objectives within the allocated budget and time frame and in accordance with the specified criteria [21].

Three fundamental elements, as shown in Figure 2.1, are at the centre of every project and are called the Project Management Triangle or Iron Triangle [36]:

- **Schedule:** Creating and adhering to timetables that specify the completion dates of the tasks [36].
- **Cost:** Relates to the financial resources allocated. Exceeding the budget might necessitate compromises in quality or extended schedules [36].
- **Scope:** Defines the work to be completed, ensuring it aligns with agreed deliverables and objectives. Expanding the scope generally increases both time and expenses [36].

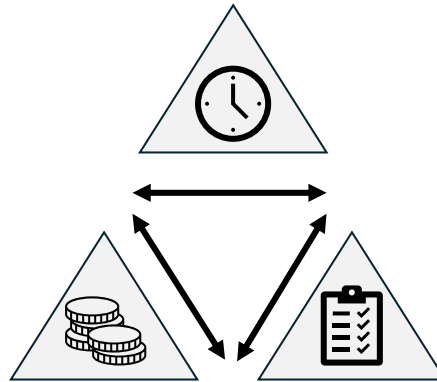


Fig. 2.1 - Project Management Triangle

Projects are essentially different from regular operations since they are designed to provide a solution that satisfies established requirements within a predetermined budget and time limit, necessitating a short-term team effort.

For any endeavour to be successful, team members must collaborate well. A group of people must collaborate, even momentarily, to do a project successfully. Teamwork is essential to managing and coordinating different work segments and meeting project goals [21]. A number of variables, including the project's size, importance, and complexity, influence how tasks are integrated and directed [30]. For example, staging the Olympics and moving a small office have quite distinct management issues, even though they share some fundamental ideas. Project objectives can be stated in various ways, as illustrated in Figure 2.2. below:

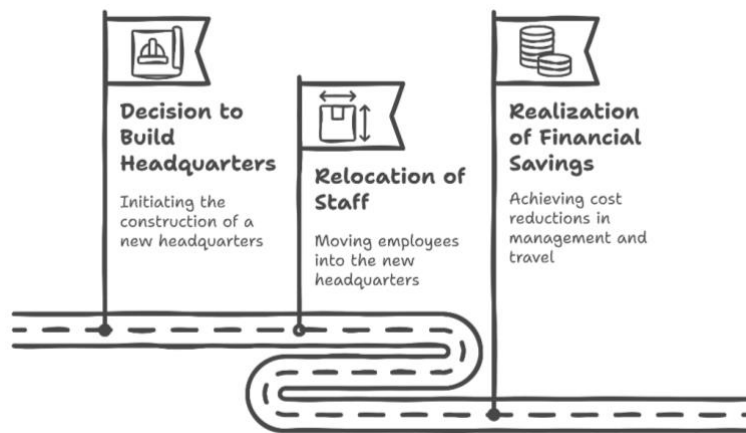


Fig. 2.2 - Project Objectives Examples

Project management's main goal is to provide a finished product that benefits the company or organisation that started the project [30],[21]. This entails starting, organising, and coordinating a number of tasks necessary to create the finished output. Certain characteristics of projects that are needed for formal management are shown in Figure 2.3 below:

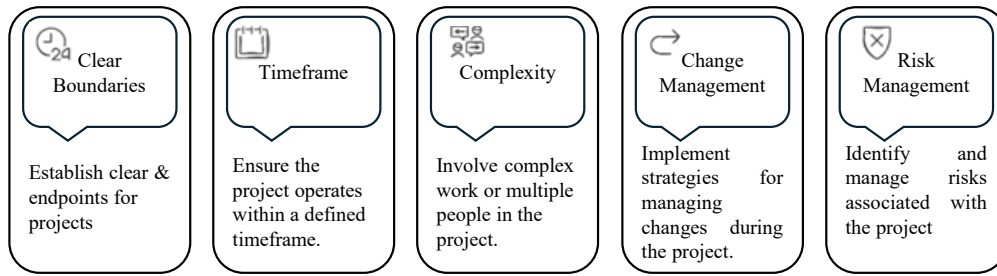


Fig. 2.3 - Project Management Criteria

There are many advantages to focusing on efficient project management, including [21],[30]:

- Increasing the possibility of getting the intended results.
- Ensuring the effective and efficient use of resources.
- Meeting the various demands of the project's participants.

2.2.2. FRONT-END PLANNING

Front-End Planning (FEP) is an essential stage in construction project management that guarantees adequate, strategically important information is acquired to control risks, distribute resources wisely, and enhance project execution effectiveness [13],[11],[37]. Alternative names for this approach include Front-End Engineering Design (FEED), schematic design, front-end loading (FEL), feasibility study, and conceptual planning [38]. The Construction Industry Institute (CII) first formally recognised the significance of FEP in [37], highlighting its contribution to lower project costs, fewer schedule and cost deviations, and more efficient project execution, which will ensure project success [31],[37]. Early-stage planning begins with the conception of a project, followed by information collection and stakeholders' consolidation, and finally ends with the final decision to proceed with the project or not. This has a major impact on project success, especially in large-scale and complicated infrastructure projects [39].

FEP is presented as the phase during which long-term strategies are formulated under constraints such as resource limitations, government regulations, and environmental restrictions, making the process fundamental to overall project success [40].

Front-End Planning (FEP), also referred to as programming, schematic design, and design development in architecture, is regarded as one of the most important phases in the building project life cycle [29]. Nevertheless, it is frequently done poorly, which results in less-than-ideal project outcomes. Establishing and preserving a solid connection between a project's business needs, strategy, scope, cost, and schedule requires FEP [29].

Effective FEP is uncommon in the industry, despite its importance being acknowledged. The results of a study at The University of Texas at Austin, which examined case studies from projects valued at more than \$1.5 billion, are presented in this publication [29]. The study looks at the connection between FEP and project performance, namely in terms of cost and schedule control, and provides useful advice for experts in the field. With an emphasis on building projects, the research incorporates data from many construction sectors. The cost of FEP as a percentage of the overall project cost is one important factor that is looked at. The results show that FEP usually accounts for 2-5% of the overall budget, with smaller projects (less than \$5 million) setting aside a bigger portion than larger projects because of economies of scale [29].

In the past, owners were thought to be in charge of planning, but successful projects show that both owners and contractors must be actively involved [29]. Better outcomes were attained by owners who

planned and stayed engaged throughout the project's lifecycle. Successful results were also attributed to contractors who actively participated in FEP. Planning tasks were occasionally assigned to outside experts, with varying degrees of effectiveness; project stakeholders' efficient oversight and well-defined duties were essential [29],[11],[27]. One of the most important factors was the project team's experience and capability; teams with greater experience were more productive, had better coordination, and had fewer design disagreements. Success was also found to require strong leadership. While projects with weak or conflicting leaders suffered from scope instability, inefficiency, and poor team cohesion, those with clear leadership guidance fared well [29].

2.2.2.1. Evolution & Terminology

From Pre-Project Planning to Front-End Planning

Historically, the process was termed Pre-Project Planning (PPP) or pre-design planning. In 1992, CII developed a standardised four-step process that included [17]:

- Team Organisation: Forming a dedicated PPP team.
- Project Alternatives: Selecting and evaluating various project options.
- Definition Package: Developing a comprehensive project definition.
- Decision Making: Determining whether to proceed based on synthesised information.

CII's 1994 case study confirmed that PPP is an owner-driven process that must be tailored to the organisation's business needs, with early integration of operations and clearly defined corporate guidelines. Recognising that planning activities extend throughout the project life cycle, CII replaced "Pre-Project Planning" with "Front-End Planning (FEP)" in 2006 [CII 2006, apud Mahdi 2013][12].

Alignment with Business Objectives

Research in the area of construction project planning, including studies on "pre-project planning"[41], "front-end loading" [42], and "front-end planning" [43], has validated the hypothesis that investing effort in strategic project planning improves project results and overall performance. This evidence underscores FEP's role in establishing a strong early connection between an owner's strategic goals and the project's scope, cost, and schedule, which eventually results in improvements such as approximately 10% better cost efficiency, 7% enhanced schedule performance, and 5% fewer change orders [44]. This alignment is essential for the project's strategic goal to be upheld throughout its implementation. According to [40], several companies have historically overlooked matching project execution with their strategic objectives, a flaw that leads to cost and schedule overruns, even though FEP is linked to feasibility studies, prioritising, and timing considerations.

2.2.2.2. Integration of Construction Knowledge and Expertise

Addressing Inadequate Input and Uncertainty

Oh et al. [17] emphasise how plan constructability is compromised by inadequate construction input during the pre-design and FEP phases. Enhancing the success rate in achieving predetermined goals is the main goal of adding pre-design resources [17],[45],[46],[47],[48]. However, the lack of strong frameworks for resource flow, as stated by Gibson et al. [49] and inherent uncertainties in the early stages of the project, as mentioned by Georges et al. [50], such as "inadequate scope definition" and "risk identification", present serious difficulties.

Mitigation Strategies

Prior studies have addressed these challenges by:

- Identifying Critical Activities: CII (1994, 1995a) apud Oh, 2015 [17] and subsequent research by George et al.[50] outline key actions that reduce uncertainties.
- Establishing Benchmark Metrics: Efforts by CII (1996, 1999) apud Oh, 2015 [17] and Yun et al. [51] have focused on developing metrics to gauge planning effectiveness.
- Developing Organisational Frameworks: CII's work (1993, 1997, 2005) apud Oh, 2015 [17] has emphasised the need for structured processes to facilitate construction input and communication.

2.2.2.3. Strategic Planning and Performance Outcomes

Strategic Role in Megaprojects

Construction projects are sequential activities that depend on detailed planning and programming [52]. During FEP, long-term strategies are formulated in the face of various constraints, such as resource limitations, governmental regulations, and environmental restrictions, that inherently increase project risks. However, many companies have historically failed to align project execution with these strategic plans [53],[54],[55],[56]. This misalignment has been evidenced by studies such as the City of Edmonton research, which examined over 200 capital projects and found that only a small portion achieved the desired estimation accuracy [57]. Additionally, traditional planning, estimating, and execution methods have been shown to be inconsistent and ineffective, leading to cost and schedule overruns [57],[58].

Empirical Evidence of Benefits

Studies, including those conducted by the City of Edmonton and researchers such as Abd Majid and McCaffer et al. [57] and Ariaratnam et al. [58], have consistently shown that detailed front-end planning leads to:

- Improved cost accuracy and schedule adherence.
- More reliable risk management.
- Enhanced overall project performance, with FEP-linked projects outperforming others by notable margins.

FEP is defined by CII (1995) as the process of developing sufficient strategic information with which owners can address risk and commit resources effectively [29]. Cleland and Ireland [59] further elaborate that FEP involves explicitly outlining the goals and strategies necessary for guiding a project to a successful conclusion.

2.2.2.4. Technological Integration and Front-End Planning Tools (FEPT)

Need for Integrated Management Systems

For capital projects with total installed values exceeding \$1 billion, the FEP phase produces thousands of documents and requires collaboration among large teams [12]. Traditional tools such as spreadsheets, printed documents, and ad hoc communications are inadequate for managing this volume and complexity. The CII research team, Griffith et al. [60], demonstrated that investment in FEP yields savings that justify expenditure on advanced systems, personnel, and other resources. A study by Mahdi

[13] emphasises that without integrated management systems, the execution of FEP remains inconsistent, leading to inefficiencies that can significantly affect project outcomes.

Emergence of Workflow and Automation

Recent advances in electronic product and process management systems have enabled the adoption of workflow concepts, long utilised in regulated industries like human resources and product support, to manage FEP more effectively [13]. These integrated systems, commonly referred to as front-end planning tools (FEPT), enforce standardised procedures regarding:

- Archiving and access
- Naming conventions and version control
- Metadata management and milestone tracking
- Workflow task assignments and compliance

Front-End Planning Tools and Methods

Structured FEP is supported by a number of tools. One popular instrument for evaluating project scope definition is the Project Definition Rating Index (PDRI), which was created by CII in 1994 [32]. By measuring important scope-defining components, PDRI offers an early indicator of the likelihood that a project will succeed [32],[37]. The 70 components are divided into three categories: Front-End Definition/Preliminary Design (42%), Execution Approach (8%), and Basis of Decision/Scope (50%). [37]. Studies have confirmed that a lower PDRI score (below 200) is associated with more successful projects and that it is beneficial in lowering scope changes and cost overruns in projects in the building and industrial sectors (CII, 1997 apud Sarde, 2016)[37].

The Construction Input Assessment Tool (CIAT), created by Oh et al. [17], is another essential tool that makes it easier to systematically incorporate construction knowledge into FEP decision-making. According to research, incorporating construction knowledge early on improves constructability, decreases uncertainty, and minimises rework [14].

To improve the effectiveness of FEP in megaprojects, the Front-End Planning Tool (FEPT) was created [12]. It incorporates workflow-enabled methods to decrease inefficiencies, enhance document management, and expedite approval processes. Research has shown that by encouraging cooperation among stakeholders, FEPT implementation leads to cost reductions and better decision-making [12].

To enhance coordination among project stakeholders, other approaches include the use of Building Information Modelling (BIM), benchmarking frameworks, and strategic alignment tools [17].

2.2.2.5. Detailed Phases and Critical Activities in FEP

Phases of Front-End Planning

A structured FEP process, as represented in Figure 2.4, is typically divided into three primary phases:

1. Phase 1: Feasibility Analysis

This initial phase involves developing and documenting all potential project options, evaluating them against agreed-upon criteria, and producing a report that recommends a course of action and realistic estimates of total and life cycle costs. All influencing factors, such as resource availability, time constraints, outsourcing strategies, facilities, and environmental considerations, are analysed [13].

A study by Gibson [29] mentioned that it evaluates project viability in this stage through business needs identification, risk assessment, and initial cost and schedule estimates.

2. Phase 2: Concept Development

Building on the feasibility report, this phase analyses each alternative against mission requirements and business objectives. The project team develops, optimises, and specifies process parameters and equipment, culminating in a comprehensive concept report that enables accurate budgeting and scheduling [13].

A study by Gibson [29] enhances project scope, site research, regulatory considerations, execution plans, and stakeholder alignment.

3. Phase 3: Detailed Scope Development

In this phase, the project's scope is finalised. Deliverables include :

- A strategic plan for execution (comprising initial estimates, schedules, and safety strategies) [13]
- Identification of risk drivers [13]
- Clear definitions of physical and non-physical interfaces (approximately 80% complete) [13]
- Technical reports (e.g., piping and instrumentation diagrams) [13]
- Detailed scope of work for work package definition [13]

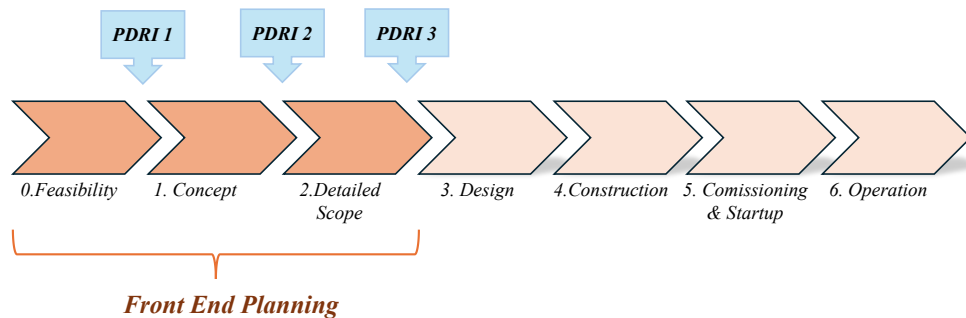


Fig. 2.4 - Front End Planning Process

Completes engineering design, site layouts, and cost estimates to secure project approval [29].

This phase establishes the foundation for contractor selection, work breakdown structures, and subsequent project phases. A comprehensive strategic plan is critical at this stage; without it, a fragmented supply chain approach may result, leading to further project [61].

At every level, decision gates aid in risk management and project alignment, eventually enhancing cost control and execution effectiveness.

Critical Activities and Decision Gates

As outlined by George et al. [62], the FEP process can be viewed in two tiers:

- a) Tier One (Primary Phases):
 1. Business Plan: Establishing strategic business objectives [62].
 2. Contract Strategy: Defining methods for selecting partners and Engineering, Procurement & Construction (EPC) contractors [62].

3. Project Execution Plan (PEP): Developing detailed plans that include initial estimates, schedules, and safety measures [62].
4. Facility Scope Plan: Documenting facility and process scope, including utility requirements and regulatory restrictions [62].
5. Product Technical Plan: Identifying technical requirements such as licensing and testing protocols [62].

b) Tier Two (Expanded Activities):

This level details the activities within each primary phase, including milestones and decision gates (DG) that ensure all objectives are met before progressing to the next phase [62]. The final decision phase is particularly critical, as decisions must be made under conditions of high uncertainty with minimal information. Early warning systems [63] and best practices for project security [64] have been developed to address these challenges.

Retrospective Insights

A 30-year literature review highlights the importance of FEP within the broader project life cycle [27]. It differentiates FEP from general project planning by emphasising that:

- FEP covers the initiation and early planning stages, culminating in a Final Investment Decision [27].
- Inadequate FEP can lead to unclear scope definitions, unstable team structures, incomplete requirements, ambiguous roles, and ultimately, project rework, delays, cost overruns, and stakeholder dissatisfaction [10],[65].
- For megaprojects, where the consequences of early decisions are profound and costly, dedicating sufficient resources to FEP is essential [63],[66].

Benefits of Front-End Planning

Successful front-end planning has been demonstrated to significantly enhance project results. A properly implemented FEP results in fewer change orders, lower schedule overruns, and more cost efficiency. According to Faniran et al [10], one of the main benefits of FEP is the decrease in contractual disputes that results from its explicit aims and well-defined scopes, which reduce ambiguities and conflicts among stakeholders. Furthermore, by incorporating construction expertise early in the project, FEP improves constructability and risk management [14]. Better risk identification, more predictability, and more efficient use of resources result from this.

According to George et al. [62], FEP also enhances supply chain management and contractor selection by prioritising transparent bidding procedures, which filter out underqualified contractors. Additionally, early financial planning helps avoid project delays brought on by financial constraints and minimises funding shortfalls [27].

Furthermore, another important element that is impacted by FEP is labour availability. Workforce shortages are reduced by organised hiring, training, and logistics planning [67]. Furthermore, contingency planning successfully manages weather-related risks, guaranteeing minimal delays in unfavourable situations [37].

2.2.3. ROYAL INSTITUTE OF BRITISH ARCHITECTS

From project conception to post-occupancy, various phases of project development are outlined in the Royal Institute of British Architects' (RIBA) Plan of Work, a structured framework. To give architects and their clients a more organised framework and to make the various phases of a project clearer, the RIBA Plan of Work was developed in 1963 [15]. To accommodate various purchase techniques while preserving its fundamental design principles, the framework underwent its first significant revision in 2013. Two significant new stages were added in this revision: Stage 0, which recognises the necessity of strategic planning at the beginning of the project, and Stage 7, which concentrates on building use and its long-term lifecycle [15].

Other task bars, as shown in Figure 2.5, were added to the framework to improve it even more.

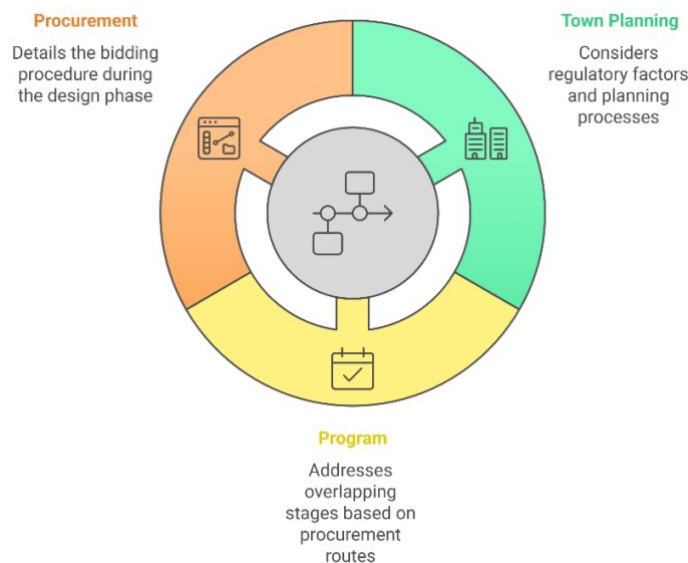


Fig. 2.5 - Construction Project Management Task Bars

Project processes have changed significantly due to technological breakthroughs, which have brought about a paradigm shift rather than merely improvements on long-standing procedures [15]. Modern methods of construction (MMC), such as volumetric modular building, are becoming more and more popular [15]. This is changing business models and modernising the residential industry.

Design teams face a great deal of difficulty in managing complicated factors, including ethical standards, regulatory compliance, and best international practices, while juggling changing client expectations. A structured approach is crucial due to the increasing complexity of the design process, which is driven by sustainability objectives, maintainability needs, and new procurement methods [15]. Different team members may adhere to their own interpretations of best practices in the absence of a uniform procedure, which could result in inefficiencies and misalignment [15].

RIBA Plan of Work Stages

The history of the RIBA Plan of Work, a popular framework for outlining project phases in the UK, reflects improvements in briefing techniques [15]. The 2007 version of the process started with Stage A: Appraisal, which determined the needs and goals of the client. These requirements were then developed into a comprehensive project brief in Stage B: Design Brief. Stage 1: Preparation and Brief, which created the project brief utilising feasibility studies and early design input, and Stage 0: Strategic

Definition, which concentrated on high-level project goals like site selection and project scope, were added in the 2013 iteration [68]. This structure was further developed in the 2020 update, which improved feasibility research and stakeholder participation while maintaining the project brief's alignment with strategic objectives [69].

A strong client-architect/designer relationship is built on the foundation of the briefing process, which is the first stage of the design process. Projects are guaranteed to be completed to the necessary quality standards, on schedule, and under budget, with a well-organised briefing [15]. Numerous studies emphasise how crucial a thorough client brief is to lowering change orders and enhancing project performance as a whole [70],[71].

Usually, the briefing procedure is divided into phases that correspond to the building project's total lifecycle. It includes methodically outlining the client's needs and making sure they are clear and understandable. Two primary viewpoints on briefing are identified by research: one sees it as a static document that is completed early in the project, while the other sees it as a dynamic process that changes during the early stages of the project [72]. Strategic briefing and project briefing are the two primary phases of the briefing process [73]. This stage assesses whether developing a specific type of structure in a given location aligns with the organisation's needs. A strategic briefing study should outline the business program's purpose and its alignment with corporate goals, expressing the client's value system both in business terms and cultural values [68]. Stakeholders can now investigate a variety of delivery methods, enabling strategic management to make well-informed choices before moving forward.

During the project briefing phase, strategic objectives are converted into precise design specifications. It outlines the performance standards for the project with relation to a number of factors, such as the needs of the client, user requirements, site conditions, environmental concerns, regulatory compliance, and construction limitations[74]. The project brief is basically the construction industry's response to the strategic brief to ensure that the client's initial goals are successfully translated into workable design and construction plans. Researchers widely accept this distinction between the two briefing stages [72],[68],[75].

Figure 2.6 illustrates the current RIBA Plan of Work stages and their sequence:

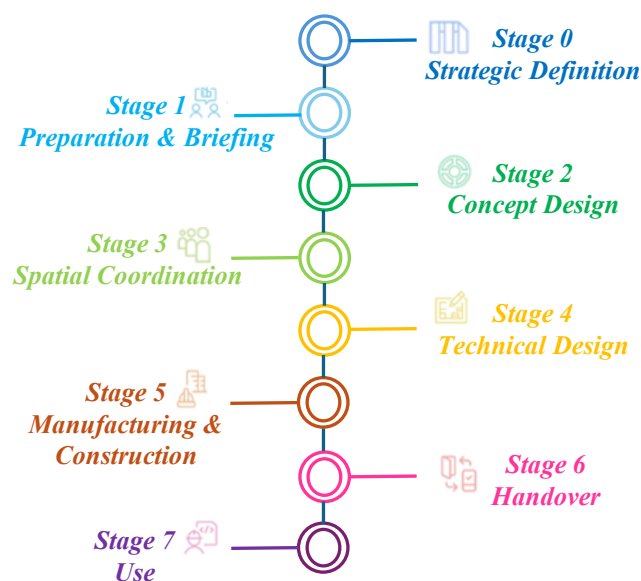


Fig. 2.6 - RIBA Plan of Work Stages: From Concept to Completion

a) Stage 0: Strategic Definition

Finding the most effective way to meet the client's requirements is the focus of stage 0. Keeping an open mind is crucial because a building might not be the greatest choice. Some clients use this stage to draft a comprehensive brief [15]. However, the proposal needs to be strategic and include the Business case and Client requirements. To guarantee the optimum result for this stage, the client must take into account the level of experience needed within the client team [15].

Stage 0 is more concerned with high-level strategic decision-making than design development. It entails assessing several options, estimating project risks, and ensuring alignment with the project budget. To analyse viability and choose the best plan of action, this step frequently includes site appraisals and planning reviews [68].

At this stage, the client team is essential and, when needed, seeks the advice of experienced consultants. Early engagement of relevant stakeholders will result in a well-structured and data-driven Business case and Client requirements [15]. The business case is created by evaluating the project's limitations, possible hazards, and financial feasibility. Site assessments aid in determining the appropriateness of a place while taking sustainability goals into account[15]. Decision-making can be improved by incorporating the knowledge gained from prior projects. Before moving on to the next phase, the main objective of this stage is to determine the project's direction, budget, and client requirements [15].

Verification of the most effective plan for meeting the needs of the client is the outcome of this stage.

b) Stage 1: Preparation and Briefing

The client team begins the briefing process when Stage 0 concludes that the construction project is the most effective way to meet the client's needs. This entails carefully analysing the client's requirements, location limitations, and feasibility studies to ensure the project is feasible [15]. The Project Brief documents the essential needs and limitations of the project throughout the Preparation and Briefing phase [15].

A key document that outlines the desired project outcomes, sustainability objectives, and quality expectations is the project brief [15]. Depending on the project's complexity, the client starts putting together the project team, which may comprise engineers, architects, cost consultants, and specialised advisors. Feasibility studies are frequently carried out to confirm that the chosen location can support the project's requirements while staying under budget [15]. Procurement strategies are also determined at this stage, influencing the design and construction approach [15].

Before design starts, a project program is set up to ensure all required site surveys and planning evaluations are finished. This stage is crucial to the success of the project since any ambiguities or gaps in the briefing could result in later, expensive revisions [68].

Furthermore, the Responsibility Matrix, Information Requirements, and Project Execution Plan are established as essential project management tools [15]. Before proceeding, these guarantee that design roles and execution techniques are clear.

Stage 1's outcome is the acceptance of the Project Brief and verification that the location is suitable for the project.

c) Stage 2: Concept Design

Stage 2 is the start of the design phase, during which preliminary ideas are created using site-specific information and client specifications [15]. The project's architectural vision is decided upon during the Concept Design phase. To create an initial design that complies with the Project Brief and Site Information, the lead designer, usually an architect, works closely with the client and additional experts [15]. The design idea considers sustainability and engineering considerations when defining the building shape, functional arrangement, and spatial organisation. The concept is refined through a number of Design Reviews with stakeholders to make sure it complies with technical feasibility, budgetary restrictions, and planning policies [15]. A formal Change Control Procedure must be used to agree on any necessary changes to the Project Brief. The Cost Plan is modified to reflect the conceptual design to provide early insight into whether the project remains financially viable. Early planning consultations may also be conducted to address regulatory requirements. The Architectural Concept, which forms the basis for more intricate spatial coordination in Stage 3, is approved by the client by the end of this phase [15].

Stage 2's outcome is where the Architectural Concept's approval guarantees that it complies with the Project Brief.

d) Stage 3: Spatial Coordination

Integrating the structural, architectural, and building services ideas into a cohesive proposal is the main goal of the spatial coordination stage [15]. Before technical detailing starts, it is important to ensure all design components are in harmony and that any possible conflicts, like mechanical systems and structural elements, are settled. Specialised consultants, such as accessibility, acoustics, and fire safety experts, may be brought in to refine specific aspects of the design. Planning authorities may also be consulted before submitting a formal planning application to address any concerns [15].

Cost estimates are refined to handle changes effectively, and Change Control Protocols are put in place [15]. The Stage 3 Design Program guarantees that every component is appropriately coordinated and compliant with legal specifications. A Spatially Coordinated Design is completed at the end of this phase, which serves as a strong foundation for Stage 4's more intricate technical work [15].

Stage 3's outcome is a fully integrated design through the coordination of engineering and architectural components.

e) Stage 4: Technical Design

During Stage 4, all of the technical design information required to complete production and construction is developed. Detailed designs of structural, electrical, mechanical, plumbing, and architectural elements are developed [15].

In design-and-build contracts, specialised subcontractors may be in charge of detailed technical designs based on descriptive information, whereas in traditional contracts, the design team provides fully prescriptive technical drawings [15]. The degree of detail in the design is determined by the procurement strategy. Any pre-commencement planning conditions are fulfilled, and compliance with the Building Regulations is reviewed. The project team completes material and system specifications, making sure they satisfy sustainability, safety, and performance standards. The Building Contract is written, and the Construction Program is developed [15]. Before beginning construction, it is essential that all design elements are appropriately coordinated and confirmed, as this step has a direct impact on build quality.

Stage 4's outcome is that all technical paperwork needed for building and manufacturing has been completed.

f) Stage 5: Manufacturing and Construction

The contractor takes control of the site during the Manufacturing and Construction phase and starts carrying out the project by the contract specifications and the agreed-upon design [15]. This step includes purchasing supplies, producing prefabricated parts, and on-site building. The project complies with health and safety norms thanks to quality control and site logistics management. The contractor or design team responds to any site inquiries that come up during construction. Routine inspections are carried out to confirm craftsmanship and make sure that construction complies with authorised technical specifications. In the latter stages of this phase, the commissioning of building systems, including mechanical and electrical services, starts. Offsite manufacturing techniques also strongly emphasise supply chain management and logistics planning. Efficiency can be increased by using digital tools and 4D building sequencing. Practical Completion, when the structure is judged ready for occupation, marks the end of this stage [15].

Clear contractual agreements must specify when and how construction activities begin because Stages 4 and 5 sometimes overlap [15].

Construction is finished, and operational use begins in Stage 5's outcome.

g) Stage 6: Handover

The building is officially turned over to the client during the handover phase, and all outstanding contractual duties are completed. The client receives the Building Manual, Health and Safety File, and Fire Safety Information, guaranteeing that they have all the paperwork they need for upkeep and operation [15]. The Defects Liability Period starts, during which the contractor fixes any lingering problems or flaws. To acquaint the facility management crew with building systems, training sessions may be held [15].

The building's initial performance and user satisfaction may be evaluated using a light-touch Post Occupancy Evaluation (POE). The project team does a Project Performance Review to document lessons learned for upcoming projects. The Building Contract is officially closed after all flaws have been fixed and the Final Certificate has been granted. The Final Certificate, which formally ends contractual responsibilities, is granted around a year after Practical Completion [15].

Building handover, construction completion, and the start of aftercare services are Stage 6's outcomes.

h) Stage 7: Use

Stage 7, which focuses on building performance and lifespan factors, begins concurrently with Stage 6. Use, the last step, deals with the building's continued upkeep, functioning, and eventual adaptation or decommissioning [15]. Facility managers ensure the building runs well by maximising asset management, sustainability results, and energy performance. Post-occupancy evaluations that compare actual building performance to design assumptions may be carried out in more detail [15]. Future projects can benefit from the lessons acquired from in-use performance, resulting in ongoing design and construction enhancements. To provide a sustainable lifespan strategy, the procedure loops back to Stage 0 whenever the building has to be renovated, refurbished, or repurposed [15].

This phase emphasises the significance of long-term asset management, maintenance planning, and sustainability monitoring to minimise expenses and environmental effects. Building information models (BIM) and digital twins may be updated over time to facilitate continuous facilities management (FM) and strategic planning for upcoming additions or changes [15].

Effective management, maintenance, and optimisation of long-term building performance is Stage 7's outcome.

2.2.4. PROJECT MANAGEMENT INSTITUTE

Project management is a methodical technique that efficiently arranges tasks, resources, and deadlines to guarantee the successful completion of projects [21],[30]. Five key process groups are defined by the Project Management Body of Knowledge (PMBOK Guide) to help project managers effectively plan, carry out, and oversee projects [30]. The foundation of project management approaches, these process groups, as shown in Figure 2.7, Initiating, Planning, Executing, Monitoring & Controlling, and Closing, offer a methodical way to accomplish project goals. To guarantee that projects fulfil stakeholder expectations, remain below budget, and follow scheduled timelines, each process group has a distinct function to play [30]. Each process group is covered in detail below, with an emphasis on its goals, main tasks, and importance throughout the project life cycle.

An organised method for project development is offered by a four-phase project life cycle. According to Pinto et al. [76], top management determines a strategic need and investigates initial objectives, viable alternatives, and resource availability to start the first step, conceptualisation. Key questions, including the nature of the issue, whether a project can solve it, the precise goals, and the resources needed, are all addressed in a feasibility study [30]. Following approval, the project enters the planning stage, during which a formalised plan is created that includes work allocations, budgeting, and resource allocation. After it comes the Execution phase, where materials and resources are acquired and turned into project deliverables. Performance is regularly tracked during this phase to make sure it is in line with the desired goals. The project is finally finished, the team is dissolved, the resources are returned to the company, and the finished product is given to the users during the Termination phase [30]. Projects are efficiently managed from start to finish thanks to this methodical methodology.



Fig. 2.7 - Project Management Process Sequence

2.2.4.1. Initiating Process Group

The Initiating Process Group involves defining a new project or phase and obtaining formal authorisation to begin [30]. Key stakeholders align on the project's purpose, high-level scope, and objectives, setting the foundation for successful delivery. This phase includes appointing a project manager (if not already selected), identifying stakeholders, and documenting initial data in the stakeholder register and project charter [21]. These two outputs formally authorise the project and establish its boundaries (see Figure 2.8). Once the charter is approved, planning and resource allocation can begin.

The main benefit of this phase is ensuring that only projects aligned with the organisation's strategic goals and expected value proceed. It incorporates the business case early, validating the project's purpose and benefits, an approach emphasised in the PMBOK Guide, which prioritises value and strategic alignment [21]. Most projects begin with a business case outlining strategic fit, benefits, and business need.

The charter or equivalent authorisation document typically includes the business justification, establishing a shared understanding of the project's goals, rationale, and success criteria. This aligns with the PMBOK Guide's focus on value and early stakeholder engagement, fostering a common vision and ensuring project outcomes meet stakeholder needs[21]. Ultimately, the Initiating Process Group lays a clear foundation for all subsequent work [30]. Thus, by gaining agreement and clarity on project objectives, limitations, and stakeholders' interests, the initiating activities lay the groundwork for all ensuing activity.

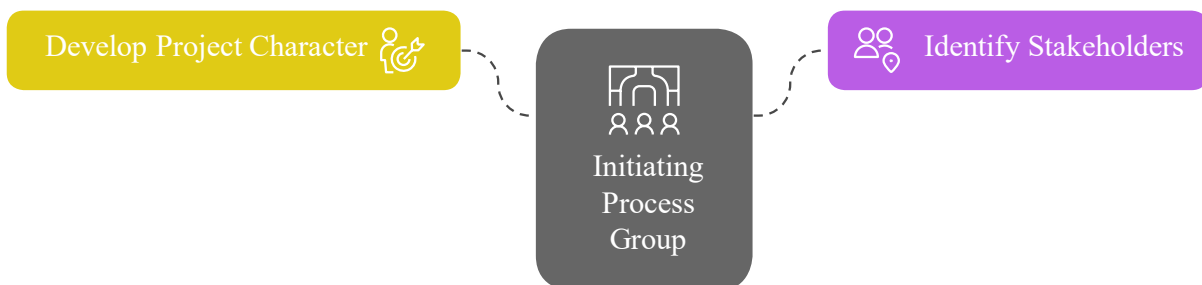


Fig. 2.8 - Initiating Process Group

2.2.4.2. Planning Process Group

The Planning Process Group involves determining the project's scope, refining objectives, and defining the strategy to achieve them [30]. The project team develops a comprehensive project management plan, incorporating subsidiary plans covering scope, schedule, cost, quality, resources, communications, risk, procurement, and stakeholders [30]. Planning establishes what needs to be done, how, by whom, when, and at what cost, engaging relevant parties to align strategies.

Initial assumptions are revisited as new information arises, leading to updated documents and baselined plans that guide execution and performance monitoring. The integrated project management plan (see Figure 2.9) becomes the official standard for measuring progress. Once approved, it can only be changed through formal change control processes. Planning is iterative; as the project evolves, the plan is progressively elaborated to reflect emerging needs and risks[30].

The Planning Process Group's key benefit is producing a realistic, shared roadmap that increases the likelihood of meeting project goals [30]. Involving stakeholders early helps manage expectations and

establish clear scope, time, and cost baselines. The PMBOK Guide frames planning as a continuous performance domain, organising and coordinating work throughout the project [21]. Effective planning adapts to context, avoids over-detailing, and remains flexible enough to accommodate change.

High-level planning may begin during Initiating, but plans are revised continuously to reflect new information, reduce risks, and engage stakeholders [30]. This approach supports adaptive project management and systems thinking, ensuring plans stay relevant and value-driven over time.

The PMBOK Guide reframes planning as an ongoing performance domain. Planning is both a starting activity and a continuous function as the project moves forward, as indicated by the Planning Performance Domain, which *"organises, elaborates, and coordinates project work throughout the project [21]."* A comprehensive and flexible strategy is necessary for effective planning: *"The project progresses in an organised, coordinated, and deliberate manner..."* Evolving information is elaborated to produce deliverables *"Time spent planning is appropriate for the situation..."* and plans are adapted throughout the project based on emerging needs[21]. *"In reality, this means that the amount of planning work and detail should be adjusted to the specifics of the project [30]."* Teams should stay clear of rigid plans or over-planning that could become outdated in favour of adequate planning to direct execution and then adjusting those plans in light of new information.

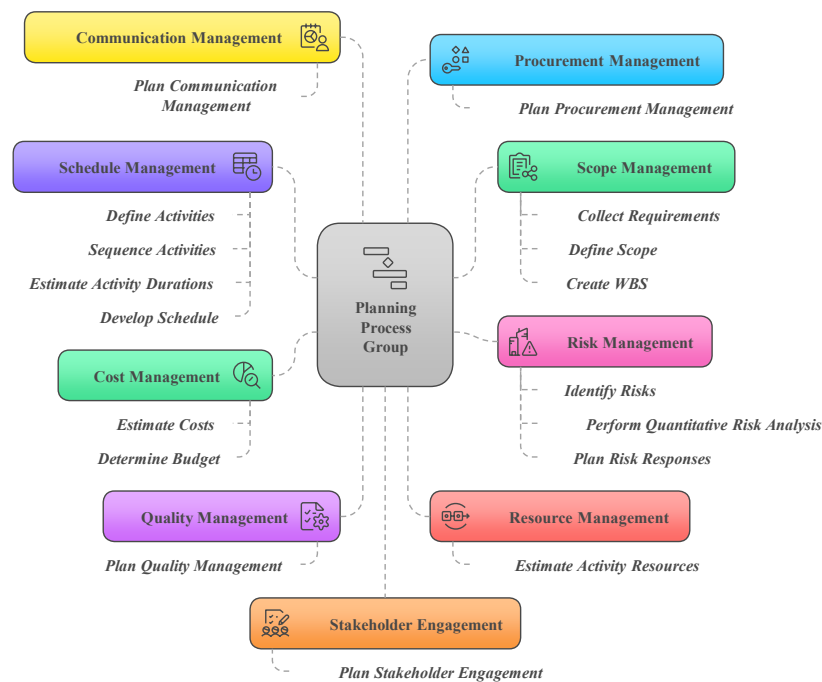


Fig. 2.9 - Planning Process Group

2.2.4.3. Executing Process Group

The Executing Process Group focuses on completing the work defined in the project management plan to meet project requirements [30]. This involves organising resources, directing project work, managing the team, ensuring quality standards, engaging stakeholders, and integrating all activities to produce deliverables. Execution is where value is delivered, when the project's products or services are developed, tested, and implemented according to agreed goals and specifications [30].

Key activities include implementing risk responses, managing procurements, and adapting to issues or change requests as they arise [30],[21]. The project manager leads the team, resolves obstacles, and ensures progress aligns with the baselines [30]. Execution is often iterative, involving cycles of task refinement and adjustment, as shown in Figure 2.10. Approved changes may feed back into planning, leading to updates or re-baselining.

This phase consumes the bulk of the project's time, cost, and effort. Its main benefit is delivering outputs that fulfil the project's objectives on time and within budget [21]. Success depends on adherence to the plan and ongoing performance tracking. Execution is dynamic, requiring responsiveness to deviations, stakeholder needs, and emerging risks.

Leadership and team management, keeping the team engaged, resolving disagreements, and increasing team performance, as well as stakeholder communications, keeping everyone updated on progress, account for a significant amount of project management effort during execution [21]. For example, the Project Work performance domain emphasises creating efficient procedures and a positive work atmosphere to enable the team to complete the task effectively. It emphasises outcomes such as “*efficient and effective project performance*,” appropriate communications, effective resource management, and continuous improvement within the team [21].

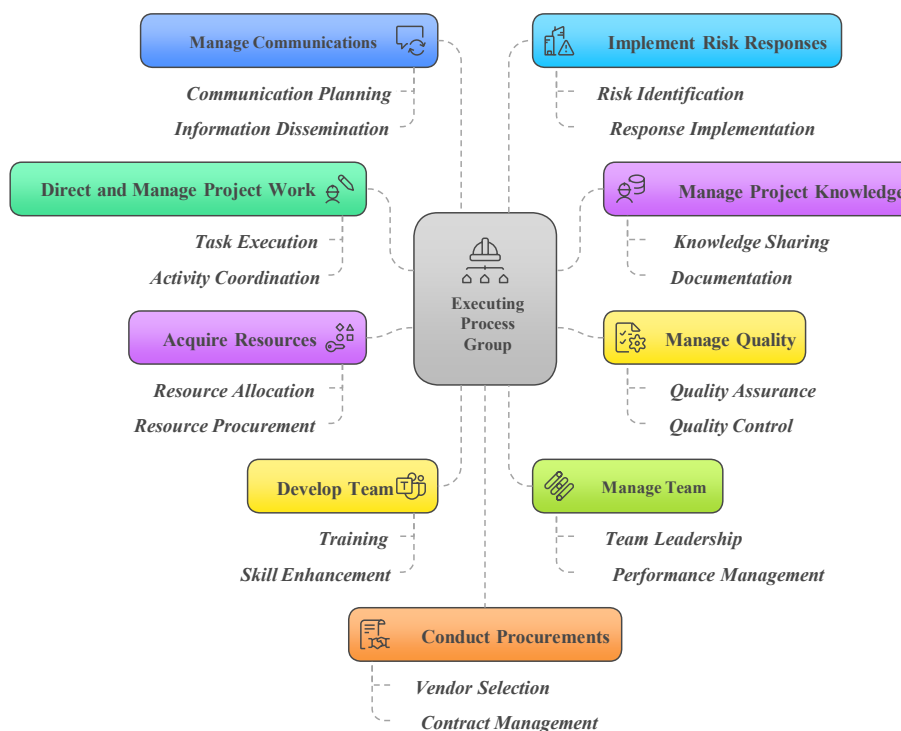


Fig. 2.10 - Executing Process Group

2.2.4.4. Monitoring and Controlling Process Group

The Monitoring and Controlling Process Group includes the procedures used to track project performance, compare it against the plan, and initiate necessary changes [30]. It involves collecting performance data, such as work completed, costs, quality, and risk status, analysing variances and trends, and implementing corrective or preventive actions. Monitoring provides performance insights, while controlling focuses on aligning actual results with the baselines [30]. Typical processes include scope

validation, change control, managing scope, schedule, cost, quality, risks, procurements, and stakeholder engagement. These activities help identify issues early, guide timely decisions, and ensure alignment with project goals. Performance is assessed regularly at milestones or throughout execution to maintain control and prevent issues like scope creep [30].

Integrated change control plays a key role by evaluating and approving or rejecting change requests, whether from unexpected issues, corrective actions, or new requirements, ensuring that only justified changes are implemented and their impacts are understood [30]. Preventive actions and proactive risk monitoring are also part of this group. Monitoring and controlling span the entire project lifecycle and interact with all other process groups (see Figure 2.11). Performance data flows from executing processes, is assessed against the plan, and informs adjustments that may lead to plan updates or realignment of execution.

According to the PMBOK Guide, monitoring is continuous and most valuable when it drives decisions. Its Measurement Performance Domain emphasises timely action and informed adjustments based on metrics like schedule variance or cost performance index [21]. Effective monitoring provides a reliable view of project status and helps ensure the project stays on track or adapts appropriately when deviations occur. The objective is to facilitate *"timely and appropriate actions to keep project performance on track"* and to guarantee a *"reliable understanding of the status of the project."* [21] To put it another way, the PMBOK emphasises that measurement is only useful if it results in decision-making and action; data by itself is insufficient; what matters is the application of data to inform changes.



Fig. 2.11 - Monitoring and Controlling Process Group

2.2.4.5. Closing Process Group

The Closing Process Group involves the procedures needed to formally conclude a project, phase, or contract. Its primary goal is to ensure all work is completed, deliverables are accepted, and the project's objectives have been met, or that an early termination has been appropriately handled [30]. The project

manager verifies that all project activities are finished, deliverables have been approved, and any outstanding items have been resolved.

Key tasks include obtaining formal acceptance from the customer or sponsor, confirming project scope completion, closing contracts, finalising accounts, and updating organisational process assets with documentation and lessons learned [30]. Final reports summarise project performance, outcomes, and transition plans for future support or maintenance. Project resources are released, and remaining assets are reassigned or disposed of. The main benefit of this group is providing a structured, official end to the project or phase [30]. It ensures stakeholders are satisfied, deliverables are transferred, and valuable knowledge is retained, even if the project ends early. As shown in Figure 2.12, typical outputs include accepted deliverables, final reports, updates to lessons learned repositories, and finalised documentation.

Although it typically includes just one process, Close Project or Phase, many organisations follow detailed closure procedures or checklists. The project manager ensures all plan requirements have been met, verifies financial closure, and completes documentation updates [30],[21]. Lessons learned are captured and archived to support future projects, marking the formal end of the current one.

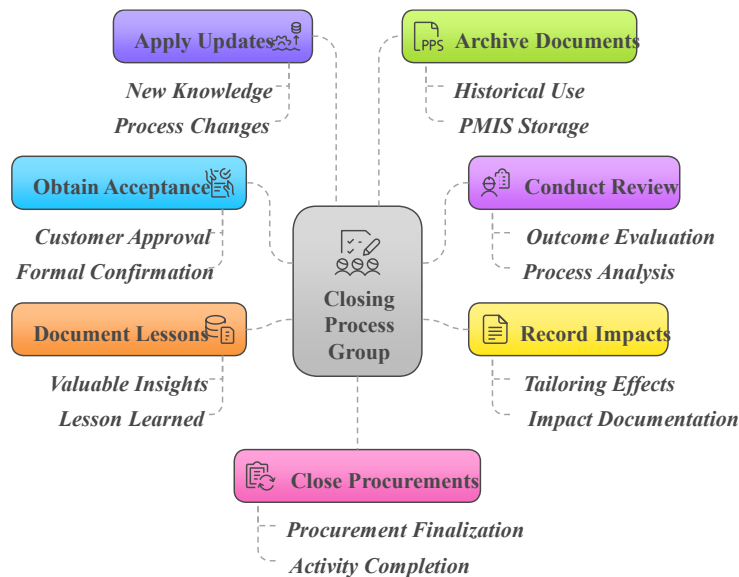


Fig. 2.12 - Closing Process Group

2.3. COMPARATIVE ANALYSIS OF PROJECT MANAGEMENT FRAMEWORKS

Three well-known project management frameworks that are frequently used in the construction sector are compared in this section: the PMI PMBOK Framework, the RIBA Plan of Work, and Front-End Planning (FEP). Although each framework provides organised methods for project development, there are notable differences in their histories, techniques, and areas of emphasis, which affect how they are used in real-world situations, as shown in Table 2.1.

In large-scale capital projects, when early planning investment yields quantifiable benefits like cost certainty and lower risks, front-end planning becomes especially important [20]. Constructability integration and strategic stakeholder alignment are crucial.

The architectural and built environment industries, on the other hand, are best suited to the design-centric lifecycle framework provided by the RIBA Plan of Work. It emphasises stakeholder cooperation and briefing, and it incorporates contemporary construction techniques like digital tools and modular building [15].

The PMI PMBOK framework, on the other hand, has a flexible and formal process-based structure and broad industry application. It works particularly well for groups overseeing several ongoing projects or working in industries that demand strict control over scope, money, and schedule [30].

Understanding these frameworks enables professionals and organisations to modify approaches based on stakeholder requirements, project scale, and complexity, which eventually results in more successful and predictable project outputs.

Table 2.1 - Comparative Analysis of Project Management Frameworks

Aspect	FEP	RIBA	PMI
Institutional Origin	Construction Industry Institute (CII), USA	Royal Institute of British Architects (RIBA), UK	Project Management Institute (PMI), USA
Sectoral Focus	Construction and infrastructure projects	Architectural and building projects	Multi-sector (construction, IT, healthcare, etc.)
Core Objective	Early-phase planning for strategic alignment and risk reduction	Lifecycle-based project structure	Process-based execution across all phases
Framework Structure	3 Phases (Feasibility, Concept, Scope) with decision gates	8 Stages from Strategic Definition to Use	5 Process Groups (Initiating to Closing)
Initiation Strategy	Evaluates business needs through structured early planning and owner-contractor involvement	Strategic briefing to evaluate site and client needs; early feasibility analysis	Initiation through a Project Charter based on the business case and stakeholder analysis
Scope Development	Uses PDRI, targets 80% scope clarity pre-execution	Structured briefing evolving from strategic to project brief	Defined through WBS, scope statements, and detailed planning documents
Constructability Integration	Explicit, integrated early via CIAT, FEPT tools & ECI	Implicit, via design collaboration	Indirect, promoted through risk planning and execution strategies
Stakeholder Engagement	Emphasises collaborative owner-contractor planning	Client-driven, with early multidisciplinary team input	Systematic lifecycle-wide stakeholder management

Risk Management	Central to FEP, risks are identified early and managed at decision gates	Integrated into feasibility and site analysis during the early stages	Continuous process with a defined risk management plan and response strategies
Use of Tools	PDRI, CIAT, FEPT, early warning systems, benchmarking frameworks	BIM, feasibility studies, procurement strategies, and the Responsibility Matrix	PM plans (scope, schedule, budget), EVM, change control systems
Performance Outcomes	Enhanced cost and schedule predictability, reduced change orders, improved constructability	Improved design quality, lifecycle sustainability, and regulatory compliance	Effective execution, stakeholder satisfaction, time-cost-scope balance
Post-Completion Strategy	Less emphasised, though planning tools encourage alignment with business goals	Explicit stages for handover and use (Stages 6-7), including POE and FM	Client-driven, with early multidisciplinary team input Emphasise "Organisational Process Assets" and "Knowledge Transfer"

2.4. CONSTRUCTABILITY

2.4.1. INTRODUCTION: A HOLISTIC VIEW OF CONSTRUCTABILITY

Constructability has become a key strategic approach in construction project management, with the goal of integrating construction expertise throughout all project phases, from conceptual design to field operations, in order to increase quality, decrease risk, minimise delays, and improve cost effectiveness [3]. From being a design-centred issue, it has developed into a comprehensive project management approach that aims to increase productivity, reduce costs, and improve project results. Constructability is a systematic methodology that integrates construction expertise with management procedures across the project life cycle, as Khan highlights [3]. It is not only a stand-alone technical evaluation.

Constructability, according to the Construction Industry Institute (CII, 1986 apud Kifokeris, 2019, page 2), is "*the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives*" [77]. This paradigm goes beyond the more limited idea of buildability, which was first introduced by Construction Industry Research and Information Association (CIRIA, 1983 apud Kifokeris, 2017) in the UK and mainly concentrated on how easy it was to create during the design stage [4]. Constructability deals with systemic integration, coordination, and project lifecycle management, whereas buildability focuses on streamlined and rationalised design. By proposing the idea of a constructability program, a methodical, structured endeavour employing skilled construction workers throughout the project lifecycle, the American Society of Civil Engineers expanded on this description [2].

Constructability has been defined and contextualised by a number of researchers. Researchers highlight its function in resolving the conventional division between designers and constructors [5],[78],[79],[80]. A more comprehensive, philosophical perspective is taken, who describe constructability as a multidisciplinary, holistic strategy required to handle projects that are becoming more complicated [4]. The study highlights the inconsistent application of constructability across projects and organisations,

despite its clear definition and demonstrated benefits. Adoption levels range from planned, strategic plans to completely non-existent practices [18]. Kifokeris and Xenidis also noted this pattern in their examination of contractual and practical constraints [4]. Figure 2.13 presents the concept of constructability and buildability, showing the similarities and differences identified in the key constructs.

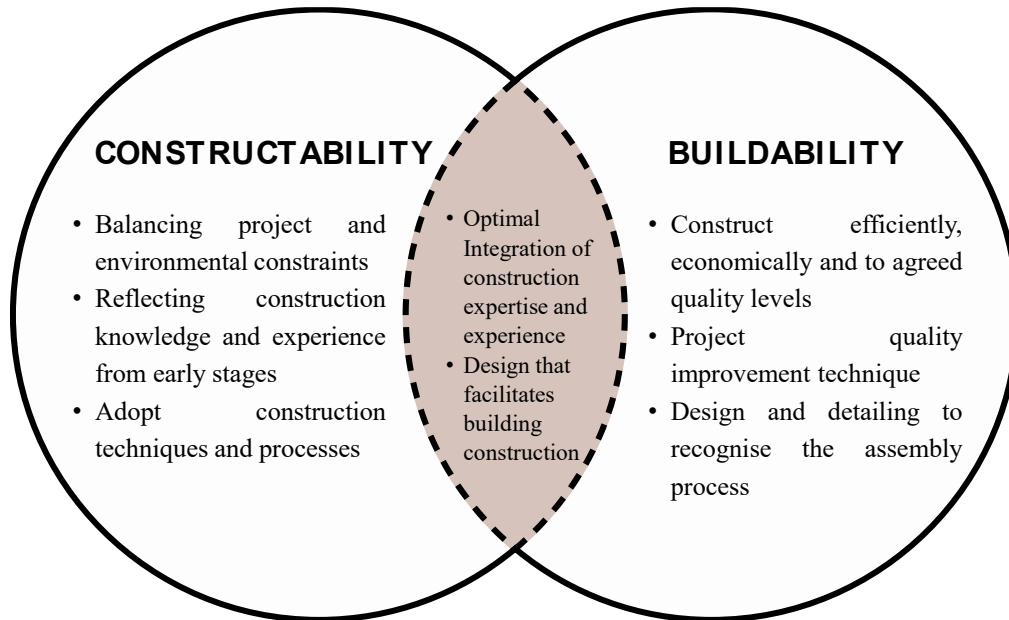


Fig. 2.13 - Similarities and differences identified in the key constructs.

2.4.2. CONSTRUCTABILITY CONCEPTS & PRINCIPLES

A significant step forward in operationalising constructability is the formulation of certain ideas and principles to direct its application. Nima [34] initially established 23 Constructability Concepts (CCs), which were later studied by Kifokeris and Xenidis [4] and cover the stages of conceptual planning, design and procurement, and field operations. Stakeholder participation, construction-informed design, standardisation, resource optimisation, and innovation are among the ten fundamental Constructability Principles (CII, 1993; Adams, 1989 apud Nima, 2002) that underpin these [6],[19] These concepts provide a methodical approach to incorporating construction expertise and promoting project effectiveness:

Concepts C1 to C7: Conceptual Planning Phase [6]

- C1: Develop a documented constructability program with participation from all project team members.
- C2: Formulate a project team with representatives from the owner, engineer, and contractor to consider constructability from project inception.
- C3: Engage individuals with up-to-date construction knowledge early to avoid design-construction conflicts.
- C4: Consider construction methods in selecting contract types and quantities.
- C5: Establish a construction-sensitive project schedule and assign it early.
- C6: Analyse major construction methods early to align design with construction feasibility.
- C7: Carefully study site layout to support efficient construction, operations, and maintenance.

Concepts C8 to C15: Design and Procurement Phase [6]

- C8: Let construction sequence dictate design and procurement schedules.
- C9: Use advanced information technologies (e.g., BIM) to overcome fragmented roles and improve coordination.
- C10: Simplify designs and conduct reviews with experienced construction personnel.
- C11: Standardise project elements without compromising cost-effectiveness.
- C12: Simplify technical specifications to ensure efficiency without degrading performance.
- C13: Consider modularisation and preassemblies to enhance fabrication, transport, and installation.
- C14: Ensure design accommodates accessibility for personnel, materials, and equipment.
- C15: Account for adverse weather by increasing prefabrication or selecting construction-friendly timing.

Concepts C16 to C23: Field Operations Phase [6]

- C16: Configure field task sequencing to minimize damage, rework, congestion, or formwork demands.
- C17: Implement innovation in temporary construction materials and systems beyond what is defined in the design.
- C18: Introduce or adapt hand tools to improve labour efficiency, safety, and accessibility.
- C19: Use or modify equipment innovatively to increase productivity.
- C20: Encourage optional preassembly to reduce scaffolding and improve constructability in challenging environments.
- C21: Innovate in temporary facility planning to enhance field performance.
- C22: Recognise and document high-performing contractors to support quality-based selection over low bids.
- C23: Establish systems to document and evaluate constructability experiences for future applications.

For example, CC10 promotes design simplification through construction expertise, while CC3 emphasises the early incorporation of construction knowledge in planning [6]. These ideas were put into practice and examined in a number of case studies conducted in different geographical areas. For instance, Zolfagharian et al. [7] showed that using ideas like C3, C6, C11, C12, C13, and C14 significantly improved Singapore's Buildability Score. These were organised into a multi-dimensional model that connected project responsibilities and stages by Griffith and Sidwell's [8] study. These ideas are valuable because they can help project teams, especially designers, contractors, and owners, produce more constructible, well-coordinated, and risk-resilient construction results. Figure 2.14 shows the project lifecycle stages for CCs division.

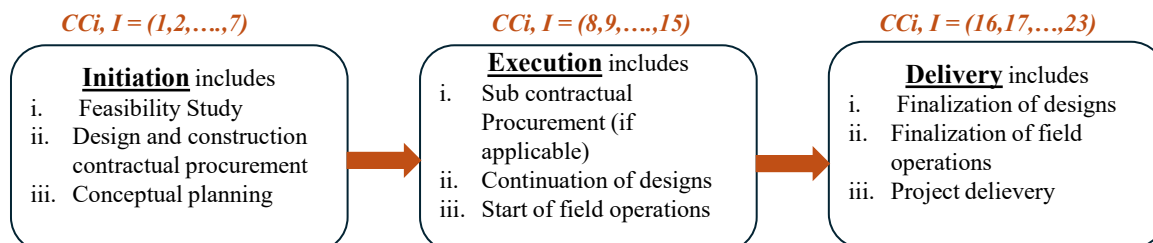


Fig. 2.14 - Project lifecycle phases for CCs' division include initiation, execution, and delivery

Raviv et al.[19] defined seven methodological families of constructability practices, which Alalawi et al.[18] use to further develop this operational framework. These consist of BIM tools, checklists, and official policy pronouncements. Alalawi et al.[18] suggest that formal procedures, owner involvement, and incentives are necessary to maximise efficacy, while Raviv highlights the power of construction engineers as implementers.

2.4.3. CONSTRUCTABILITY'S ROLE IN THE BUILDING LIFE CYCLE

Integrating constructability concepts successfully requires an understanding of a building project's life cycle. Constructability should be implemented sequentially in each of the phases that make up the life cycle of a project in order to attain the best possible results in terms of time, cost, quality, and safety. Feasibility and Conceptual Planning, Design and Engineering, Procurement, Construction, Startup and Commissioning, and Operation and Maintenance (O&M) are the usual phases that make up a construction project. There are particular opportunities and difficulties for applying constructability concepts in each of these stages [3].

2.4.1.1. Feasibility & Conceptual Planning Stage

The objectives of the project are established, and several options are investigated during the initial stage. The most significant impact of constructability can be seen at this early stage. Decisions on construction techniques, project delivery plans, and site selection have significant effects on later stages. Involving construction experts early on can help identify possible limitations, evaluate the implications of alternative concepts for constructability, and improve the alignment of the project's operational and functional goals with effective building techniques [3],[5].

Hamadani et al, [81] shows that including constructability from the beginning of a project to its completion has definite advantages, and stakeholders are generally in favour of it. Despite the initial time and financial commitments, it is crucial to formalise these processes and make sure that everyone involved, particularly owners and construction managers, actively promotes constructability throughout the course of the project.

2.4.1.2. Design and Engineering Stage

The initial concept is transformed into comprehensive engineering documentation and specifications throughout the design process [3]. Constructability assessments at this point guarantee that the design promotes worker safety, material handling, accessibility, and ease of building. Communication between designers and construction specialists is essential to optimise design elements, simplify components, and connect the design with realistic implementation techniques [3].

Constructability methods, including design checklists, constructability reviews, and interdisciplinary cooperation, can be used to find and fix problems before they impact field operations. Reduced expenses, fewer design modifications, and improved schedule dependability are all results of this proactive integration [3].

2.4.1.3. Procurement Stage

Materials, equipment, and subcontractors are all acquired through procurement. The alignment of the building sequence with the procurement plan is the main focus of constructability considerations during this phase. The availability of long-lead products and the suitability of prefabricated or modular components for field settings are guaranteed by prompt procurement planning [3].

At this point, constructability input can minimise logistical risks, simplify handling, and improve packaging options. Productivity is increased, and a seamless workflow is supported by effective procurement that is synchronised with construction sequencing.

2.4.1.4. Construction Stage

The planning and design process comes to a point during the construction phase. Techniques that improve site coordination, equipment use, quality assurance, and safety procedures directly apply constructability. Effective resource allocation, a reduction in rework, and schedule adherence are all made possible by a carefully planned construction plan founded on constructability principles [3].

Throughout this phase, constructability concepts are demonstrated in several key areas, such as the real-world implementation of modularisation, prefabrication, just-in-time delivery, and site layout optimisation [82]. Maintaining the design objective while accounting for field conditions is ensured by stakeholder contact and ongoing monitoring.

2.4.1.5. Startup and Commissioning Stage

Systematic testing, verification, and training are necessary during the transition from construction to operational readiness. In this stage, constructability refers to ensuring that systems are available for commissioning, testing, and inspection. Early commissioning planning in the design stage helps to prevent costly revisions or delays at this crucial point [3],[4].

This stage benefits from a constructability-oriented strategy that incorporates operational considerations into previous phases to ensure a more seamless transition to full operational condition.

2.4.1.6. Operation and Maintenance Stage

The operation and maintenance phase greatly benefits from constructability considerations established during earlier stages, even though they are typically outside of the scope of construction project delivery [3]. Future adaptability and simplicity of maintenance should be considered while choosing materials, access points, and system configuration.

When constructability goes beyond construction efficiency to guarantee the facility's longevity, maintainability, and lifecycle performance, long-term value is realised.

2.4.4. ROLES AND CONTRIBUTIONS OF DESIGNERS, CONTRACTORS, AND OWNERS

Constructability implementation requires the active and early involvement of all primary project stakeholders, particularly owners, contractors, and designers [18]. The idea that people and teamwork are essential to successful implementation is a recurring theme in real-world constructability studies. Checklists alone cannot ensure constructability; throughout the project development process, significant parties, particularly contractors (builders), design experts, and project owners/agencies, must actively participate [9]. The evaluated studies and programs provide a number of insights into stakeholder roles and crucial success elements:

- **Early and Ongoing Contractor Involvement:** Including construction specialists in the design and planning stages is probably the most important aspect that is frequently emphasised. Contractors contribute practicality, creative thinking, and field expertise. As noted by the North Carolina DOT, although agency employees may possess expertise,

contractors have a unique understanding of actual production rates, equipment limitations, and means and techniques[83]. Projects can find the best construction methods and anticipate issues by involving contractors (or construction managers) in design reviews, whether through formal constructability review teams, industry input sessions, or design-build delivery. One of the main causes of the problems in the West Port Highway case was the lack of this input, as a lack of a construction perspective in the design resulted in preventable problems on the site [6]. However, because they were not bidding on those works, contractors who participated in Connecticut's highway constructability studies offered ideas free from conflicts of interest and helped to enhance the plans. This cooperation is frequently formalised by successful constructability programs (e.g., co-location of design and construction teams in large projects, contractor feedback loops, or joint review committees) [83]. The takeaway is obvious: incorporating contractors' expertise early on results in designs that are easier to construct and project execution that runs more smoothly.

- ***Knowledgeable and Empowered Design Teams:*** As constructability must eventually be "designed in," design experts are essential [84]. They need to proactively modify designs for ease of construction and respond to industry feedback. In Arditi's survey, 91% of designers agreed that formal constructability evaluations are more valuable than traditional value engineering [84]. According to the same survey, designers also identified better client/contractor relationships and fewer lawsuits as key benefits, indicating an awareness of the long-term value of constructable design [84]. However, applying constructability requires proper support and expertise. Incorporating construction-experienced staff, along with training and established guidelines (such as CII's constructability ideas in the US or CIRIA's buildability guide in the UK)[7]. Nowadays, a lot of companies employ construction coordinators or skilled field engineers to carry out design peer reviews[84]. According to the interviewers for the West Port instance, many problems may have been anticipated if the team had included a constructability coordinator [6]. Design team continuity and communication are also important success factors. When designers collaborate closely with the people who will actually do the job, through a design-build contract or through early contractor engagement, they typically come up with more workable solutions. Designers can have a significant impact if they take the initiative. According to Lam et al. [85], the design team should be in charge of improving constructability. According to an architect and engineer questionnaire conducted in Hong Kong, one of the best ways for designers to increase constructability is to put in the time and effort necessary for comprehensive site investigations, well-coordinated documentation, and design standards [85]. Projects benefit from fewer mistakes and modifications later on when design teams adopt these techniques, which are commonly referred to as "design for construction."
- ***Owner/Agency Support and Integration:*** Whether constructability occurs or not is determined by owners or client agencies. They have authority over the project delivery process, financial constraints, and specifications that either support or discourage constructability review. The idea that owners oppose constructability because of the cost is rejected by a number of studies. According to Arditi et al. [84], designers thought that technical problems like undeveloped drawings were more significant than owner opposition and financial constraints. A small investment in design-phase evaluations can prevent considerably higher expenses from change orders or delays, as many owners have realised. To require constructability reviews, the American Association of State Highway

and Transportation Officials (AASHTO) handbook highlights the necessity of high-level commitment and an agency advocate [83]. Constructability is essentially built into the project when owners pick integrated delivery methods (design-build, construction manager/general contractor, etc.) or established procedures that require, for instance, a constructability assessment at 30% and 90% design completion. On the other hand, the chance for constructability input decreases if the contract environment separates designers from builders (as in conventional low-bid design-bid-build without any interim reviews). In conclusion, constructability-focused owners foster an environment where the design and construction teams may collaborate productively rather than clash.

- **Continuous Improvement and Knowledge Transfer:** Developing feedback loops to record lessons learned and enhance constructability knowledge inside firms is another essential success component. Constructability should have a continuous learning process since every project's experience, both good and bad, offers insightful information for subsequent initiatives. A post-project review is frequently a part of formal constructability programs to record issues that occurred and how design or planning could have avoided or lessened them. These results can be incorporated into revised checklists or guidelines. To attain constructability, for instance, design firms in Arditi's study [84] frequently employed peer review and feedback systems, suggesting that internal knowledge sharing is essential. Organisations can avoid making the same mistakes and progressively improve their baseline constructability when constructability is considered as a component of a continuous improvement culture, as suggested by researchers such as O'Connor and Miller (1994)[86]. A "systematic technique for transferring construction experience and knowledge" is lacking in the industry, as demonstrated by the West Port Highway case [6]. This is essentially a knowledge management gap that, if filled, might improve the constructability of numerous projects. The Building and Construction Authority (BCA) provides industry training and dissemination support for successful initiatives like Singapore's BDAS, guaranteeing that new best practices, such as the efficient use of precast technology, are broadly disseminated [87]. Constructability is a learning-oriented process rather than a one-time checklist item, and companies that learn from their mistakes and invest in educating designers and engineers on constructability principles will eventually benefit from their efforts on project after project [83].

The constructability results of the project are largely shaped by the designers. Standardising design features (C11), guaranteeing technical clarity in specifications (C12), and creating coordinated, construction-friendly drawings are some of their duties. However, conventional design considerations like utility and aesthetics frequently overlook realistic building constraints, as noted by Lam et al. [85] and Khan [5]. One of the main reasons for constructability failure is the confusion between designers and constructors. Designers are seen to play important roles in how a project is conceived. The stages of the project life cycle and the related degree of control that designers have over the project's budget and timeline are depicted in Figures 2.15 & 2.16 below. It is evident that the designer has the most influence at the start of the project and that this effect progressively wanes as it goes along. On the other hand, costs typically rise as the project progresses.

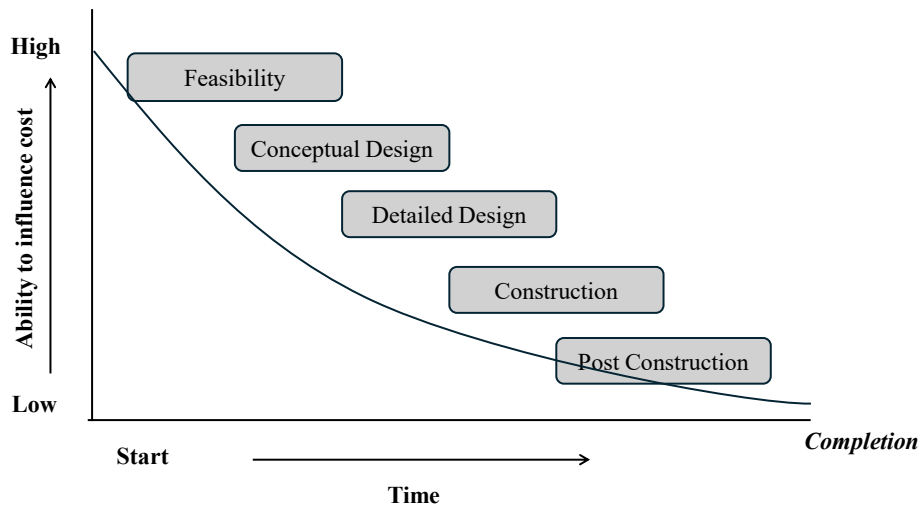


Fig. 2.15 - Cost influence through the project life cycle

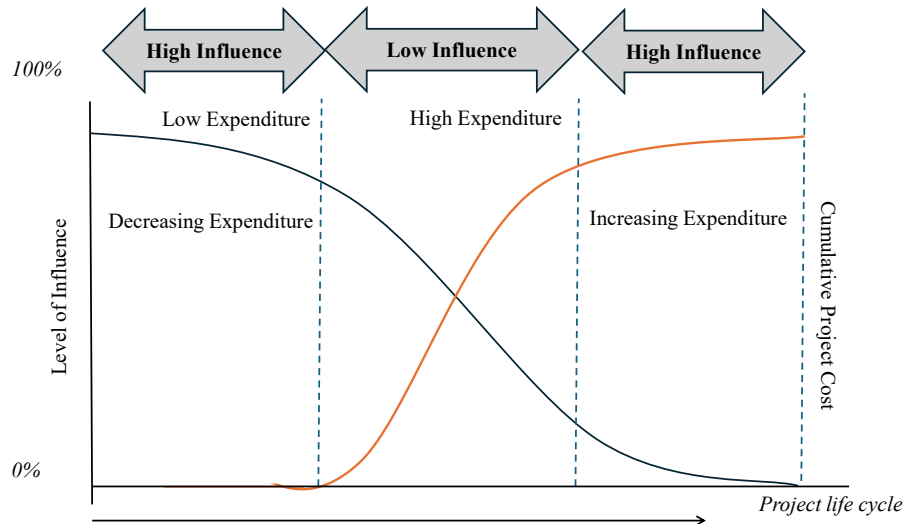


Fig. 2.16 - Designer's Level Influence in the Project Lifecycle

Contractors provide crucial expertise in construction that may reduce timelines and avoid costly mistakes. They play a particularly important role in creating schedules that are sensitive to construction (C5), confirming construction techniques (C6), and influencing procurement choices (C8). Constructability is negatively impacted when contractors are hired late or informally, as was the case even with a design-build structure, as demonstrated by case studies like the West Port Highway project [6]. On the other hand, Bakti et al. [9] used mentorship programs, structured evaluations, and 3D modelling to show the importance of contractor participation.

Owners also have an impact on contractual benefits; some might offer pre-construction service fees or bid payments to motivate contractors to offer ideas early on. The lesson to be learned is that strong constructability practices frequently require owner leadership and a cooperative contract approach [83]. Notably, agencies report fewer claims and more seamless construction phases where constructability reviews are standard practice (as is the case with many federal agencies for big projects and several U.S. state departments of transportation)[83]. In the end, constructability-focused owners foster an environment where the design and construction teams may collaborate productively rather than clash. Since the owner has the power to require constructability reviews for their project, respondents really

believed that owners (or their representatives) had an obligation to commission these reviews. Whether constructability will be prioritised is usually decided by the owner or the owner's agent, who frequently hires qualified consultants or construction managers to carry out the reviews [83]. All stakeholders have an interest, as seen by the wide range of responses to the question of who "requires" constructability (demands that it be done). The respondents concurred that demanding constructability evaluations is advantageous to all project participants. More than 39% of respondents chose owners and construction managers as the people who most commonly insisted on constructability [81].

Additionally, contractors (as well as other stakeholders with construction experience, such as subcontractors) were viewed as having an equal stake in mandating constructability, on level with owners. Not far behind were designers, such as engineers and architects, who, according to about 30% of respondents, also advocate for constructability standards [81]. According to the Muscat case study, owners/clients and construction managers are thought to be the main forces behind the implementation of constructability evaluations, and all of these parties acknowledge the importance of constructability [81].

2.4.5. CONSTRUCTABILITY TOOLS AND THEIR APPLICATION

Constructability tools make it easier to put constructability principles into practice and enable methodical planning, assessment, and feedback. These tools can be divided into four categories: cognitive, methodological, technological, and procedural. Functions, such as knowledge feedback, schedule integration, design coordination, and communication improvement, can also be grouped.

Kifokeris and Xenidis [4] highlight how tool application is unequal throughout project phases, with much of it focused on execution. By their very nature, these tools, which include knowledge feedback loops, schedule-cost-quality management, and evaluation techniques, help assess the effects of construction decisions made during design. Examples of these tools include design review checklists, constructability score systems, and process modelling. Notably, most tools are focused on the execution phase, leaving the initiation and delivery stages unfilled.

The Conceptual Product/Process Matrix Model (CPPMM), created by O'Connor and Miller [88], is emphasised by Alalawi et al. [18] as a knowledge transfer tool that aligns the degree of construction expertise with the corresponding project cycle. The model was effectively implemented in the Pentagon rebuilding project to facilitate constructability-based decision-making. Additionally, they offer complementary insights, especially about the strategic use of tools like modularisation and BIM to increase constructability. Nevertheless, they draw attention to the fact that, even in cases where tools are accessible, their use is not uniform. Although prefabrication has grown throughout the industry, modularisation, a strategy with considerable productivity and quality benefits, had the lowest implementation grade (1/5) in their case study, Haas et al. [89]. This underutilisation is attributed to misunderstandings that modularisation is only useful for certain projects, which the authors disprove by showing how it can be used more broadly when started early and aided by digital tools.

Data sharing, conflict detection, and dynamic visualisation are all made possible by technological tools, particularly Building Information Modelling (BIM). Digital coordination tools are acknowledged by Wong et al. [90] and Lam et al. [85] as facilitators of bettering site logistics (C7, C14), spatial sequencing (C6, C16), and standardization (C11). Singapore's BDAS (Buildable Design Appraisal System) is used by Zolfagharian et al. [7] to objectively evaluate constructability. The system promotes advancements by establishing standards for regulations and promoting early cooperation.

On the other hand, the West Port Highway case demonstrates how uneven results arise from the limited use of tools. Although prefabrication (C15), modularisation (C13), and design simplification (C10) were implemented with success, their advantages remained isolated in the absence of centralised planning, coordination tools, or systematic feedback (C23) [6]. Bakti and Trigunarsyah [9] emphasise how structured technologies, such as documentation databases and 3D Plant Design Systems, can improve performance in large-scale EPC projects.

2.4.6. BARRIERS TO CONSTRUCTABILITY IMPLEMENTATION

Globally, constructability has been acknowledged and applied to differing degrees, with every country establishing its own strategies and lessons. Despite its potential, constructability is often neglected due to systemic, organisational, and procedural constraints. These are divided into six categories by Kifokeris and Xenidis [4]: waste management (e.g., inefficiencies), owner-related (e.g., low commitment), designer-related (e.g., resistance to change), contractor-related (e.g., delayed involvement), project-specific (e.g., site constraints), and general (e.g., lack of awareness). Stakeholder complacency, ignorance, inflexible contract terms, and inadequate documenting of lessons gained are typical problems [91],[92]. According to Wong et al. [90] and Lam et al. [85], hostile contractual relationships and fragmented communication are persistent problems. Constructability may seem invasive to designers, especially when modifications are proposed after the fact.

Khan [5] emphasises that efficient knowledge integration is further complicated by the legal division of duties between design and construction. According to Alalawi et al. [18], two significant obstacles to constructability maturity are the lack of established teams and informal implementation. They support these findings by pointing out that conventional delivery techniques, such as design-bid-build, restrict early contractor participation and postpone the incorporation of construction expertise into the design process [18]. They suggest including design services for fixed-price contracts to lessen this and give contractors more control. In their case study, team creation and modularisation received the lowest implementation scores, indicating the lack of a specialised constructability team, another crucial obstacle. These results highlight the need for early integration, formal teams, and controlled processes to optimise constructability's advantages.

Schedule delays, redesigns, and logistical inefficiencies resulted from the West Port Highway project's [6] lack of a structured constructability program (C1), coordination (C2), and early construction feedback (C3). According to Zolfagharian et al.[7], professionals frequently lack incentive structures, institutional support, and training, even in cases where awareness is present. Griffith and Sidwell (1997) conclude that leadership-driven transformation, stakeholder integration, and adaptable systems are necessary to overcome these obstacles.

2.4.7. INFLUENCE OF CONTRACTUAL FRAMEWORKS

The constructability results are significantly influenced by the system of project delivery that is selected. Integrated approaches that promote early contractor involvement and shared responsibilities include design-build and Integrated Project Delivery (IPD). According to Kifokeris and Xenidis [4], design-and-build contracts are ideal since they centralise authority and align interests. To facilitate constructability from the start, Alalawi et al. [18] advise using fixed-price contracts to include design services in the contractor's scope. They do, however, warn that this strategy raises contractor liability, especially in fields like design that are often outside of their purview [93].

Conventional design-bid-build structures are criticised by Khan [5] for separating designers from construction expertise. Despite using a design-build approach, the West Port Highway project's potential benefits were lessened by a lack of collaboration, strategic planning, and constructability leadership [6]. Constructability necessitates supplementary procedures, including establishing integrated teams (C2), applying structured planning techniques (C5), and the inclusion of explicit constructability goals in procurement papers, even in the case of advantageous contractual structures [6].

Additionally, Bakti and Trigunarsyah [9] point out that continuous supervision, feedback, and role clarity are essential for success; a contract form alone cannot guarantee it. Owners must use contract frameworks to institutionalise constructability requirements and enable all parties to participate from the outset. The significance of contract strategy is echoed by Alalawi et al. [18], who point out that traditional delivery frameworks frequently restrict contractor engagement to later phases, limiting the influence of constructability standards. They advise including design services in fixed-price contracts to close this gap and match contractor incentives with early-stage decision-making and procurement timing [18].

2.4.8. INTEGRATION WITH RISK MANAGEMENT

Constructability anticipates and reduces construction-related hazards throughout planning and design, offering a proactive approach to risk management. Kifokeris and Xenidis [4] suggest mathematical methods that establish criteria for determining risk exposure and quantify constructability elements. Improved constructability is empirically linked to reduced project risks in terms of safety, quality, time, and cost, according to Wong et al. [90]. In risk frameworks, constructability is usually viewed as a separate variable, even when its goals overlap [94], [35].

Early constructability integration improves logistics and sequencing, minimises design flaws, and reduces labour. According to Alalawi et al. [18] and Khan [5], constructability uses collaboration and construction-informed decision-making to handle latent risks. For example, in the West Port case [6], insufficient weather adaptation (C15) caused construction delays, and failure to assess crane location (C6) or site layout (C7) led to disruptions.

Bakti and Trigunarsyah [9] show that constructability input may be empirically analysed to predict project performance, establishing a direct correlation between risk control and constructability quality. Additionally, Zolfagharian et al. [7] state that performance measurements and risk registers could define constructability's role in risk management. Alalawi et al.'s discussion of modularisation, early-stage decisions, and constructability planning discreetly supports this integration, even if they do not openly frame constructability in terms of risk management [18]. According to their findings, several planning inefficiencies, such as poor construction phase scheduling or omitting start-up considerations, can be recognised and reduced as hazards resulting from deficient constructability planning.

2.4.9. ORGANISATIONAL COMMITMENT AND OPERATIONAL SKILLS

Constructability needs to become a formal competence for organisations rather than an informal technique. Leadership commitment, methodical planning, and the creation of internal procedures like training, feedback loops, and incentive systems are all necessary for implementation maturity. Constructability should be redefined philosophically as a fundamental component of project management, according to Kifokeris and Xenidis [4]. Khan [5] recommends incorporating constructability into pre-contract planning, company strategy, and education.

Based on the CII evaluation matrix, Alalawi et al. [18] indicate that their investigated organisation's planning-phase implementation was 63%, and its execution-phase implementation was 67%. However, overall effectiveness had been reduced by the lack of established programs, specialised teams, and careful scheduling. They suggest feasible strategies that include designating program champions, providing innovation-focused training, and putting in place financial incentives to encourage uptake. Their results highlight the need for intentional structural, contractual, and procedural changes, all backed by research and empirical data, to move from unstructured practices to sophisticated constructability programs [18].

The West Port project is an example of the effects of immaturity. In the absence of documentation (C23), knowledge was discarded [6]. Innovative formwork (C17) and other successful techniques remained isolated in the absence of official leadership. Griffith and Sidwell [8] and Zolfagharian et al. [7] claim that a cultural change from reactive correction to proactive integration is necessary to institutionalise constructability. Contractual and procedural change must be accompanied by education, tool development, and cross-functional training.

It is well known that the increasing level of specialisation needed, particularly in post-war industries, has caused a gap between design and manufacturing departments, which has made it difficult to produce high-quality products that are easy to manufacture, assemble, inspect, and disassemble (Cunha, 2003 apud Marilucy, 2005) [95]. According to the author, this issue has caused the development of fields like Design for Manufacturability (DFM), Design for Assembly (DFA), and Design for Human Assembly (DHA) that are especially concerned with product analysis from the viewpoint of each of these domains in recent decades. Below is a brief overview of each of these approaches [95].

2.4.9.1. Design for Manufacturability (DFM)

DFM, according to Bralla [96], is a process that includes a number of rules, ideas, or suggestions to be considered while designing a product, with the primary goal being to increase the product's manufacturability. Manufacturability, according to Bralla, is the ease of producing a product or component.

The simplicity concept is the most notable of Bralla's [96] suggestions for improving product manufacturability. By reducing the number of parts, streamlining shapes, lowering the level of precision needed for changes, and cutting down on production time, this theory seeks to lower manufacturing costs. Bralla argues that taking care of these elements improves the product's dependability. Apart from simplification, Bralla also discusses concepts like standardising components and materials and expanding tolerances, among other things. Also, evaluating the production costs of several design alternatives can be used to assess their manufacturability; the option with the lowest cost is thought to be the most straightforward to produce. He emphasises that in addition to cost, it is crucial to estimate and compare the labour time needed to construct each design alternative to ascertain which is simpler to make [96]. Björnfot and Stehn [82] claim that constructability and manufacturability are related. Manufacturability in the manufacturing sector and constructability in the construction sector are comparable, according to Sharma and Gao (2002, apud Björnfot and Stehn, 2004). The product's fundamental qualities include constructability and manufacturability, with the latter phrase referring to goods from different industries. Since they both relate to how simple it is to manufacture things in their respective industries, it may be claimed that they have similar qualities.

2.4.9.2. Design for Assembly (DFA)

Methods like DFA have helped efforts to incorporate optimal production techniques into the design process, which has led to major contributions in many industries [33]. Additionally, this strategy has led to a huge improvement in both productivity and quality [33] [95].

DFA is a systematic analysis approach with the primary goal of lowering assembly costs through design simplification. This technique makes it easier to assemble items, whether they are put together mechanically or by hand. Using a set of principles, including minimising the quantity and variety of parts, avoiding the need for modifications, and engineering parts to be self-locating and self-aligning, results in this simplification. To compare various design solutions, the DFA approach additionally computes a design efficiency indicator based on the time and cost needed for assembly procedures (Boothroyd & Dewhurst, 1989; Tatikonda, 1994 apud Marilucy, 2005)[95].

Usually, a group of designers and production engineers does the study while the product is still in the design stage. It begins with a preliminary design concept for a product or component, estimating the time and cost of assembly for each element. Each element receives a score as a result of this examination, punishing those that take longer to complete or cost more to assemble. The overall assembly efficiency of the design is then calculated by adding up these ratings. A new efficiency indicator value is determined once the product is rebuilt based on DFA principles. Tatikonda (1994, apud Marilucy, 2005) [95] asserts that reducing the number of parts leads to fewer failure-prone components and fewer interfaces between parts, which is crucial because each interface could cause failure.

Additionally, DFA guarantees the ease of assembly of the remaining components. The primary advantages of using DFA are the reduced material costs, lower human or automation expenses for assembly, a shorter assembly cycle time, and increased product quality and reliability due to less complexity. Product simplification may also result in other indirect benefits, such as decreased inventory, lower procurement costs, fewer material handling, less paperwork, and enhanced and more efficient materials flow [97]. Fox et al. [33] examined particular DFA rules as a foundation for creating new constructability principles because they thought they could help promote constructability. These included designing components to prevent incorrect installation and guaranteeing access and visibility for every activity. Fox et al.'s [33] experience resulted in design enhancements, advantages like decreased production costs and time, and lower rework costs. They recommend that more DFA principles be considered as possible sources for creating new constructability standards.

Constructability provides a multifaceted approach to improving construction delivery. All parties involved must be committed, the risk and procurement systems must be in line, and there must be ongoing feedback channels. Constructability, when completely adopted, improves the built environment's overall performance and durability in addition to construction efficiency.

2.4.10. CONSTRUCTABILITY STUDIES

Case studies from the real world clearly illustrate how constructability implementation, or lack thereof, affects project performance. One noteworthy example is Malaysia's West Port Highway project, a multi-package highway and bridge project completed by design-build in the late 1990s. To pinpoint the practical uses and omissions of constructability ideas, Nima et al. [6] studied this project. There was no official constructability program or coordinator for the project, and no organised constructability meetings during the design phase. Any constructability attained instead depended on personal experience and on-the-spot judgment in the field. During the building, the effects became apparent.

Better early-stage planning could have prevented the major construction challenges encountered by the raised viaduct part of the highway [6].

For example, crews found insufficient space to operate cranes because of nearby houses and fences when they started launching massive precast girders in an urban section of the alignment. This was a result of a site layout planning error. Work was delayed because the contractor had to take reactive measures to install the girders, such as removing and then rebuilding a fence and transferring cranes from spans that had already been constructed. In another instance, the close spacing of the bridge pile caps prevented traditional compaction tools from adequately compacting the earth between foundations; this issue was discovered only after work had begun. The anticipated completion date was delayed by six months due to these problems. Crucially, the decisions (or omissions) made in the early stages of design and planning were shown to be the primary cause of these issues; significant building techniques and site limitations had not been sufficiently considered during the conceptual stage [6].

The West Port instance lacked a systematic method to incorporate construction information up front, even though it was a design-build project, which theoretically permits the constructor's involvement during design. Indeed, the project team did a good job of putting some constructability ideas into practice. By standardising pier, beam, and deck designs, they simplified details and decreased the variety of elements that needed to be built, capitalising on the repetitive nature of roadway components. To prevent over-specified, "gold-plated" needs, the designers also adjusted technical standards to the available materials and, in some situations, chose performance-based specifications (such as acquiring proprietary bearing pads)[6]. These strategies probably helped the project succeed since they aligned with accepted constructability principles (design simplification, standardisation, and suitable specifications). The West Port Highway research makes a very clear point: projects do better when constructability is carefully addressed from the beginning, and they do worse when it is ignored. In this instance, the improvements were mostly motivated by personal experience rather than a formal procedure, but the interviewers concurred that using constructability concepts improves project results (maximising schedule, cost, and quality for all parties).

Another example is a construction project in Singapore, where a strict grading system is used to enforce constructability, which is known locally as "buildability." To show how implementing constructability principles can raise a three-story residential building's Buildability Score (BS), Zolfagharian et al. [7] conducted a study on the building's design. A design's ease of construction is measured quantitatively by Singapore's Buildable Design Appraisal System (BDAS); since 2001, the government of Singapore has mandated that all building designs achieve a minimum buildability score prior to approval [7]. The case study revealed that the original design was not as construction-friendly as modern benchmarks required, as seen by its score being below the required standard. The team then determined changes that adhered to constructability best practices to improve the score. Two important recommendations were using dry partition wall systems in place of conventional masonry walls and moving from cast-in-situ reinforced concrete structural systems to precast components. These adjustments cut down on construction time and labour intensity, which is crucial for Singapore's efforts to increase productivity and employ fewer workers on-site [7].

When these procedures were included in the design phase, the building's Buildability Score rose to the required level. This study demonstrated how early design choices (such as selecting prefabrication or standardised systems) significantly affect construction efficiency in addition to achieving regulatory compliance. However, even in a highly developed constructability program like Singapore's, the study found that there are still implementation barriers: some owners/developers were not willing to invest additional design effort or money up front, some design teams lacked understanding of constructability concepts, and there was occasionally insufficiently effective multidisciplinary teamwork. These

difficulties reflect global trends, highlighting the need for organisational and personal factors to ensure the success of constructability initiatives and technical requirements [7].

Constructability principles have been successfully implemented in various contexts beyond individual projects. Kissinger, 1998 apud Nima, 2002 [6] gave the example of the Milwaukee Convention Center project in the United States, where a design-build team took advantage of late design modifications without causing schedule delays. This was made possible by the constructability of the integrated design/construction method. Numerous case studies showing cost and schedule reductions via constructability assessments have been published by the Construction Industry Institute (CII); one CII report detailed four projects where formal constructability initiatives produced quantifiable advantages [7]. These examples, which originate from civil infrastructure to industrial buildings, demonstrate the broad applicability of proactive constructability review. Early contractor involvement, multidisciplinary design-review workshops, using experienced construction personnel to vet design details, and implementing creative techniques recommended by builders (e.g., using modularisation or prefabrication to avoid on-site labour) are common successful practices in these case studies [7]. Real-world examples collectively demonstrate that projects typically encounter fewer delays, fewer change orders, lower costs, and more seamless execution when constructability is prioritised through formal programs or close collaboration [84].

Bakti and Trigunarsyah [9] commented on a case study of corporate constructability implementation. An Indonesian construction company that employs the design-build project delivery method for industrial plant projects was the subject of a case study. The case study aimed to examine constructability in detail and concentrate on how it is applied at the corporate level during the planning and design phases. The study's primary goals were to determine the advantages of implementing constructability, resolve the difficulties and obstacles that might hinder its adoption, and offer suggestions for its application that are thought to enhance the procedure. The primary finding of the study was that the use of constructability during the planning and design phases enhanced the project's performance, particularly the timetable, which was the most influenced component [9]. Project performance can also be improved by implementing constructability throughout the planning and design stages. Additionally, the study provided evidence that enhanced project performance was significantly impacted by using the lessons acquired from earlier, comparable initiatives.

In 2018, Al Mussad [98] presented the benefits of incorporating constructability into Saudi construction projects. Change order values were found to have decreased by 40%. For projects in the private sector that do not use constructability, the baseline percentage of change orders to the entire project value is 24.94%; if constructability is implemented, this decreases to 15.24% [98]. Regarding the benefits of the timetable, the schedule was optimised when constructability principles were applied as early in the building projects as feasible. According to both the public and private sectors, schedule optimisations during the conceptual planning stage are about 20% [98]. However, when constructability ideas are applied during the construction phase, the schedule optimisation for that phase is only about 8%. Regarding the cost, Al Mussad [98] stated that early implementation of the constructability concept can reduce the overall cost because many unforeseen problems can be resolved at the beginning of the project, lowering the chance of omitting any problems that may arise later in the project's life cycle.

The study aimed to determine when constructability efforts started in the project lifecycle. Constructability should be considered in the pre-contract phases, specifically during pre-project planning, conceptual design, or detailed design, according to the overwhelming majority of responders (about 86%). Indeed, according to 45% of respondents, constructability initiatives usually start at the very beginning (pre-project planning) [81]. This demonstrates a keen understanding that constructability should be implemented as early in a project's life cycle as possible for maximum effectiveness. Although

it was comparatively rare, a smaller percentage of practitioners began constructability only at the time of contract award or during construction (the combined total for those late-start situations was significantly lower, made up of the balance of respondents) [81]. To guarantee that designs are construction-friendly, a number of methods are employed during the design phase.

Adhering to a formal constructability technique or guideline throughout design was the most often mentioned strategy (used by almost 60% of respondents) [81]. Many companies use established best-practice manuals or checklists; for instance, the most popular option among respondents was to follow a constructability guideline or manual of practice. Another popular design approach is conducting a design review by an experienced construction expert, typically a senior constructor or construction manager who was not initially on the design team, to ensure that the plans are buildable [81]. Early construction expertise engagement (either through specialised constructability evaluations, incorporating a construction expert into the design team, or utilising design-phase checklists) was equally important in the Muscat example and was frequently carried out in tandem. In basic terms, the study discovered that checklists, standards, and formal design reviews are common instruments for assessing constructability throughout the design process.

Constructability implementation changes to field execution procedures throughout the building phase. Applying proper construction means and methods (i.e., employing the right techniques and equipment for efficiency) and detailed pre-task planning prior to job execution are the most typical constructability practices throughout construction, according to the survey [81]. The fact that these two practices received the highest ratings at the building stage suggests that, to prevent issues, attention should be paid to workface planning and method selection once construction has begun. Using construction engineering skills during pre-construction planning meetings and, when feasible, innovative construction methods were the second most popular activities [81]. Although they were stated less frequently than the previously described activities, coordination between various trades on the job site and seeking advice from specialised specialists when necessary were also mentioned as mechanisms. Overall, the findings demonstrate that professionals in Muscat work hard to apply constructability principles during the building phase through meticulous planning and systematic execution techniques.

By including certain clauses in project contracts, clients can play a crucial part in ensuring that constructability is ingrained across the project lifecycle. Requiring formal constructability evaluations at specified design milestones, usually at 30%, 60%, and 90% design completion, is a commonly advised approach. Cross-functional teams comprising designers, construction managers, and contractors participate in these evaluations, which operate as benchmarks to evaluate the design's viability and effectiveness from a construction standpoint. The client's requirement that these evaluations be included in the contract guarantees that constructability is viewed as an ongoing, proactive activity rather than an afterthought.

Contracts can also specify the exact responsibilities and obligations of each participant in the constructability assessment procedure. The project promotes accountability and coordination by clearly defining who is responsible for what, whether the design team, the project manager, or an impartial third-party reviewer. This clarity is crucial for controlling expectations and preventing disputes, especially when significant scope modifications or design transitions occur. Additionally, the contract must outline a methodical procedure for carrying out constructability assessments. This entails defining documentation processes, standardising approaches, and establishing review objectives.

Constructability assessments are guaranteed to be consistent and significantly contribute to design optimisation and risk reduction when this procedure is included in the overall project management plan. It is crucial that clients include enough time and funds in the project budget and schedule for these

assessments. Constructability programs frequently fall to time limitations or cost-cutting measures without specific timetables or financial support. The importance of constructability to project success is emphasised by contractual wording that protects this allocation.

Lastly, clauses pertaining to a feedback and lessons-learned process may be included in contracts. Organisational learning and continuous improvement are improved when insights from each review cycle are captured and applied to ongoing and upcoming projects. A culture of cooperation and technical excellence is reinforced throughout the project lifetime when the client requests such a system.

The next chapter offers a thorough analysis and discussion of the survey data, building on the ideas, theories, and issues covered in this literature review. This survey was created and carried out directly in reference to the insights discovered in the literature to ensure that the results are based on recognised theoretical and practical viewpoints. A suggested guideline approach covering all important constructability stages will be produced in addition to the analysis. The outcome seeks to close the gap between theory and practice by providing an organised method based on the literature and empirical data.

3

DATA ANALYSIS & DISCUSSION

3.1. INTRODUCTION

This chapter presents the analysis and discussion of data collected through two comprehensive surveys conducted as part of this research. These surveys targeted individuals working across the construction sector and together form a robust empirical investigation into current constructability practices. A total of 27 participants responded to the first survey and 16 to the second, providing a broad and insightful sample for analysis. The findings from both surveys are analysed and discussed in this chapter to generate evidence-based insights that support the development of the constructability framework presented in the following chapter.

The first survey was a broad-based questionnaire designed to gather general data about the participating companies and their constructability practices. It explored company characteristics, project management methodologies, and levels of constructability awareness. More specifically, it assessed how familiar companies are with constructability principles and how they apply these principles to projects. Survey 1 aimed to get a broad picture of the industry's current condition, including how different types of companies handle constructability, what formal procedures or frameworks they have in place, and how much constructability is acknowledged and applied during a project. This provided a baseline understanding of constructability attitudes, practices and gaps.

Building upon these insights, the second survey adopted a more focused, scenario-based approach to explore real-world constructability challenges. It presented participants with open-ended, project-specific questions to elicit detailed examples of constructability application in practice. By examining how constructability is used in practice and the obstacles encountered, the aim was to bridge the gap between theoretical best practices and real implementation. Respondents, many of whom were seasoned professionals, shared rich qualitative accounts of specific challenges encountered, strategies used, and lessons learned. These insights offer depth and context to the general trends identified in Survey 1, allowing for a better understanding of how constructability is addressed in field conditions.

Both surveys were meticulously developed and carried out in alignment with the structured research methodology outlined in Chapter 1 (Section 1.4). This methodology outlines a structured sequence of stages for the study, including company selection, data collection, qualitative analysis, and framework development. Accordingly, the analysis presented in this chapter is not only systematic but also directly

tied to the next step of the research. Indeed, the findings and discussions in Chapter 3 form the empirical foundation for the constructability framework developed in Chapter 4.

3.2. SURVEY 1- COMPANY OVERVIEW & CONSTRUCTABILITY PRACTICES

3.2.1. DATA DESCRIPTION, ANALYSIS, & DISCUSSION

A targeted questionnaire survey was conducted to capture industry practices and opinions on constructability across the entire project lifecycle. Unlike studies focused solely on Front-End Planning (FEP), this research explores constructability integration at all stages, from concept through execution and handover using RIBA, FEP and PMI [27],[68],[76]. Although the questionnaire survey was distributed to engineering offices, some of the data received represented contractors and clients. Of 40 invited participants, 27 responses were received (a 67.5% response rate), providing a robust sample of experienced professionals. The 27 participants in the survey represented project owners, consultants, and contractors. The survey serves as a key component of the research methodology, gathering insights to inform the development of a constructability framework within the project management frameworks. This section presents a detailed analysis of the results, with quantitative distributions of answers (percentages of the 27 respondents) and qualitative observations. The findings are discussed in the context of current industry practices and the research objectives, highlighting patterns, standard practices, gaps, and unexpected insights. Each question and its responses are examined, and implications for the proposed constructability framework are drawn throughout.

3.2.2. PARTICIPANTS' ROLES AND EXPERIENCE

The respondents to the survey represent a diverse and experienced sample of construction and engineering professionals. As illustrated in Figure 3.1, the participants' years of experience in the industry span a broad range from early-career professionals to those with over three decades of practical involvement. Over half hold project management or coordination roles (e.g. Project Managers, Technical Coordinators), with others serving as directors/principals, engineers, BIM managers, construction managers, and specialists (contractual/commercial, structural, quality, sustainability, planners, process, etc.).

The data shows a relatively even distribution across early-, mid-, and late-career professionals:

- The largest groups were those with 0-5 years and 18-23 years of experience, each accounting for 22.2% of respondents (6 individuals).
- Respondents with 6-11 years, 12-17 years, and ≥ 30 years each comprised 14.8% of the sample.
- The smallest group, 11.1%, had between 24 and 29 years of experience.

Notably, the most senior respondents (≥ 30 years) are primarily from owner organisations and consultancy roles, offering strategic-level insights into constructability from a client and advisory perspective. The mid-career group (12-23 years) includes a balanced mix of design professionals, contractors, and consultants, reflecting hands-on experience in design coordination, planning, and on-site implementation of constructability measures. Cumulatively, 42% of respondents had more than 20 years of experience, and over two-thirds ($\approx 66\%$) had at least 12 years of industry tenure. The median experience level across the sample is approximately 17 years, reinforcing that the respondent pool mainly comprises seasoned professionals. This strong level of industry maturity, coupled with representation across all major project stakeholders, owners, designers, contractors, and consultants, adds significant weight to the data. The perspectives shared are informed by practice and reflect a comprehensive understanding of constructability across the full project lifecycle. This depth of

experience suggests that the insights reflect seasoned perspectives. Most respondents have strong technical backgrounds with high degrees like master's and doctoral degrees (e.g. civil/structural engineering degrees, architectural, electrical, etc.) and long tenure, which lends credibility to their views on constructability practices.

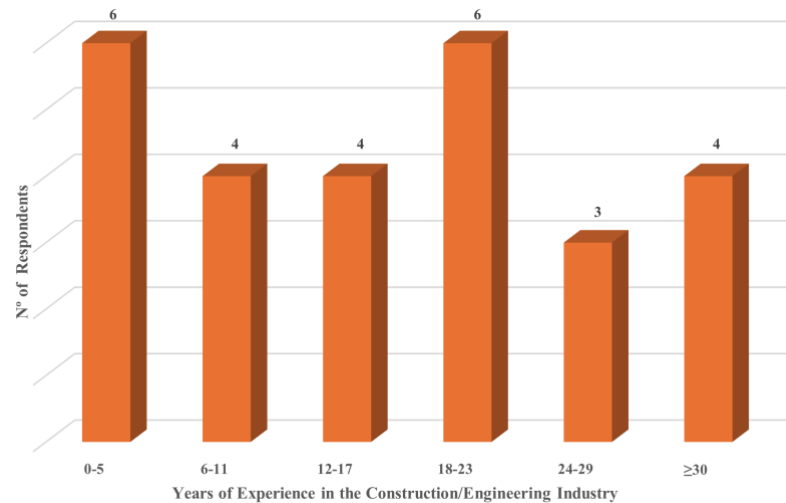


Fig. 3.1 - Distribution of 27 Respondents by Years of Experience in the Construction/Engineering Industry

3.2.3. COMPANY TYPE & SIZE

Most respondents ($\approx 67\%$) work in engineering design consultancy firms, about 22% are from construction contracting organisations, and the remainder ($\sim 11\%$) indicated integrated design-build operations as illustrated in Figure 3.2. This skew toward design firms is notable; many respondents approach constructability from a designer's perspective, though several contractors' views are included.

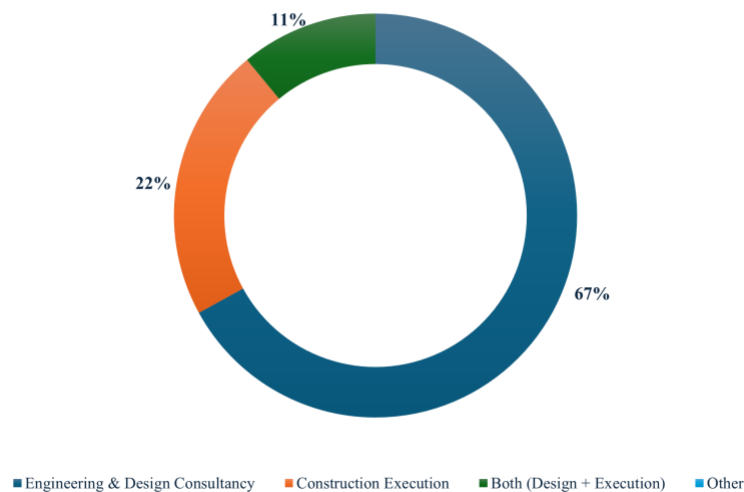


Fig. 3.2 - Distribution of 27 Survey Respondents by Company Industry Focus

Company sizes vary widely, from small firms to huge enterprises. Just over half (52%) reported their company has 50-200 employees (medium-sized), while about 30% are with large organisations (1000+ employees). The rest are split among small firms (<50) and mid-large (200-1000) as shown in Figure

3.3. This diversity suggests that the survey captured nimble companies and large corporations, potentially with differing formal processes. Indeed, more prominent organisations might be expected to have more formal management frameworks, an aspect explored in the survey.

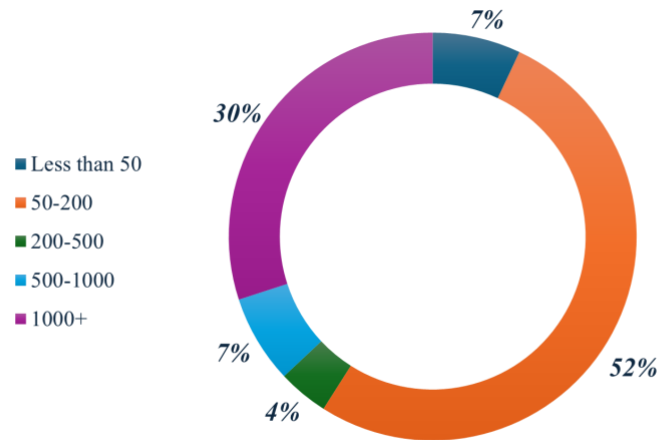


Fig. 3.3 - Company Size (Number of Employees)

The broad geographical reach of these companies was evident, as many operate internationally. A multiple-choice question was asked about the geographical presence of the companies to see how constructability practices differ. Projects span, see Figure 3.4, Europe (19 respondents), Middle East (22 respondents), Africa (16 respondents), with some in the Americas (11 respondents) and Asia (7 respondents), indicating global experience and that constructability is considered across different regional contexts.

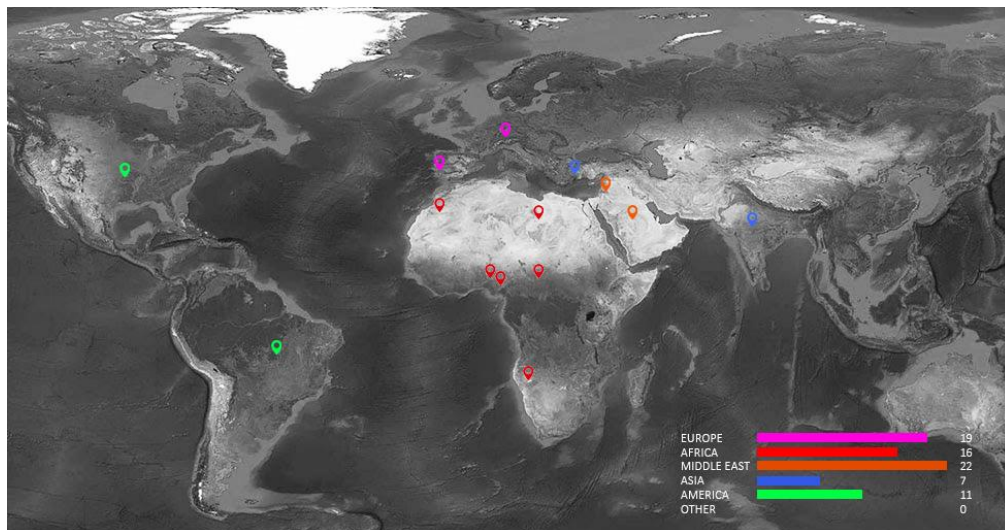


Fig. 3.4 - Respondents' Geographical Presence

To understand the range of projects where constructability is applied, participants were asked to identify the types of projects their companies typically engage in. This was a multiple selection question, allowing respondents to select all applicable sectors.

Table 3.1 shows that most of the participants' companies are involved in building-related projects, with 24 out of 27 respondents selecting this category. Transportation infrastructure also featured prominently, with 21 respondents indicating involvement in projects such as bridges, roads, railways, and airports. A

substantial number (17 respondents) are engaged in environmental and energy-focused projects, including sustainability initiatives, utilities, and water infrastructure. Meanwhile, seven respondents work on industrial sector projects like oil and gas developments. A smaller group (3 respondents) selected “Other” project types. In their comments, these respondents mentioned specialised works such as constructing new university campuses, marine infrastructure, and sports stadiums, further demonstrating the breadth and complexity of the projects represented in this study.

This diversity demonstrates that constructability is not limited to a single sector but is a cross-cutting discipline applied across vertical and horizontal construction, public and private developments, and small to large-scale projects. Such a range enhances the value of the survey findings, as they reflect constructability practices across various technical and operational contexts.

Table 3.1 - Companies Type of Projects

Type of Projects	N° of Respondents
Buildings (Residential, Commercial, Industrial, Healthcare, Sports, etc.)	24
Transportation (Bridges, Roads, Rail, Airports, Tunnels, Ports)	21
Environmental (Water, Energy, Sustainability, Infrastructure)	17
Industry (Oil, Gas, etc.)	7
Other	3

Many companies thus have multidisciplinary portfolios. Regarding project scale, when asked about the average budget of projects their company handles, the most common category selected was Large-scale projects (US\$ \$100M - 1B), 41% of respondents identified this as typical for their company. Notably, 19% indicated Mega-projects (> \$1B) are their average scale, while others work mostly on Medium (10 - 100M) or Small (< \$10M) projects (about 18% and 22% respectively). This spread shows that while many respondents are accustomed to large, complex projects, many focus on smaller-scale projects. Furthermore, two-thirds (67%) reported that their company had undertaken at least one mega-project in the past 5 years. As shown in Figure 3.5, the primary sectors for those mega-projects were buildings (56% of those with mega-project experience) and transportation infrastructure (28%), underscoring that large projects in vertical building and civil infrastructure are common in the sample. This context is essential because constructability challenges can be more pronounced in large, complex projects, precisely the environment of interest for improving project frameworks.

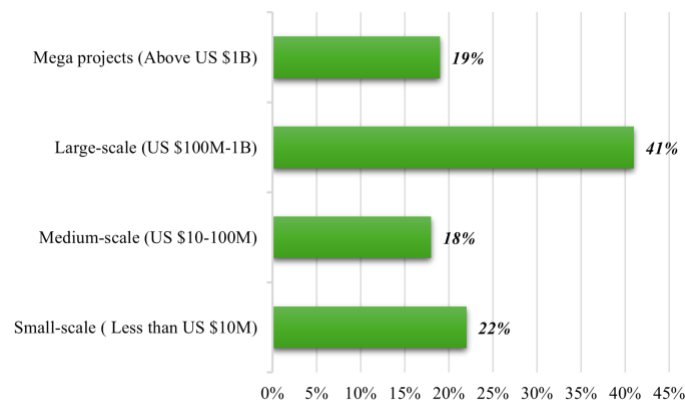


Fig. 3.5 - Average budget of projects that the respondents' company handles

Consistent with the scale and diversity of project types reported, most respondents indicated that their projects span multiple years, reflecting high complexity and long-term coordination. Specifically, 67% of participants reported that their projects typically last between 1 and 3 years, aligning with medium-term construction cycles. Additionally, 26% stated that they primarily work on long-term projects exceeding 3 years. In contrast, only 7% of respondents are engaged in short-term projects under one year. This distribution suggests that most professionals surveyed are involved in lengthy and often complex project lifecycles, where the integration of structured planning and constructability processes is critical. The prevalence of longer project durations reinforces the importance of robust planning methodologies such as FEP, the RIBA Plan of Work, and the PMI PMBOK framework, all of which emphasise early-stage decision-making and lifecycle integration.

In such extended project timelines, constructability reviews conducted during planning, design, and execution phases can yield significant benefits in cost control, risk mitigation, schedule reliability, and design efficiency. Therefore, the survey population provides a valuable window into how constructability is, or is not, being leveraged in projects where it can have long-term, strategic impacts.

3.2.4. PROJECT PHASES AND DECISION-MAKING

The survey examined which project life cycle stages the companies handle and how decisions are made. The analysis of 27 organisational responses regarding project phase management reveals distinct patterns in how companies structure their involvement across the project lifecycle. Predominantly, firms engage in design-related stages, including conceptual, schematic, and detailed design, often paired with construction supervision to ensure technical compliance and quality control. A significant subset extends services to pre-design activities such as master planning, feasibility studies, and permitting. At the same time, fewer entities specialise in post-construction phases like testing, commissioning, operations, and maintenance. Several companies emphasise end-to-end project management, covering the full lifecycle from initial feasibility assessments through construction to post-delivery support. While design and construction oversight dominate industry focus, a minority target niche areas such as procurement or technical assistance. This diversity underscores varied strategic priorities, with some organisations positioning themselves as holistic lifecycle managers and others concentrating on specialised phases.

The findings highlight an industry inclination toward integrated design-construction workflows, complemented by growing recognition of operational sustainability in post-construction stages, reflecting evolving project management paradigms in response to client demands for comprehensive solutions. This emphasis on design and construction phases suits this study, as FEP primarily concerns early planning and design decisions [37]. This spread of phase involvement is significant: organisations active across the whole project timeline have more opportunity to integrate constructability from start to finish, whereas those confined to later phases can only react to upstream design decisions.

Ideally, best-practice frameworks encourage broad phase coverage, the RIBA Plan of Work defines stages 0 to 7 (from Strategic Definition through Design, Construction, and Use) as a continuous sequence [15], and companies aligning with RIBA or PMI processes would engage with multiple successive stages. The survey confirms that most companies span several stages, a positive sign for lifecycle integration. Yet, it was noted that formal mechanisms to link these stages (such as structured handover of lessons or requirements between design and construction teams) were not strongly evident in the responses, hinting at potential gaps despite multi-phase involvement.

When asked how major design and construction decisions are made in their projects, respondents (who could select multiple options) revealed various influencing factors, as presented in Figure 3.6. The most frequently cited were client directives (chosen by 19 respondents) and financial/budget considerations

(15 respondents), indicating that client requirements and cost constraints are primary drivers of key decisions. Top-down governance by senior management was also shared (12 respondents), while only 6 respondents reported decisions made through internal project team reviews or consensus. A few respondents provided write-in responses mentioning factors like time or resource constraints, though these accounted for only one respondent each.



Fig. 3.6 - Major project design/construction decisions

This distribution suggests that decision-making is often externally driven or hierarchical rather than collaborative, a dynamic that may compromise constructability. For example, when clients or senior management dictate decisions without input from construction teams, practical on-site challenges (e.g., material feasibility, safety, or logistical constraints) may be overlooked. The rarity of internal team reviews implies that formal constructability review processes or interdisciplinary forums are not standard practice in many organisations. This suggests that while many companies strive for a collaborative decision process, others still rely on hierarchical decision-making.

A collaborative approach is more in line with modern project management good practices ; for example, PMI's Integration Management emphasises coordinating inputs from all stakeholders for a unified decision [30]. These findings highlight the need for structured frameworks to systematically integrate constructability considerations into decision-making alongside client demands and budgetary criteria.

3.2.5. MANAGEMENT FRAMEWORKS UTILISED

A related question asked whether companies follow structured management frameworks or standards. Multiple selections were allowed, and most respondents indicated that they rely on internal, company-specific guidelines (22 respondents) as the basis for project management. Additionally, nine respondents adhere to PMI (Project Management Institute) standards, and 5 respondents use the RIBA Plan of Work, a stage-gate framework commonly applied in architecture and engineering, see Figure 3.7. A few mentioned International Organization for Standardization (ISO) or country-specific frameworks (one cited an Irish government construction management framework), or Front-End Loading (FEL) stage-gate processes used in the oil and gas sector. Only 4 respondents selected "*No standardised framework*," suggesting that the majority follow some form of structured methodology, whether in-house or industry-standard. The prevalence of internal guidelines indicates that while companies value structured management, they often customise frameworks rather than relying solely on external ones. However, some of these internal guidelines do not include constructability practices; a notable gap, given that Front-End Planning (FEP) is known to improve project outcomes. For instance, Construction Industry Institute reports show that robust front-end planning can yield approximately 10% cost savings and a 7% schedule reduction on average (Gibson,2010 apud Safa,2013)[13]. Also, internal methods might prioritise certain phases or omit some best practices.

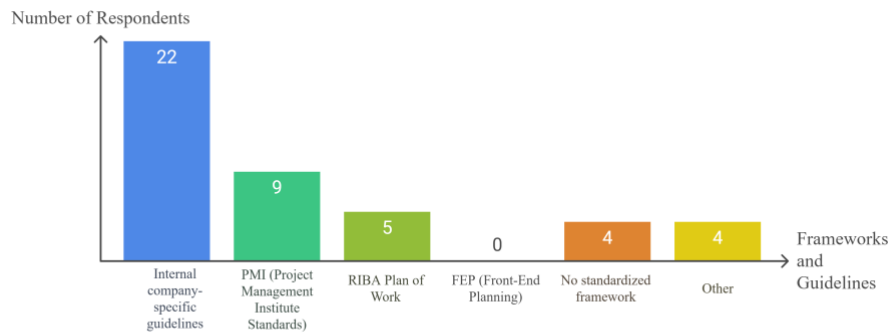


Fig. 3.7 - Company Use of Structured Approaches, Frameworks, or Standards for Management

The low adoption of FEP suggests that many firms may not fully realise these potential benefits. Company practices often diverge from formal standards, relying instead on experience-based internal processes. This highlights an opportunity: organisations can identify gaps, such as missing risk reviews or constructability checkpoints, by benchmarking internal methods against comprehensive frameworks like PMI or stage-wise models such as RIBA and FEP. Developing a new constructability guideline framework could help bridge these gaps by integrating the strengths of established project management approaches into company-specific processes. A well-defined management structure can support systematic constructability reviews, whereas the absence of a framework may lead to a more reactive or informal approach to project constructability.

In summary, the respondent profile reflects a group of seasoned professionals from diverse, predominantly design-oriented organisations, working on medium to large-scale projects globally. Though most follow some structured approach, they operate within various management systems, with decision-making often driven by client needs and budget constraints. This context frames their views on constructability: they bring substantial practical experience, and their companies have established planning practices. As we move into the constructability-specific findings, we will examine how these background factors, such as project size and management style, correlate with reported constructability practices and challenges.

3.2.6. CONSTRUCTABILITY AWARENESS AND PERCEIVED RELEVANCE

A fundamental first step was assessing awareness of the constructability concept. The survey asked if participants had heard the term “constructability” or “buildability” before. 81% answered “Yes”, while 19% said “No”. The few who responded “No” to hearing the term still demonstrated a basic intuitive grasp of the idea in subsequent questions. For instance, even those unfamiliar with “constructability” provided definitions referring to ease of construction, feasibility, and efficiency, which align closely with the formal concept. This suggests that even if the specific terminology is not universally known, the underlying principles are widely understood by practitioners.

In an open-ended question, participants were invited to define “constructability/buildability” in their own words. The definitions given consistently revolved around the same core themes, reflecting a shared understanding:

- Ease and efficiency of construction: Many described constructability as measuring how easily and efficiently a design can be built in the field. Phrases like “*how easy and efficient a design is to build*” or “*the ease and efficiency with which a project can be constructed*” were common, highlighting that constructability is about making the construction process

as straightforward as possible. One respondent said it means “*how easy and efficient a design is to build, considering materials, construction methods, and sequencing.*”

- Integration of construction considerations into design: Respondents emphasised that constructability involves considering construction methods, site conditions, sequencing, and logistics during the design phase. It was noted that it is a process of influencing the design to adopt optimal construction methods and to ensure the design can be built safely on time and within budget. One respondent’s detailed definition mentioned “*influencing the design stage by adopting optimal construction methods and technological solutions*” to address constraints and feasibility. This underscores the idea that constructability is a proactive, design-informed approach to facilitate construction.
- Project outcomes (time, cost, safety, and sustainability): Many definitions linked constructability to key project outcomes such as timely completion, budget compliance, and safety. For example, ensuring a project can be built without “*unnecessary complications*” and “*avoiding rework*” was mentioned. Some respondents explicitly included sustainability and life-cycle efficiency in their definitions, indicating that constructability also means designing with long-term operations (Operational Expenditure OPEX) and environmental considerations in mind, not just immediate construction convenience.
- Holistic feasibility: A few definitions conveyed a broad perspective, equating constructability with overall project feasibility and well-defined project requirements. One respondent described it as an asset project being “*well defined to fulfil all economic and sustainable issues... regarding an efficient asset life cycle,*” thereby linking constructability to the effective achievement of project goals throughout the project's lifespan. Some definitions referenced the entire project lifecycle or emphasised alignment with “*local resource availability*” and “*country constraints.*” While a few responses were more general, such as “*permanent and temporary works*” or simply “*it can be constructed*”, the majority framed constructability as a strategic, multidisciplinary process that supports smooth, cost-effective, and safe project execution under real-world conditions. Figure 3.8 below presents three example definitions provided by respondents.

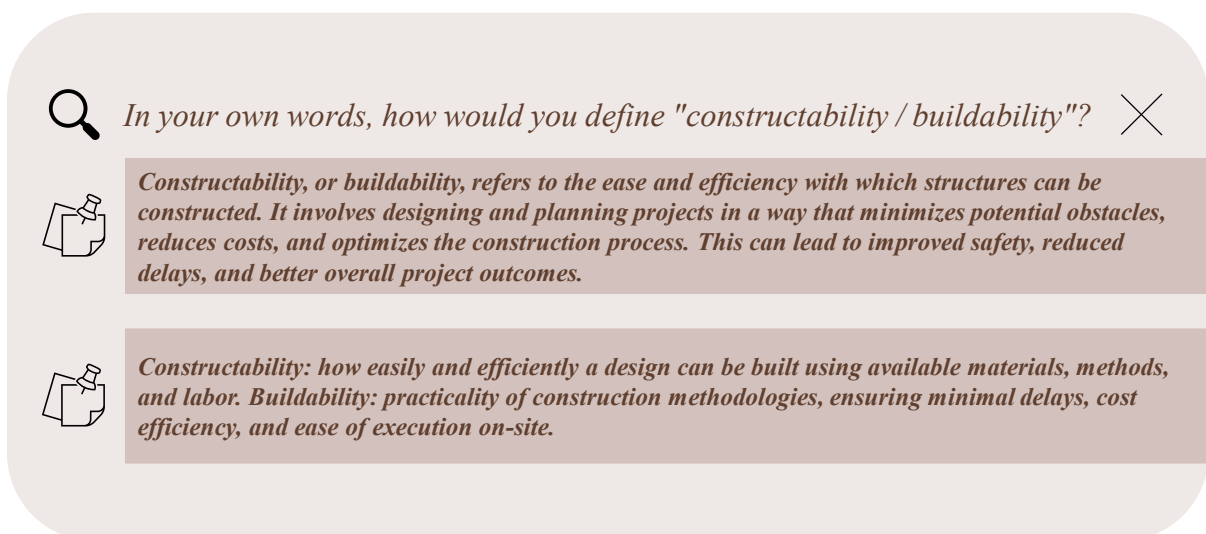


Fig. 3.8 - Respondent Definitions of "Constructability" or "Buildability"

Constructability is considered by many to be relevant to the respondents' ongoing projects. They were asked to rate "How relevant is constructability/buildability in your company's projects?" on a scale (presumably 1 = not relevant at all, up to 5 = extremely relevant). As Figure 3.9 shows, the ratings skewed heavily positive: 15 out of 27 (56%) gave the highest relevance score of 5, and 8 more (29.6%) rated it 4. Thus, about 85% consider constructability highly relevant. Only a few were lukewarm, two respondents (7.4%) chose 3 (moderate relevance), and two (7.4%) indicated low relevance (1 or 2). The mean rating was 4.3 out of 5.

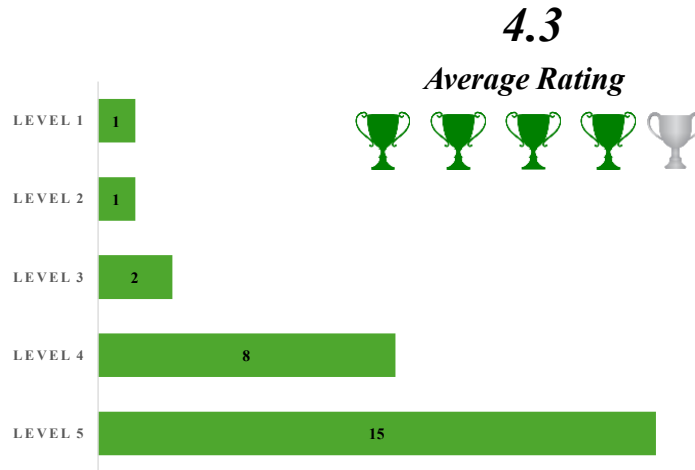


Fig. 3.9 - Rating of Constructability/Buildability Relevance in Company Projects

Even those less familiar with the term believed it was important once the concept was clarified. For example, several individuals who initially said they hadn't heard the term rated its relevance as high (and in some cases, these individuals had effectively applied constructability principles unwittingly). This strongly supports professionals' belief that constructability is essential to project success. It supports the widely held belief in project management culture that improved constructability results in fewer issues during construction.

Interestingly, even those who rated relevance low frequently offered justifications that pointed to outside influences. For example, one respondent who gave relevance a score of "1" (not relevant) said that fast-track delivery constraints typically cause constructability to be neglected, and another low scorer said that although constructability should be considered, it's frequently disregarded until it has an impact on cost. These remarks highlight a possible weakness: even if constructability is essential in theory, timetable or business constraints may prevent some organisations from prioritising it in practice. This suggests a recurring theme: the constructability gap between knowing and doing.

They were also asked whether constructability is relevant in their company's projects and, if so, to specify how. Many emphasised cost and time efficiency, noting that constructability helps prevent delays and rework, enabling faster and more economical project delivery, an essential factor in today's competitive and financially constrained environment. Others cited financial pressures and market competition, while some mentioned that constructability ensures designs are practical, cost-effective, and achievable within project timelines, thereby reducing risks and avoiding potential issues during construction. Additionally, some respondents referred to its role in project phasing and comparing costs between different material typologies; for example, evaluating labour costs of building with timber versus traditional methods, which might initially seem more expensive. Although these aspects were highlighted, it was also noted that, despite the theoretical importance of constructability, it may not be considered relevant or prioritised in some companies' workflows.

A Yes/No question was included: “Do you think constructability is important in the current/future construction industry?” A clear majority of respondents (100%) said “Yes,” confirming that constructability would continue to be significant in the future. In follow-up with an open-ended question, they were asked, “Why do you think constructability is becoming more important?”. All 27 gave reasons, and common themes, as described in Figure 3.10, emerged:

- **Project complexity and scale:** Modern projects are getting more complicated, whether in terms of scope, logistical difficulties, or architectural complexity. To avoid cascading issues, it is increasingly important to address buildability early in a project as its complexity increases. To guarantee that these projects are truly viable to carry out, respondents pointed out that complexity, when combined with ambitious technical or architectural feats, necessitates thorough constructability planning.
- **Cost and schedule demands:** Many pointed out that there is mounting pressure to control costs and meet tighter deadlines. With materials and labour costs rising and clients expecting faster delivery, optimising constructability is a way to save time and money. For example, one wrote “*limited financial availability...key to success, requiring careful constructability to avoid waste*”. The notion that optimising construction methods can control costs and schedules in a tight market was prevalent (about half explicitly cited cost or efficiency).
- **Sustainability and environmental impact:** A few respondents (≈11%) highlighted sustainability demands, optimising material use and reducing waste through constructability. As the construction industry’s push towards sustainability is another reason, constructability is crucial. Efficient construction methods minimise waste and carbon footprint. One comment highlighted the need to “*optimise material use and reduce waste*” through constructability studies, aligning with sustainable practices. Rehabilitation of existing structures (*making do with what is there instead of new builds*) was also cited as an area where constructability is key to extending life cycles cost-effectively.
- **Prefabrication and modular construction:** These two technological advancements make constructability factors a top priority in design due to their growing usage. As these cutting-edge construction techniques become increasingly prevalent to increase efficiency, respondents pointed out that incorporating modular design thinking necessitates having a constructability mindset from the beginning.
- **Technological advancements (BIM, digital tools):** A frequent topic in several responses was how constructability analysis is becoming more widely recognised thanks to new technologies (such as Building Information Modelling (BIM), 3D/4D simulations, and digital project management tools). For instance, constructability assessments are more successful when teams use BIM to visualise and troubleshoot construction sequencing and conflicts beforehand. Because constructability approaches are easier to apply with technology support, their availability encourages a broader acceptance of these practices.
- **Safety and quality expectations:** Integrating constructability guarantees that safety is “*built into*” the design and that the finished product satisfies high-quality standards without requiring rework, which is essential as safety requirements and quality demands rise. According to respondents, constructability ensures that projects may be completed securely in addition to being quick or inexpensive. This is becoming increasingly crucial in a sector that aims for high reliability and zero accidents.
- **Collaboration among stakeholders:** It was noted that there is a tendency for owners, designers, and contractors to work together more, and constructability is a key area where these parties come together. Constructability is naturally elevated by early contractor

involvement and multidisciplinary teamwork, which are becoming more widely acknowledged as excellent practices. As a result, industrial culture is gradually changing to dismantle silos and make constructability a shared goal for all stakeholders.

- Risk reduction: Last but not least, respondents brought up risk management: project risk is significantly decreased by recognising any construction issues early on, which is a key advantage of constructability evaluations. This proactive approach is appreciated in an industry that is increasingly aware of risk allocation and management.



Fig. 3.10 - Importance of Constructability in the Construction Industry

In summary, constructability is crucial for meeting modern industry challenges by controlling costs, delivering fast without errors, and integrating new methods (like prefabrication or automation). This strong consensus on importance clearly mandates the research: any framework to improve constructability would address an area practitioners already acknowledge as key to future success.

Figure 3.11 below highlights three viewpoints cited by respondents on why they believe constructability is becoming increasingly important.

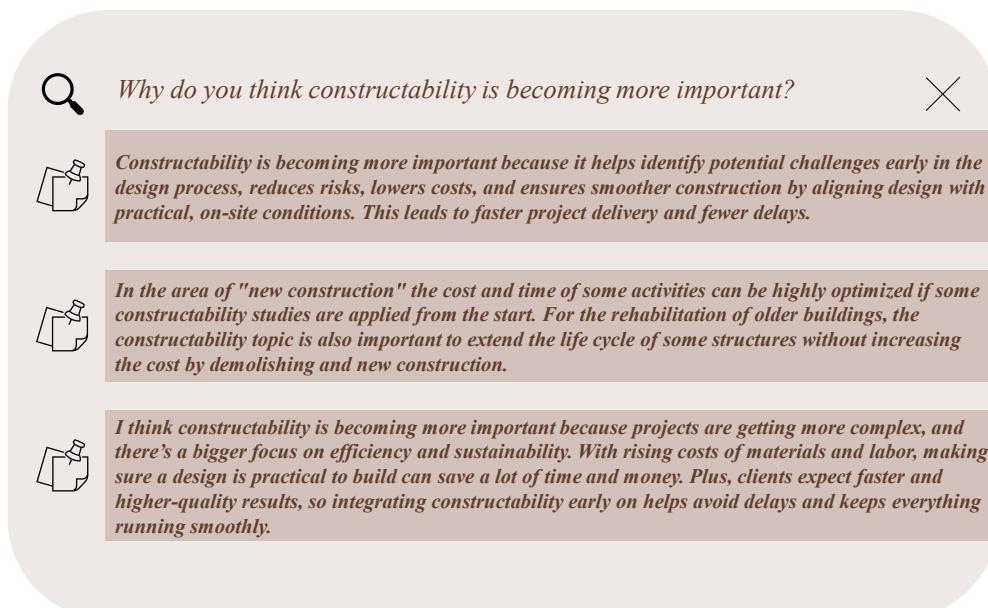


Fig. 3.11 - Respondent Descriptions of Why Constructability Is Becoming More Important

3.2.7. APPLICATION OF CONSTRUCTABILITY IN CURRENT PRACTICE

3.2.7.1. Experience and Usage

After proving that constructability is commonly regarded as a good idea, the respondents looked into how companies handle constructability during projects and how much these ideas are used. The findings present a contradictory picture: while many respondents and their organisations try to incorporate constructability, the methods differ and are not consistently methodical.

When asked, “Have you ever applied constructability/buildability in any of your projects?”, 41% of respondents stated they had not specifically used constructability or buildability in their projects (or at least do not recognise having done so), 59% of respondents indicated they have done so. Approximately half of those aware of constructability have not formally implemented it because 81% of respondents had heard of the word ‘Constructability’. This suggests a disconnect between implementation and awareness.

There could be several reasons, such as the fact that some people work in positions or phases of projects where they believe they have little control over constructability (for example, a planner who has to adhere to the design exactly as it is) or that organisations do not have procedures in place to apply constructability even though people are aware of its benefits. Additionally, some people may conduct constructability (such as informal design reviews) without referring to it as such, which could be a reflection of definitional ambiguity. However, the fact that more than 40% have not used it indicates that there is still space for development, which is what the suggested framework seeks to do.

Most of the 16 who have used constructability have done it more than once. In fact, 52% of the total stated that they had personal involvement, when asked, with projects where constructability played a significant role in the approach or success of the project. Although a couple may have denied the first but then recalled an example, or vice versa, these 14 most likely overlap with the 16 who replied "Yes" to having applied it. This suggests that roughly 50% of the sample has direct experience with constructability's impact on a project.

Qualitative insights can be gained from such experiences. Many of these respondents described particular projects in which constructability was important. One contributor, for example, gave the example of a large drainage project in which early constructability research resulted in design modifications that expedited the building process and avoided considerable delays. An example of a high-rise structure where constructability evaluations found a conflict and permitted a design change that prevented rework during construction was provided by another. The use of digital tools was also widely emphasised. In a project mentioned, foundation designs were adapted to complex terrain using BIM and constructability reviews. This allowed construction delays and costs to be reduced significantly. A similarly complex scenario was managed during the rehabilitation of an operational airport. The project was executed in carefully sequenced phases, with digital simulations and daily coordination meetings. These measures ensured that construction did not interfere with ongoing flight operations, proving that constructability can be critical in maintaining operational continuity.

Prefabrication and modular construction techniques were frequently cited as effective responses to constructability challenges. For instance, in a project in Paris, the incorporation of prefabricated roof shells and revised construction methods allowed coordination issues to be resolved, ultimately leading to the project's successful completion. In another example, a company adopted a redesigned façade and structural system using prefabricated panels, contributing to improved buildability and cost savings.

Constructability considerations were found to be particularly vital in projects located in remote or challenging environments. Limited material access and logistical constraints were addressed in Africa

through tailored construction phasing and planning. Another project involved the construction of a building inside a mountain, where tunnels had to be created to access excavation zones, an effort that required additional constructability discussions and planning. Similarly, the placement of cranes near a critical electrical substation was reconsidered to avoid disruptions to early project phases.

In many cases, it was shown that construction sequencing played a fundamental role in ensuring successful execution. For example, phased planning was employed to manage structural calculations for tunnels and viaducts, while off-site construction was used to overcome access limitations in a separate project. Across all these cases, constructability was identified as a decisive factor in enabling complex construction activities to proceed safely, efficiently, and within budget constraints. A few respondents said they had no example to provide, reflecting either a lack of experience or confidentiality constraints. Still, most of those who utilised constructability could recollect tangible outcomes.

3.2.7.2. Methods of Ensuring Constructability:

Respondents were asked (open-ended), “How does your company ensure constructability/buildability is addressed in your projects?” They described various approaches (or sometimes, the lack thereof). Several key practices emerged:

- Internal design reviews: The most common mechanism mentioned was conducting constructability reviews or design reviews as part of the design process. Many noted that their company has an internal review process where senior engineers or experts (sometimes explicitly Subject Matter Experts (SMEs)) evaluate designs for buildability. For example, one respondent said their company “*either has internal reviews of designs or engages subject matter experts to check constructability.*” Another stated “*by design review*”, which implies a standard step in their workflow. Many companies have a practice where, at certain design milestones, the plans are explicitly reviewed for construction feasibility. This can involve experienced in-house professionals examining the drawings and models to spot any issues that could arise during construction. This indicates that peer reviews or specialist checks are a primary tool for ensuring constructability in practice. However, the formality of these reviews likely varies; some might be ad hoc, while others follow a checklist.
- Early involvement of construction experts or contractors: Several responders stressed cross-departmental collaboration; in other words, early involvement of individuals with building expertise. This could be a dedicated constructability team, seasoned construction managers, or even third-party consultants who weigh in on the design. One participant noted their company ensures constructability by “*involving construction experts early in the design phase*” and conducting feasibility reviews with site teams. Some companies rely on close coordination between the design department and the execution (construction) department. For example, one response highlighted “*deep coordination between the design and execution department*” as the primary mechanism, implying continuous dialogue so that on-site realities inform design choices. Similarly, another pointed out that to spot such problems, they include construction specialists early in the design process. This relates to the Early Contractor Involvement (ECI) concept, which we shall review in more depth soon. Some companies, especially integrated organisations or design-build contractors, seem to unofficially guarantee constructability by having construction workers evaluate or co-develop the design.

- Standard procedures and guidelines: Respondents mentioned that constructability is built into their standard operating procedures. For instance, *“It’s part of our company’s procedures”* and *“each designer in his field must design taking constructability into account,”* as one respondent put it, suggesting an ingrained expectation rather than a separate activity. Another mentioned they are starting to have a *“constructability management department”*, implying a formal organisational commitment to the topic. A few noted checklists, guidelines, or phase-gate requirements that mandate constructability considerations. One mentioned using *“internal standards and methods, developed and adjusted to each country or market”* to ensure buildability is considered despite regional differences.
- Digital tools: Several respondents cited technology as an enabler. One respondent mentioned an *“internal software that follows every step from design to installation”* that tracks constructability and interface issues (likely a custom project management or BIM-based tool). While not everyone has such advanced tools, some indicate that digital methods (3D models, simulations) are increasingly part of constructability practice in leading firms.
- Reliance on contractors at the procurement stage: A few responses, particularly from design consultants, implied that contractors ultimately ensure constructability rather than the design firm. For example, one respondent said, *“None specifically, but bidders have to include a full constructability plan”*. In other words, their company (a design consultancy) does not internally do much for constructability, but they require the construction bidders to address it. Another noted *“means of construction is considered in the procurement phase”* suggests that decisions about constructability are deferred to engaged contractors. If contractors suggest adjustments, this method can identify problems before construction begins. Still, it may not fully incorporate constructability insights into design decisions until the input is included in a redesign. It represents a more conventional division of labour between design and construction.
- Past experience and lessons: Additionally, constructability is ensured by utilising the knowledge gained from previous projects. According to several responders, teams avoid making the same mistakes by drawing on lessons learned from past projects. Some respondents tacitly acknowledged that their organisations lack robust constructability assurance procedures. According to one, *“it’s not really standardised at the moment, but it’s supposed to be done via our internal quality procedures.”* Formal means for recording lessons learnt are not always there, as will be discussed.

While several companies have some formal or informal process to consider constructability, the consistency and rigour of those procedures seem to vary. This is precisely the gap the research aims to fill by providing a guideline/checklist with a structured framework that standardises how and when constructability is evaluated (instead of relying on ad-hoc efforts or hoping the contractor will fix issues later). A key component of any successful constructability program will be multidisciplinary communication between designers and constructors, as highlighted in the descriptions provided by respondents.

3.2.7.3. Tools and Techniques Used:

Respondents' constructability tools range widely in expertise, as seen in Figure 3.12. While certain companies use modern technologies like digital twins and BIM, others use straightforward checklists, the expertise of SMEs, or hold regular review sessions. This variation emphasises how constructability

practices are not standardised, emphasising the necessity of a scalable framework that can be used in high-tech and low-resource settings. When asked “What type of constructability/buildability tools or methods does your company use?”, responses ranged from simple to sophisticated:

- BIM and digital modelling: As indicated, several responders use BIM as a tool to increase constructability (for complex assembly visualisation, clash detection, etc.). “*Building Information Modelling (BIM), 3D visualisation and clash detection*” was mentioned as a crucial technology in one thorough response. Another mentioned exploring digital twin technology and 4D/5D modelling (integrating schedule and cost into BIM). It helps designers and builders in the virtual identification of construction sequencing challenges and spatial conflicts. Teams can use BIM to model construction, identify problems such as system interferences, and modify designs for easier assembly. BIM allows “*3D visualisation, clash detection, and coordination among disciplines to optimise construction sequences and reduce errors,*” according to one response. It is evident that BIM has emerged as a key technology for constructability in numerous businesses.
- Constructability review meetings/workshops: Some respondents referred to structured workshops where various stakeholders review the design. One mentioned conducting “*internal standards, software, and programming applications to ease the process, digitalisation, and automatisms*”, suggesting collaborative sessions focusing on constructability improvements. Apart from internal reviews, some companies hold formal constructability workshops or review sessions, often involving multidisciplinary teams. Nevertheless, A noticeable gap exists, given that many companies do not yet have regular, dedicated constructability review sessions. This reveals a significant flaw in the way things are done now. One crucial element that is sometimes overlooked is an organised and cooperative constructability review process, which is essential for spotting design flaws early on, boosting buildability, and eventually increasing project results.
- Value Engineering (VE): Value engineering was mentioned by a few responders as a constructability-related technique. In one case, the respondent’s answer enumerated “*Value Engineering by evaluating materials and methods to balance cost, quality, and performance*” as part of their constructability toolkit. Since VE workshops seek cost-effective solutions, which usually involve speeding construction, they typically overlap with constructability reviews. VE or similar cost-optimisation initiatives were highlighted by roughly 19% of respondents as a way to solve buildability.
- Dedicated roles or departments: As previously indicated, one company is setting up a constructability management division, which suggests that skilled workers are putting constructability tools and procedures into practice. Only one respondent explained this relatively uncommon and sophisticated organisational strategy. Still, it highlights a crucial point: some major companies may have managers or engineers specifically focused on constructability (much like safety or quality departments). Project managers or design leads are in charge of the work without such positions.
- Standard software and checklists: Companies utilise specialised software tools and checklists in addition to BIM. One referenced “*internal software that follows every step from design to installation,*” referring to a specialised project management or design QA/QC tool that checks constructability factors. Another comment implied using scheduling tools in conjunction with BIM for constructability-related planning by only mentioning software names or abbreviations (e.g., “BIM; P6” - P6 referring to Primavera P6 scheduling software).

- No specialised tools: It should be mentioned that several respondents said they didn't utilise any particular constructability tools. A few responses were as simple as “SME review only” (i.e. relying on expert judgment rather than any specific tool) or “None specifically” except for what contractors offer during the tender stage. Another from a company that would not place much emphasis on constructability stated that methodologies and tools “*depended on the type of project,*” with no particular limitations, suggesting an ad hoc mindset. These situations probably relate to businesses where constructability is not codified, and individual teams select the tools (if any) they employ on a project-by-project basis.

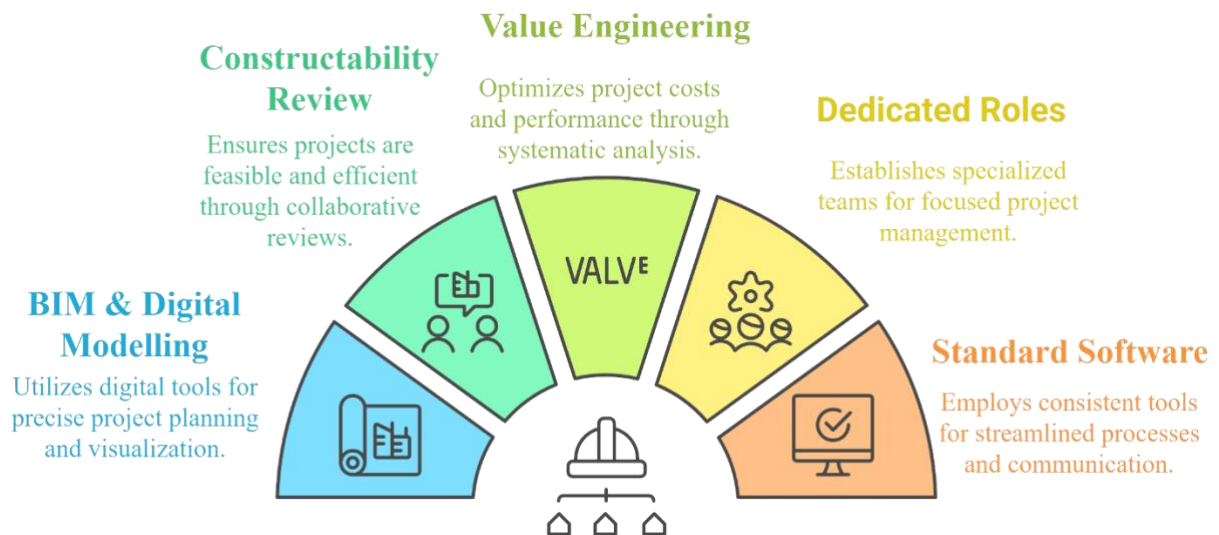


Fig. 3.12 - Constructability/Buildability Tools and Methods Used by Companies

The wide range of answers regarding tools and techniques points to the lack of industry-wide standardisation in constructability procedures. While certain companies use more conventional methods, others use more contemporary approaches (BIM, formal VE workshops). This implies that the constructability framework should be scalable, meaning companies with varying maturity levels may use it. To guarantee that even companies with limited resources can methodically integrate constructability, the framework suggests BIM-based evaluations for those who can do so while offering straightforward checklists for others lacking advanced technologies.

Notwithstanding these varied approaches, a common trend emerges: most respondents' organisations take constructability into account, but frequently in an unofficial or semi-formal manner. Constructability is sometimes handled inconsistently or late since there is no standard method. This emphasises the importance of creating a thorough framework, which is what this study aims to do by offering a standardised road map for including constructability into early project planning.

3.2.8. INTEGRATION OF CONSTRUCTABILITY IN PROJECT STAGES AND STAKEHOLDER INVOLVEMENT

Understanding how and when constructability is currently included in projects is critical. The survey included questions about which project phase constructability is typically integrated and who influences constructability decisions most. The responses indicate a broad agreement that early is preferable, but they also demonstrate that practice and ideals don't always meet, particularly concerning contractor involvement.

3.2.8.1. Project Phase for Constructability Integration:

Participants answered open-ended questions, “At which phase/stage does your company integrate constructability?” Most responses pointed to the design phase, especially early design:

- Most of them mentioned conceptual or early design phases. Common terms included *"concept stage," "schematic design," "preliminary study,"* and *"initial design stage."* Almost half of the respondents say constructability is (or should be) addressed from the conceptual or very early design phase. One said, for instance, *"Masterplan Level - Concept Stage (it can also be applied during detailed design, but that hasn't been normal)"*, implying that they strive for integration at the concept stage.
- *"Design"* or *"Design stage"* were the answers given by several others, which we understand to mean *"during the design process"* (perhaps implying detailed design). Some defined it as *"from concept through detailed design"*.
- A few respondents stated that constructability concerns are maintained consistently by those companies from design through procurement and construction, with some mentioning *"all," "different for each contract,"* or simply *"all phases."* One integrated contractor, for instance, noted that their company usually deals with constructability from the engineering/design stage through the construction review.
- A few participants admitted that although it should occur in the initial stages, it may appear later. *"Should be at the beginning,"* one person remarked openly, suggesting it isn't at the moment. While they attempt to consider constructability from the outset, most constructability input is incorporated in the detailed design, according to another who said, *"Since the beginning, but more on the detailed design."*
- Remarkably, very few indicated incorporation of the construction phase. One said, *"usually on the shop drawings phase,"* which occurs at the point of design and construction, late in the design cycle. Another used *"execution"* may indicate that they mainly address constructability once construction starts (which may be pretty late, essentially resolving difficulties on site). These were exceptions; people generally believed that earlier integration was intended or practised.

Constructability integration was reported across multiple phases of the project lifecycle:

Concept → Early Design → Detailed Design → Procurement → Construction → Execution

This is illustrated in Figure 3.13, which shows the frequency of constructability integration across each project phase.

-  Most common: Concept / Early Design
-  Moderate: Detailed Design
-  Less common: Procurement / Construction
-  Rare: Execution / Shop Drawings

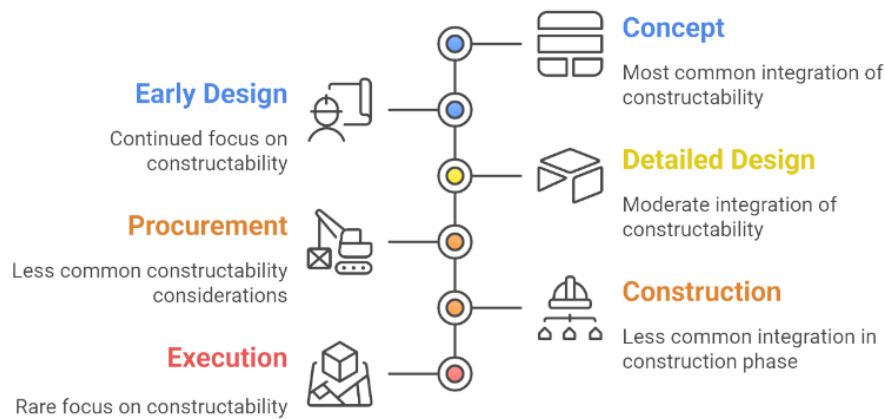


Fig. 3.13 - Frequency of Constructability Integration Across Project Phases

This supports a crucial realisation: constructability input needs to be addressed at every level of the project lifecycle, even though it works best when incorporated during front-end planning and early design. According to many responders, constructability is an early design challenge. It fits nicely with the goals of organised frameworks that stress incremental development and decision-making, such as FEP, the RIBA Plan of Work, and PMI's PMBOK. Influence and efficiency are maximised when constructability factors are incorporated early, especially during concept and design development. However, the early phases of the project were not mentioned in terms of strategic or master plan briefing. Other practitioners only referenced constructability later on, specifically during the production or execution of shop drawings, indicating a missed opportunity. Delays reduce the efficiency of constructability assessments by making them reactive rather than proactive. This highlights the necessity of a lifecycle-based paradigm incorporating constructability as an ongoing factor, emphasising early integration. It also emphasises how critical it is to address structural obstacles that frequently impede timely engagement, such as contract structures, procurement schedules, and limited early contractor involvement.

3.2.8.2. Primary Influence on Constructability Decisions:

In response to the question, "*Who influences more the constructability decisions in your company?*" The single-choice answers offer an insightful glimpse, as shown in Figure 3.14, into the power dynamics of the present:

- Decisions about constructability were most commonly attributed to design engineers, with 41% (11 out of 27). Responses indicate that engineers, likely the design engineers or engineering managers, have the most influence when determining whether a design is constructable or what modifications should be made for buildability. This makes sense because they are responsible for designing the plans and must balance practical approaches and architectural intent.
- Project managers are the next most influential group at 30% (8 respondents). Several respondents stated that project managers have significant influence or perhaps the final word on decisions about constructability. This is probably because they are in charge of project delivery and are worried about the cost and schedule effects of design choices. They frequently push for constructability improvements because of their role, which enables them to collaborate between the design and construction teams.

- Clients/Owners were selected by 15% (4 respondents) as the primary influencers. In these situations, the client's demands or insistence on particular methods might take priority over other considerations. For instance, to achieve a deadline, a client may indirectly require great constructability, or a client more focused on design may be less concerned with constructability. Sometimes, the client insists on a specific design feature regardless of difficulty. The comparatively lower percentage indicates that although clients determine many project criteria, the project delivery team is typically more responsible for optimising constructability.

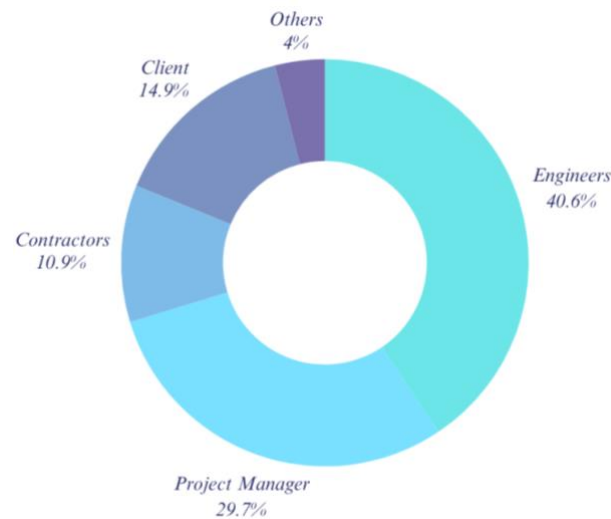


Fig. 3.14 - Key Influencers of Constructability Decisions Within Companies

- Contractors were surprisingly low, at only 11% (3 respondents). This is noteworthy since it would seem that contractors, who are in charge of construction, would have a significant impact on constructability. The low number suggests that contractors do not enter the picture early enough or with enough sway to dictate constructability-related decisions in many projects, particularly those represented by our sample, which is mostly design-centric. They might only carry out the design provided to them or have little influence if the project is not structured to allow for early contractor engagement.
- Others: According to one respondent (3.7%) who selected the "Other" option, constructability is a collaborative process between the design team and stakeholders. This respondent focused on cross-functional influence rather than highlighting any one party. Even though one person specifically said this, it's important to remember that the best constructability processes involve collaboration, with clients, designers, and contractors offering their perspectives.

These findings indicate a possible misalignment: contractors with the most field knowledge frequently have less influence over constructability decisions than engineers and project managers (internal team). This implies that designers attempt to anticipate construction-related problems out of necessity, though frequently without getting direct contractor input. It reaffirms the significance of early contractor involvement, which was examined independently in the study. One of the most essential topics that emerges from this is the importance of early contractor involvement and other cooperation problems covered in the subsequent section.

3.2.8.3. Lack of Early Contractor Involvement

As shown in Figure 3.15, not incorporating contractors early enough is the second most common issue with timing and participants. The survey also addressed this topic, asking participants if, in their perception, early involvement of contractors is beneficial for the project, and 85% answered Yes, it is useful, while 15% said No. According to several responses, contractors with real-world construction experience are usually brought in after designs are mostly finished, which reduces the influence of any constructability comments they may have. This demonstrates that respondents had broad theoretical support for ECI, which aligns with research showing that early contractor input can improve cost/schedule performance and minimise downstream adjustments. Although a small percentage, the few who replied "No" may believe that early contractor engagement is unnecessary or could complicate the design process (perhaps because of communication or contractual issues).

In practice, when asked "In your projects, are contractors involved early in the design phase to improve constructability?" Only 52% said Yes, while 48% said No. This split of almost 50/50 is illuminating. It demonstrates that only roughly half of organisations actively apply ECI to their projects, even though 85% of people agree that it is beneficial. This discrepancy is shown in Figure 3.15, where nearly all respondents concur that early contractor involvement is necessary, but in practice, about half do not do so. To put it another way, there is a significant gap between ideal and actual practices, which is probably caused by conventional design-bid-build procurement methods or other institutional limitations that postpone contractor involvement.

Figure 3.15 represents the Early Contractor Involvement (ECI): Perceptions versus Practice. The blue "Yes" column indicates that almost all respondents (23 vs. 4) think it is advantageous to involve contractors early. Nonetheless, there is a divide in the answers when asked if contractors are truly involved early in their projects (14 Yes vs. 13 No, right bar), suggesting that despite the apparent advantages of early contractor involvement, almost half of the projects do not use it.

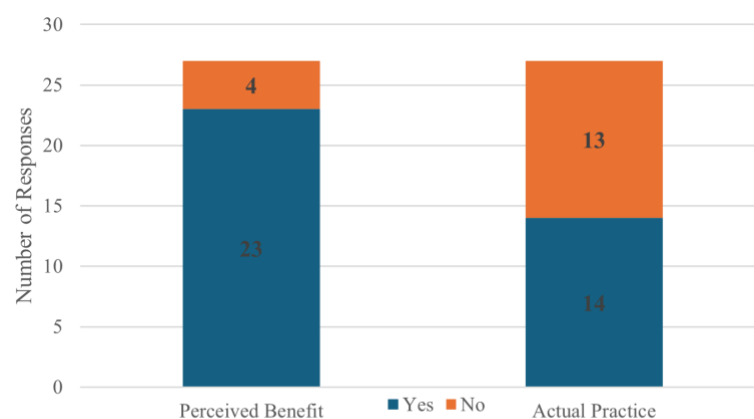


Fig. 3.15 - Early Contractor Involvement (ECI): Perceptions vs. Actual Practice

This indicates that a key recommendation for the constructability framework will include mechanisms to incorporate contractors or construction experts into the project lifecycle. This could be achieved through integrated project delivery methods, constructability consultants, or partnership agreements. Respondents' strong belief in the benefits of Early Contractor Involvement (ECI) suggests they would be receptive to frameworks or standards that help eliminate the practical barriers to implementing ECI.

Based on respondents' experiences, the practical consequences of not involving contractors early were referred to. ECI could lessen a lot of the particular difficulties and inefficiencies that were highlighted

(rework, design modifications, etc.). For instance, the type of problem that early collaboration could identify is demonstrated by one respondent's example of a project in which a crane position conflicted with a structural element (discovered later in the process). In fact, in one of the open-ended example narratives, a responder explained how the team overcame a significant obstacle in a particular project after implementing constructability principles (which included contractor participation). This emphasises how late contractor involvement frequently results in constructability issues being discovered, which can have a more significant financial and scheduling impact.

On the other hand, the survey's success stories highlight the benefits of ECI and teamwork:

1. One example explained a situation in which early planning with contractors ensured that issues were handled up front, resulting in an easier execution of a complex project (a remote site construction).
2. Another said that early collaborative planning was probably responsible for the prompt completion and efficiency of an airport project involving construction specialists who used their input (such as prefabrication concepts) during design.

It's important to note the results reported by those who do use contractors in the beginning. Early cooperation was probably necessary for many of the previously mentioned success stories (better drainage project, etc.). Furthermore, *"the importance of early stakeholder (especially contractor) involvement to uncover challenges and align expectations"* was emphasised in one of the survey's open-ended recommendations. This confirms that ECI was helpful to those who tried it. In contrast, *"lack of early contractor involvement"* was one of the most frequently mentioned issues (26% of respondents selected it), according to the challenges question (discussed below). All of them emphasise that one well-known barrier to constructability is the failure to involve contractors at an early stage.

3.2.9. CHALLENGES IN APPLYING CONSTRUCTABILITY

The questionnaire also shed light on the obstacles and difficulties companies encounter when applying constructability. It is essential to comprehend these issues because it enables the framework to address them. Respondents might choose multiple answers to the question, *"What are the biggest challenges your company faces in applying constructability principles?"* Figure 3.16 summarises the findings, with the number of respondents who selected each.

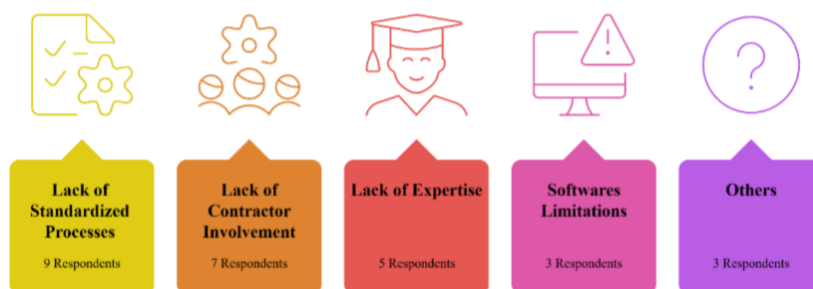


Fig. 3.16 - Biggest Challenges in Applying Constructability Principles

- Lack of standardised procedures (33% of respondents): According to nine respondents, the biggest challenge is that their company lacks a constructability framework or standard procedure. This directly supports the main idea of the study. Companies may apply constructability inconsistently or rely on human initiative if they lack defined procedures,

checklists and constructability reviews. This finding indicates that a formalised constructability framework, precisely what this study seeks to create, is desperately needed. This implies that constructability may not be established in stage-gate or quality management systems, even in structured companies. The framework can bridge this gap by offering a transparent, repeatable procedure. One responder mentioned that "*it's not standardised at the moment*" regarding their constructability efforts, which aligns with the chosen problem.

- Lack of early contractor involvement (26%): 7 respondents chose this, echoing the earlier discussion on ECI. They believe that a significant obstacle to constructability is the challenge of incorporating contractor perspectives at an early stage. Contractual frameworks (design-bid-build) or internal resistance to early external involvement could cause this. This difficulty highlights another area of emphasis for the structure: it should incorporate rules or benefits for early engagement of construction knowledge (whether through internal constructability experts, contractors, or construction managers). The fact that this was the second most popular choice suggests that many people view the timing of engagement as a challenge because, by the time contractors join the project, drawings have been finalised. Chances to increase constructability have been missed.
- Lack of expertise/knowledge (19%): 5 respondents indicated a lack of expertise or training in constructability principles as a challenge. This implies that even if they wish to implement constructability, they believe their employees could lack the skills or background needed to do so successfully. This makes sense because people learn constructability through experience or mentoring rather than formal instruction. There can be a knowledge gap as builders from older generations retire. This problem suggests that part of the answer is education and training. To help teams understand how to apply a constructability framework, training materials, documentation, and knowledge-sharing should be included or added to it. Additionally, it relates to having specific tasks; without internal constructability, leaders and information could be dispersed. A few respondents mentioned a lack of expertise. For example, one said their difficulty was "*the stakeholders' engagement needs to be empowered*," implying that they lacked the necessary skills or mentality to participate in constructability conversations. It is essential to develop that level of expertise.
- Software limitations (11%): 3 respondents believed that the implementation of constructability is restricted by software or tool limitations. This probably relates to lacking the necessary technology (like BIM) or the skills to use it efficiently. Sometimes the learning process is an obstacle, or smaller companies may be unable to purchase advanced BIM. Although most people did not find this a significant issue, it is noteworthy because it suggests that technological assistance, such as easily navigable constructability analysis tools, could be beneficial. For the framework, this could entail offering toolkits or suggesting broadly available tools (such as fundamental checklists or 2D/3D markup methods) to conduct constructability evaluations without the need for unreasonably costly software.
- Other (11%): 3 respondents provided unique answers that didn't fit the provided options. One wrote "*lack of integration of constructability experts at early stages of design*", which is another way to say early involvement of specialised expertise (similar to the ECI issue, reinforcing it). Another mentioned "*the stakeholders' engagement*" (likely meaning that low stakeholder engagement is a challenge). This may suggest that it is challenging to get all stakeholders (designers, clients, contractors, etc.) to actively engage in constructability

talks, possibly due to compartmentalised working or conflicting priorities. This emphasises once more the necessity of improved mechanisms for collaboration.

These challenges draw a picture of why constructability isn't as pervasive as it should be. For instance, the process gap is that many companies lack a formal standard process where constructability is not built into their standard project workflow. They rely on internal guidelines that are in general and informal methods, and given that 70% of companies offer no formal constructability training (as will be discussed).

Moreover, the challenge of limited early contractor involvement corresponds to a people and time gap, which was clear before the practice gap and the beneficial source of the ECI, which again connects to the lessons learned processes being absent in many companies. Teams may not have the training and experience to apply constructability principles confidently, and also the tool gap, where some lack the tools to evaluate constructability efficiently. Furthermore, these difficulties explain some of the survey's contradictory replies. Some respondents who stated that constructability isn't very relevant in their workplace, for instance, probably work in environments where these barriers are high. It's possible that their organisations lack procedures and don't often involve constructors until late, so in practice, constructability principles, while useful in theory, are not applied, which makes them believe that it is "*not relevant here*." This discrepancy between awareness and execution is best illustrated by a participant's remark that the organisation acknowledges constructability but has to do more about it.

These insights directly inform the focus areas for the framework where it should define a formal constructability review process as part of early project phase, encouraging involvement of construction expertise during the project life cycle, training or guidelines to build internal knowledge and recommending appropriate tools (from checklists to BIM for example) and provide templates, lowering the barrier to adoption.

The framework can turn many of these challenges into strengths by addressing them. For instance, respondents themselves offered suggestions later in the survey on how to improve the situation: primarily by formalising processes, improving communication, and integrating teams which directly tackle the lack of process, lack of expertise, and lack of ECI as discussed previously.

3.2.10. IMPACT OF CONSTRUCTABILITY ON PROJECT OUTCOMES

The survey explored how constructability practices impact the project. Respondents were asked if they had cases where constructability improved project efficiency and what specific impacts they observed. Broadly, the impacts are positive and varied, affecting cost, schedule, safety, quality and scope.

In response to "Did you have any cases where constructability improved your project efficiency?", 16 respondents (59%) said Yes, and 11 said No (41%). This aligns with the number of respondents who claimed to have used constructability, indicating that efficiency gains were typically the result of meaningful constructability implementations. People who never had the chance and possibly some who tried but did not see clear benefits (or were unable to isolate constructability's effect) may have been among those who responded "No." Worth noting that a few respondents who, despite not having personally applied constructability in their projects, still answered that yes, they had seen project efficiency improved by constructability.

To delve deeper, the 16 respondents were asked to share an example where constructability changes improved a project's efficiency. These examples, summarised in Figure 3.17, illustrate how constructability considerations impacted areas such as design, logistics, and materials.

- One respondent gave an example of a major drainage project that was made easier to construct after a constructability study changed the design alignment. Practical considerations on the job site led to this modification, which produced "*significant cost savings and time efficiency*." These examples demonstrate how labour, material, or time needs can be directly decreased by changing a design aspect (such as utility routing or repositioning structures) to make construction easier.
- The application of a strong traffic management plan in an earthworks project was mentioned in another example. The project functioned more safely and effectively by preparing for the mobility of machinery and cars on the site (a constructability concern), which helped to prevent delays caused by erratic site movement. This demonstrates that constructability includes both construction-phase planning and static design. Accidents were avoided and downtime was reduced, increasing efficiency.
- Due to constructability considerations (maybe realising import delays or costs), one respondent reported changing construction methods in an African project to employ locally accessible materials. In addition to facilitating construction by guaranteeing that resources were available, this probably reduced expenses and benefited the local economy by improving the supply chain and cost efficiency.
- Several respondents mentioned rearranging building tasks in a more logical order. To ensure construction continuity, for example, the structure of one project was modified, suggesting that the sequencing may have been wasteful in the past (possibly necessitating re-mobilisation or working in a constrained order). They could carry out tasks in a better order after implementing constructability insights, which enhanced the project's overall flow.
- In several cases, efficiency was significantly increased by moving to precast or modular systems. One respondent gave an example of an airport design in which the contractor and the design team decided to use precast parts for the whole drainage system. This modification, which was based on constructability theory, accelerated on-site installation and probably enhanced quality, saving time. Another said that a concept that "*streamlined construction and reduced on-site work*" included modular buildings, suggesting time savings and perhaps less disturbance.
- A few examples clearly demonstrated how constructability avoided issues that could have led to delays. For instance, the project avoided a potentially significant delay when crane placements were changed to prevent conflict with a central structure (had it been discovered during construction, a redesign or huge workaround would have been needed). The project remained on schedule by taking care of it in advance, which is an efficiency that comes from avoiding risks.



Fig. 3.17 - Examples of Project Efficiency Improvements Attributed to Constructability

In a multiple selection question about the impact areas of constructability on projects, respondents predominantly selected improvements in project scheduling, efficiency and cost reduction, as seen in Figure 3.18.

- Nearly all who answered, with 22 out of 27, indicated that schedule performance was improved. This reflects that speeding up construction or avoiding delays is the most widely felt benefit of constructability efforts. Projects can be completed more quickly or with fewer difficulties by improving designs and planning, consistent with research showing that constructability evaluations can lower schedule growth.
- Cost reduction was also highly cited, with 20 respondents. This means that cost savings are another highly realised benefit, likely through more efficient use of materials, fewer change orders and less rework by using cost-effective construction methods. Many respondents noted in open questions that optimising cost is a key driver for constructability (and indeed a result, as seen here).
- Material selection and sustainability were chosen by 18 respondents as an impact, implying that constructability input often leads to choosing construction methods or materials that are not only easier to build but also more resource-efficient or appropriate, tying into sustainability. For instance, modular components might enhance quality and reduce site impacts, or optimising a design may reduce waste. The fact that buildable designs frequently align with sustainable practices (less waste, better logistics) appears to be acknowledged by the respondents.
- Safety improvements selected by 10 respondents. Constructability assessments can guarantee a safer construction process by removing risky design elements. Such as safer-to-implement designs (e.g., reducing hazardous site work by prefabrication, including temporary works in design). Safety is still important, even if it is lower than the other categories. Improved constructability frequently improves safety in practice (by removing risky construction phases). Yet, it's possible that some respondents did not directly observe or consider safety changes since they were more concerned with cost and time.

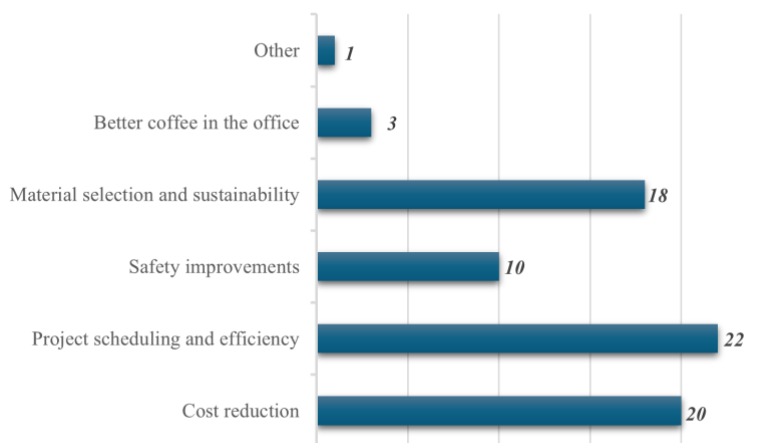


Fig. 3.18 - Areas of Project Impact from Constructability Efforts

It's interesting to note that some respondents playfully chose "*Better coffee in the office*" as one of the constructability "impacts." This humorous response (selected by a small number) probably suggests that the direct effects of constructability may not have been evident for certain people or in some projects, or that they are joking that it accomplished everything but the obvious (or just adding humour to the

survey). Additionally, one participant marked "Never used," indicating that they had not used constructability and hence did not perceive any impact. The major effects, excluding these anomalies, focus on sustainability, safety, cost, and time.

Constructability's significance is validated by the data's majority of time and cost improvements, which are often the two criteria used to determine project success. According to one respondent, constructability helps "*reduce risks and avoid potential issues during construction*," which these findings support. The difficulty lies in overcoming the previously mentioned barriers so that these advantages may be consistently achieved on all projects, rather than demonstrating the worth of constructability, which is clear from these efficiency increases. This means that for the framework, we should highlight the time and cost savings that constructability integration may provide, as these are significant reasons for industry adoption. Notable is the material/sustainability component, which implies that the framework can be promoted to achieve sustainability objectives in addition to efficiency, which is becoming increasingly crucial in contemporary projects. Safety should not be disregarded, even when there are fewer options; a thorough constructability framework will incorporate safety issues (such as planning for safe construction procedures) into its criteria.

It's a multifaceted endeavour that improves overall project performance and even stakeholder satisfaction (clients receive projects on schedule and within budget; contractors experience fewer difficulties; designers witness the effective realisation of their plans). All respondents probably view it as crucial for the industry's future because of its many advantages.

After examining the outcomes of implementing constructability, the focus switches to how companies monitor the performance of these projects and what tools are available for learning and improving from one project to the next. These aspects affect how effectively constructability information is recorded and applied.

3.2.11. PROJECT PERFORMANCE TRACKING AND LESSONS LEARNED

Constructability is strongly related to how companies share information and learn from previous projects. By emphasising achievements and shortcomings and instituting that knowledge, good performance monitoring and lessons learned procedures can strengthen constructability. However, the responses show that formal lessons learned processes are frequently absent, even though basic performance tracking is commonplace.

To understand the context in which constructability improvements occur, the survey examined how companies track project performance and whether they learn from past projects. The question included 4 mechanisms as discussed below and illustrated in Figure 3.19:

- Client feedback and reviews: This was among the most often cited techniques. Several companies rely on client input (such as formal project evaluations, post-project client satisfaction surveys or client meetings) to determine how well a project went. Constructability can be indirectly touched upon by client feedback. For example, if a client comments that a project was delivered smoothly or with fewer modification orders, this speaks favourably of constructability elements.
- Key Performance Indicators (KPIs): According to the majority of respondents, KPIs are used by their firms to track performance. These could include safety statistics, the number of RFIs (requests for information), technical reports, contributions made towards cost savings/value engineering, material submittals, test reports and change orders (which frequently correspond with constructability difficulties), document control log, schedule

adherence, budget deviation, etc. By monitoring these KPIs, companies may measure productivity and identify areas that require development. However, this might not directly lead to constructability improvements unless certain constructability related KPIs are utilised, such as "constructability review completion" or "constructability issues identified."

- Lesson Learned sessions: Approximately 50% of companies have meetings or sessions to discuss lessons learned at project milestones or close-out. Teams talk about what worked and what didn't at these meetings. Respondents who brought this up view it as a performance evaluation component; by considering efficiency gains or losses, they want to improve in the future. Lessons learnt include, for instance, if a project had delays due to late design modifications (a constructability issue).
- No formal tracking system: Several respondents acknowledged that their organisation does not have "*a formal tracking system*" for project performance. Performance may be evaluated informally or solely based on significant financial results in these situations. Continuous improvement may be challenging; if possible, constructability advantages or problems are not consistently documented or examined due to a lack of formal tracking.

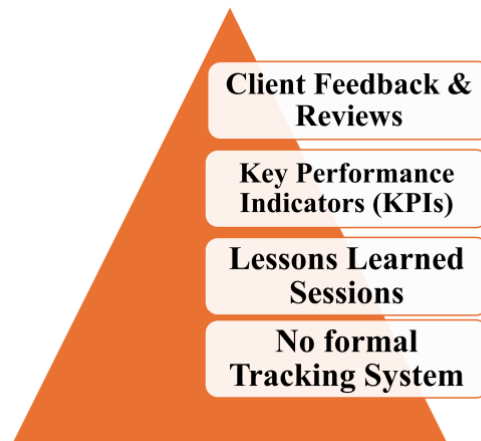


Fig. 3.19 - Methods Used by Companies to Track Project Performance and Learn from Past Projects

A slight majority of respondents (16 out of 27) stated that their company lacks a clear procedure for documenting and implementing lessons learnt. Just 11 people said that a formal process does exist. This division implies that many companies deal with lessons learnt either randomly or not at all, which is consistent with the problem of the previously mentioned absence of defined procedures. This is crucial for constructability since knowledge doesn't build up inside the company if lessons learned from previous constructability problems or achievements aren't recorded.

For the companies that do have formal lessons learned processes, respondents described how lessons are documented and shared:

- Documentation is often done via structured templates and reports. Several mentioned using formal templates, logs, or standard forms that are filled out at the end of a project. For example, some respondents cited it as "*formal template and in meetings*," "*structured templates after final delivery*". Also, some noted that they have databases or shared folders/portals accessible to employees. For example, "*on company shared folder*," "*company portal*," "*internal website*," or "*every project database*." In one of the answers,

a respondent mentioned internal standards and onboarding sessions that incorporate lessons from past projects, indicating integration of lessons into training for new staff.

- Others admitted issues: “*We have a process, but I believe it is not being used (or if used, not shared properly)*,” showing that even when a system exists on paper, it may not be actively utilised.
- Some organisations schedule post-project meetings or workshops to discuss lessons learned, and the outcomes of those discussions are then documented. This interactive approach can enhance the quality of lessons captured, as multiple perspectives are shared.

Regarding responsibility for managing lessons learned, answers varied:

- Many companies place this responsibility on the Project Manager (PM) or the project team. Project managers, in charge of project delivery, often lead lessons learned discussions and ensure the documentation is completed. Several respondents explicitly said, “*the PM for the project*,” “*project managers*,” “*the project management*”, etc.). Noteworthy, through my experience, I once had the opportunity to work with a project manager who was not only highly responsible but also committed to sharing knowledge. He led by example and ensured the team learned from every project phase. He took the lead in documenting lessons learned and encouraged open discussions, turning them into real learning opportunities. This aligns with how many companies view the role, taking responsibility for lessons learned by the project manager or team.
- Some larger or more structured organisations have dedicated roles or departments, such as a Quality Control/Assurance (QC/QA) manager or an Innovation/Knowledge department overseeing lessons learned. For instance, one noted a “Knowledge Department” in charge, and another mentioned an “innovation department” tasked with capturing and disseminating lessons.
- A few respondents indicated that a specific engineer or representative per department collects lessons for their discipline, which then might be consolidated. This suggests a decentralised approach where each speciality (structural, mechanical, electrical & plumbing (MEP), etc.) gathers its own lessons.
- One referred to the document control department, which implies there is an established process integrated into the company’s management procedures.

Ensuring that lessons learned are communicated across teams and departments is another challenge. 11 Respondents from companies with formal processes indicate how lessons are shared across teams:

- Structured knowledge-sharing initiatives: For example, one respondent detailed that their company uses post-project review meetings, internal training sessions, and a centralised lessons-learned database, complemented by cross-department meetings and newsletters to distribute key insights. This comprehensive approach indicates a strong learning culture; constructability issues identified on one project would thus be shared company-wide and likely not repeated.
- Workshops or frequent meetings: Some participants stated that internal meetings are held regularly to discuss project experiences. These could be yearly company meetings or quarterly forums to review lessons learned.
- Informal or ineffective communication: Some responses implied that although lessons might be documented, the communication is weak. Phrases like “*not very normal and efficient procedures*” or “*that is not being applied at this moment, I believe*” suggest

breakdowns in disseminating the knowledge. In some companies, lessons learned documents may be filed away without broader discussion or may only reach a limited group.

- Digital platforms: Some mentioned using shared platforms or online databases to store and access lessons. However, one respondent openly stated that they had a procedure, but "*it is not being used*"; access does not equate to usage. This demonstrates that even when lessons are recorded, ensuring people read and apply them can still be challenging.

Finally, respondents were asked, “How often does your company update or improve internal processes based on past project experience?”. Responses were, as also shown in Figure 3.20:

- “Regularly”, 11 respondents (41%) indicated their company regularly updates processes from lessons (which is encouraging).
- “Occasionally”, 7 respondents (26%) said occasionally. These companies improve, but perhaps not as systematically, only after major issues or once in a while when management undertakes a review.
- “Rarely”, 2 (7%) said rarely, meaning processes remain static despite new lessons. This could be due to bureaucracy or a lack of a champion for change.
- “Not sure”, 7 (26%) were unsure, which might imply a lack of visibility or clear updates. This could indicate that staff are unaware of the practice; changes may occur in the background or not at all. It might also suggest that changes are so small or rare in some organisations that employees are unaware of them.

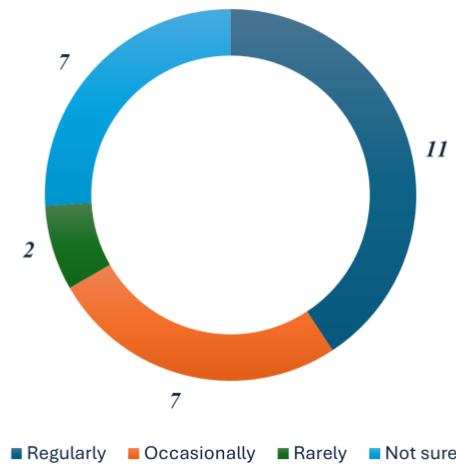


Fig. 3.20 - Frequency of Updating Internal Processes Based on Past Project Experience

The pattern that emerges is that many firms lack a robust lessons-learned feedback loop. This has direct implications for constructability: if issues encountered in one project (*a design detail that caused a construction delay*) are not recorded and communicated, the same issue could recur in future projects. Similarly, innovative solutions discovered (for example, a novel construction method that saved time) might remain isolated incidents if not shared. The absence of formal lessons learned in 60% of surveyed companies is a concern. Still, it aligns with the earlier challenge of “lack of standardised processes”; lessons learned programs are part of having a mature process.

For our framework, this means incorporating a feedback loop mechanism. We should recommend that, after each project (or during, at key milestones), constructability lessons be captured and fed back into the planning of future projects. The framework could include a step for a post-project constructability

review, feeding into a lessons repository. Furthermore, given the lack of formal training, these lessons could form the basis of internal training content (essentially learning from one's mistakes and successes).

3.2.12. TRAINING AND KNOWLEDGE SHARING ON CONSTRUCTABILITY

The survey explored whether companies provide any internal training or knowledge-sharing specifically on constructability, and what such programs entail or should include. The responses show that formal training on constructability is relatively rare, even though many see its value.

The majority of respondents (19) replied "No" when asked if their company offers internal constructability training or knowledge-sharing, while just 8 said "Yes." This indicates that the companies represented lack specific workshops, training, or knowledge-sharing events centred around constructability or buildability principles. This result aligns with the previously mentioned issue of "*lack of expertise*" and the ubiquity of non-standardised procedures; in the absence of training, companies depend on people to acquire constructability skills independently. It also fits with the reality that many have not defined constructability; formal training is unlikely if constructability is not a formal component of the approach.

The survey also inquired "What would be useful to include?" presumably asking those whose companies lack training what would be helpful to include if a training or knowledge-sharing program were developed (though many who do have training also answered, perhaps suggesting improvements). 19 people responded with suggestions, which provide valuable guidance:

- Constructability concept overview: Many felt the training should start with introducing constructability principles, ensuring everyone has the same basic understanding. This includes, as illustrated in Figure 3.21, definitions, objectives, and benefits of constructability, essentially making sure all staff, especially younger engineers, know what constructability is and why it matters. One explicitly suggested an "*introduction on constructability as basic knowledge for all project managers and developers*" and more specifics per discipline.
- Real Project Case studies: Many respondents desired real examples. Phrases like "*examples of successful implementation*," "*real case studies*," and "*constructability examples/case studies*" came up repeatedly. This could involve studying completed projects (within the company or from industry) and extracting lessons. As highlighted in Figure 3.21, case studies make the training practical and relatable. From personal experience, I recall one instance where the company organised a dedicated session day to showcase various project presentations. This initiative gave employees valuable insights into ongoing and completed projects, highlighted lessons learned, and fostered a better understanding of practical challenges and solutions in the field. Such knowledge-sharing activities enhance learning and build a culture of continuous improvement and collaboration across teams.
- Best practices and guidelines: Respondents want to know how to do it. One suggested "*best practices in value engineering, digital tools like BIM and 4D/5D, prefabrication strategies, and coordination techniques*." Another mentioned "*industry best practices and guidelines for implementing constructability programs, tailored to the company's projects*." As shown in Figure 3.21, this indicates interest in a structured body of knowledge, exactly what a formal framework would encapsulate. People are asking for the codified wisdom to be made available.

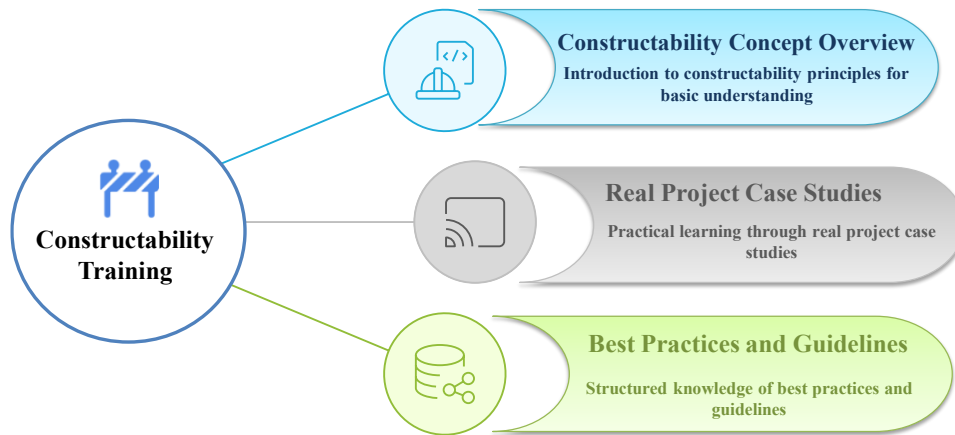


Fig. 3.21 - Respondent Suggestions for Improving Constructability Training Content

- Collaboration and communication techniques: One detailed answer highlighted “*training on conducting comprehensive reviews to identify and resolve potential construction challenges early in design,*” and “*emphasising effective communication and collaboration between designers, engineers, and construction teams.*” This underscores training in soft skills and processes, e.g., how to run a constructability review meeting and how to facilitate cross-team collaboration. Indeed, knowing the technical principles isn’t enough; teams must know how to work together to apply them.
- Value engineering and alternative methods: Training could also include methods like value engineering, showing how to evaluate different design alternatives for better buildability and cost effectiveness. Also, exposure to new construction technologies or materials (e.g., modular construction techniques, 3D printing in construction, innovative formwork systems) would broaden engineers’ and managers’ toolkit for constructability solutions.
- Multi-discipline coordination: Some respondents implied the need for training on how different disciplines (architectural, structural, MEP, etc.) should coordinate for constructability. For example, mechanical systems should be designed with installation space in mind alongside structural elements. Training could involve interdisciplinary workshops or simulated coordination exercises.
- Basics for all and advanced for some: Some responses suggested tiered training, e.g., “*basic introduction sessions for all project managers and developers... and more technical ones... maybe case studies too.*” This implies an awareness that different levels of detail are needed for various audiences. Senior management might need an awareness session on constructability benefits, while engineers need detailed technical guidance. A framework implementation could mirror this, with broad orientation for stakeholders and in-depth training for practitioners.
- Formalising lessons learned: Some suggestions indirectly pointed to better use of lessons learned (e.g., “*sharing lessons learned sessions,*” “*allow time for wide engagement to capture new methods,*” etc.). This indicates training is not just a one-off but an ongoing learning culture.

Overall, respondents are effectively outlining components of an educational program to accompany constructability initiatives: include examples, best practices, new tech, collaboration, and multi-level engagement. This feedback will be invaluable in designing the rollout of the constructability framework, ensuring that guidance documents or workshops cover these aspects so that companies can overcome the expertise gap.

3.2.13. INDUSTRY TRENDS AND FUTURE INSIGHTS

Through more open-ended questions, the survey invited respondents to look forward and consider future changes in the industry and their profession, particularly in relation to technology and roles. One question asked respondents: if they had unlimited resources, what innovation would they introduce to improve construction projects? The answers were heavily centred on advanced technologies and automation, suggesting where the industry is headed:

- Many respondents said they would spend more on robotics and automation in the building industry. The concepts included introducing automated equipment, robotic construction systems, and AI-driven building procedures. By making project execution safer, quicker, and less reliant on physical labour, these ideas hope to transform the industry entirely. One respondent, for instance, predicted that "*advanced automation and AI-driven technologies will revolutionise construction*," pointing to a time when algorithms and machines will perform daily tasks.
- Integration of artificial intelligence (AI) was a common theme. According to the respondents, AI is crucial to optimising project management tasks like risk assessment, scheduling, and modifications to in-the-moment plans. AI is intended to "*optimise scheduling, predict delays, and adjust designs in real-time based on construction conditions*," according to one specific proposal. This relates to constructability since an AI that can adapt designs to different circumstances effectively automates real-time constructability enhancements.
- Digital twins and Building Information Modelling (BIM) were often discussed. To fully utilise BIM, people would integrate it with 4D (time) and 5D (cost) to realistically view and precisely manage the project's execution. Construction process simulation and problem-solving before they occur on site may be made possible by digital twins, which are virtual versions of the project that are updated in real-time.
- 3D printing and modular construction: A few respondents emphasised the widespread usage of prefabrication/modular building techniques or the 3D printing of building components. These advances can significantly increase constructability by shifting more work off-site and simplifying on-site tasks. They would scale up these techniques to make building quicker and more effective if they had limitless resources, particularly for standardised or repeating aspects.
- Improved platforms for collaboration: A few people brought up the necessity of stronger stakeholder and software integration. Infinite resources would allow the creation of completely integrated software environments that eliminate tool fragmentation by smoothly connecting design, scheduling, and execution data. This may entail developing unique systems that combine field data, AI, BIM, and project management.
- Human factors: Not all suggestions were purely tech. Some respondents said they'd improve communication or "*increment human communication across teams*" with unlimited resources, perhaps by investing in better processes or tools to ensure everyone is on the same page. Another mentioned providing "*better work environment and conditions*" for workers, recognising that human well-being is also part of successful project execution (a nod towards safety and productivity).

These innovative concepts suggest that although the construction sector will become increasingly automated, data-driven, and digitalised in the future, human supervision will still be necessary for creative problem-solving and coordination. Powerful tools (such as AI-driven design checks) will help

with constructability in the future. However, human judgment and interdisciplinary cooperation will still be essential to direct these tools and implement solutions locally.

Another forward-looking question asked: *How do you think the role of engineers/designers will change in the next 10 years?* Respondents foresee significant evolution in their roles:

- Integration with technology: A frequent one is that engineers and designers collaborate considerably more with automation and artificial intelligence, as can be seen in Figure 3.22. AI may replace humans in routine jobs (such as drawing, simple computations, or typical designs), freeing humans to focus on supervision, decision-making, and solving complicated or new problems. Some even predicted that AI would "replace" some components of the design function, particularly those that are repetitive or heavily computational, and some citation responses "*Will be replaced by AI*". Engineers will need to learn how to use digital tools like generative design algorithms, AI design assistants, and BIM as part of their everyday work.
- Data-driven and multi-disciplinary approach: It is anticipated that future engineers will be more data-centric and use analytics to guide design choices. Additionally, they will be more interdisciplinary, comprehending their primary area of expertise and constructability, sustainability, and project management. A "*more data-driven, multidisciplinary, and problem-solving approach*" was highlighted by one respondent, suggesting that engineers will transcend traditional barriers.
- Enhanced stakeholder involvement and collaboration: Future designers are anticipated to collaborate more with construction teams and other stakeholders, in keeping with the constructability philosophy. With early engagement and perhaps more design-build or integrated delivery models becoming prevalent, the lines separating the jobs of designer and contractor may become less distinct. To make sure their designs make sense in the field, designers may collaborate virtually or on-site with builders more frequently.
- Human engineers may concentrate more on conceptual design, strategic planning, and creative problem-solving as automation takes care of the tedious tasks. Instead of sketching every detail by hand, they would be the ones to define the issue and its limitations, then direct AI technologies to create solutions. As a result, the position becomes more supervisory and analytical. As a result, the skill set changes from just technical drafting to innovation, critical thinking, and validating AI outputs.
- Adaptability and lifelong learning: According to some respondents, engineers must constantly pick up new skills and techniques. Because technology is developing so quickly, an engineer's education continues after graduation; being proficient in AI tools, new building techniques, or software becomes a position requirement.
- For some, nothing has changed: There was a minority view that the fundamental functions would not change (*the construction team will be the same, but design will be replaced with AI, implying the construction side still needs people*). Therefore, even if design is automated, human interaction is still necessary for the physical component. Even so, a construction engineer's duties may expand to include managing automated procedures or operating sophisticated equipment.

10 Respondents (37%) answered AI for this question



Fig. 3.22 - How Engineers' and Designers' Roles Are Expected to Evolve with Technology

According to the respondents, the industry will become more technologically sophisticated, and experts will need to adjust by learning new skills and working more closely with machines and one another. Crucially, constructability is emphasised rather than diminished in any of these future scenarios. Constructability is improved by the focus on early collaboration, the use of digital twins and BIM, and data-driven design. For instance, constructability might be a criterion for generative design algorithms in the future, which would essentially bake the idea into automated designs with human input.

3.2.14. PROFESSIONAL SKILLS AND ORGANISATIONAL CULTURE

Constructability implementation is heavily impacted by people's abilities, attitudes, and corporate culture; it is not only about procedures and equipment. The survey results provide light on the abilities that experts in the field value, or don't value, as well as how constructability is viewed culturally in businesses.

One open-ended question asked: "What do you think is the most undervalued skill in the construction/engineering industry?" The responses were illuminating. Selected descriptions from the respondents are cited and presented in Figure 3.23 below.

By far the most frequent response revolved around communication skills:

- Communication, or effective communication, is underestimated, according to many respondents. This includes managing expectations with clients and contractors, coordinating across disciplines, and effectively communicating ideas. According to one respondent, communication is essential for planning the flow of information and providing clients and team members with positive and negative feedback. Another said that "*the stakeholders' engagement needs to be empowered*," which means that everyone needs to be involved and communicate.
- Some emphasised listening, teamwork, and communication, basically interpersonal skills. One respondent's reference to "*psychology, i.e., people and social skills*", highlights how our technically driven field is perceived to undervalue human factors, team dynamics management, and empathy.
- Additionally, rationality and strategic thinking were addressed. This could involve making thoughtful judgments instead of impulsive ones or planning ahead (foreseeing problems related to constructability thinking). This implies that some believe the industry occasionally undervalues the capacity for methodical planning and holistic thinking.

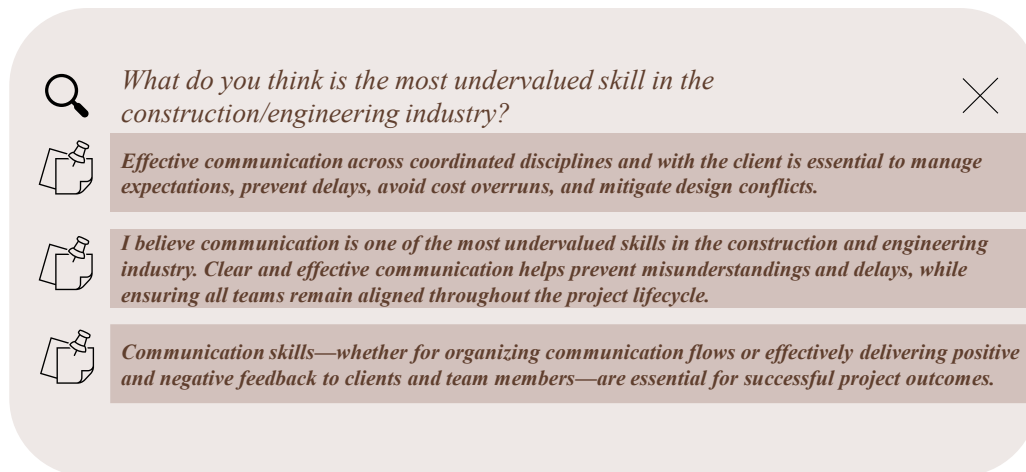


Fig. 3.23 - Respondent Views on the Most Undervalued Skills in the Construction and Engineering Industry

The heavy focus on communication implies that constructability depends on soft skills. Constructability initiatives frequently entail bringing disparate viewpoints together, such as designers outlining their goals and constructors outlining site requirements. These interactions fail if there is inadequate communication. Therefore, some constructability concerns (such as incorrect expectations resulting in design revisions or problems with stakeholder participation) may be caused by undervaluing communication.

In terms of advice to young professionals (engineers or project managers) from the seasoned respondents, similar themes emerged:

- Continuous learning and openness: Many advised newcomers to keep learning and remain open-minded. Phrases like “*continuously learn from real-world challenges*,” “*be open-minded*,” and “*embrace learning, don’t be afraid to make mistakes*” were common. This advice implies that the industry requires adaptability and that knowledge (like constructability know-how) is accumulated over time by being receptive to new ideas and lessons.
- Prioritising practicality and collaboration: Advice such as “*Always prioritise practicality and collaboration*” and “*engage with construction teams early*” was given. This directly advocates for a constructability mindset: focus on what will work in practice and work together with others (especially those who build) to ensure success. Seasoned professionals are essentially telling young ones to break the silo mentality and value buildability from the start.
- Respect and teamwork: Some urged being respectful, helpful, and a team player. This fosters a positive culture where ideas can be freely shared, which is necessary for constructability reviews and can sometimes challenge someone’s design. A respectful team can discuss constructability issues without defensiveness.
- Communication: As expected, “*communication*” was explicitly mentioned in advice, e.g., “*Always prioritise communication and collaboration*.” Young professionals were encouraged to develop good communication habits, as asking questions, clarifying doubts, and coordinating effectively is vital.
- Patience and understanding the field: A couple of respondents advised patience and understanding the field conditions. This suggests not rushing through design without appreciating how things get built on-site, reinforcing a constructability attitude. Patience also plays into dealing with complex projects where not everything goes right initially.

- Innovate but stay practical: Some advice balanced openness to innovation (*travel, see new processes, embrace digital tools*) with a grounding in practical reality. This combination is essentially the recipe for successful constructability: use new methods and ideas, but make sure they are feasible on the ground.

It is evident from these suggestions that the human element, communication, collaboration, and ongoing development, are regarded as crucial to closing the gap between design and building. Since these are offered as recommendations, it is necessary to emphasise them to newcomers because the current industry may not adequately support or teach them.

The survey also included a couple of more imaginative questions that reveal cultural perceptions:

- When asked to describe the construction industry using one emoji as illustrated in Figure 3.24, the top choices were the construction crane 🏗️ and the exploding head 💣. The crane emoji (selected by about half) signifies “*industry in progress*”; it’s a positive or neutral symbol of building and hard work. The exploding head, chosen by many others, humorously indicates “*managing chaos daily*”, capturing the stress and complexity of construction. A few used the hourglass “*always waiting for approvals*” and one the money bag 💰 “*costs are always rising!*”. These choices reflect a culture that is simultaneously proud of building things but also acutely aware of the chaos, delays, and cost pressures, precisely the issues constructability seeks to alleviate. In a sense, a successful constructability implementation might move the industry culture more towards the crane (progress) and away from the hourglass (delays) and exploding head (chaos).

This indirectly supports the push for better planning and frameworks like constructability, which aim to reduce chaos by foreseeing issues.

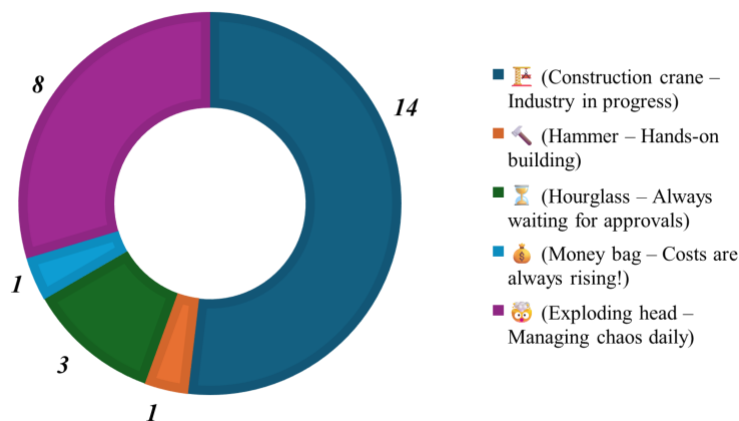


Fig. 3.24 - How Respondents Represent the Construction Industry Using Emojis

Another creative question: “*If constructability were a person in your company, what kind of employee would they be?*” This yields direct insight into how constructability is viewed culturally within organisations. As represented in Figure 3.25, options included characters like Team Player, Overlooked Genius, Strict Boss, Ghost, and Rebel. The most selected was “*The Team Player*” (48% of respondents), described as someone who “*helps engineers, project managers, and contractors work together.*” This is telling nearly half personified constructability as a cooperative, facilitative role within the company. It suggests that those respondents see constructability as a positive, integrative force (when it exists).

The second most common was “*The Overlooked Genius*” (33%), “*a great idea but ignored by management.*” This indicates that many feel constructability is a brilliant concept that isn’t getting the attention it deserves, again highlighting a gap in uptake at the management level. A small number saw it as “*The Strict Boss*” (7%) who “*makes everything harder, but saves time later,*” reflecting the view that constructability might impose stricter rules or upfront effort that pays off (interesting that this was minor, most didn’t see constructability as onerous, except 2 people). This reflects a culture where constructability is recognised as a necessary discipline; possibly in companies with formal processes, the team might view constructability checks as a rigorous hurdle that nonetheless pays off.

Another 7% chose “*The Ghost*” - “*no one talks about constructability here*”, meaning in some companies it’s essentially non-existent (this aligns with those who hadn’t heard of it or applied it).

Only 1 person chose “*The Rebel*” (*considered only when things go wrong*). The predominance of Team Player vs. Overlooked Genius tells a story: Constructability can be the ultimate team facilitator, but is often undervalued. This duality reinforces the need to elevate constructability (so it’s not overlooked genius/ghost) and formalise it as a team effort, precisely by implementing a framework that institutionalises it as a “team player” role in projects.

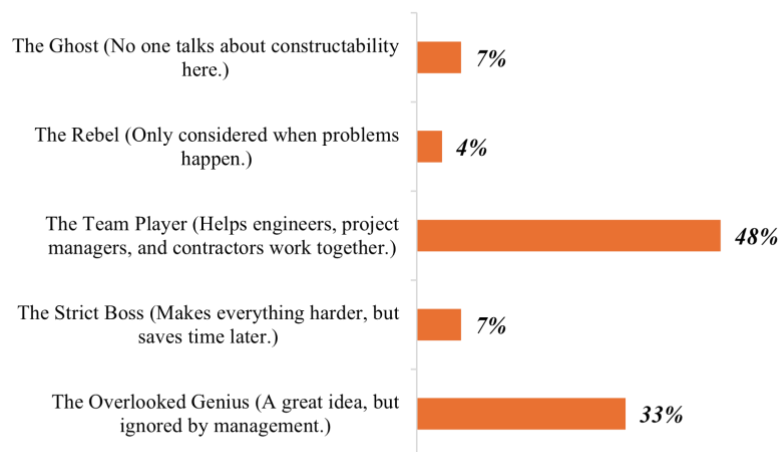


Fig. 3.25 - Imagining Constructability as a Company Employee by Respondent

Another interesting question was “*if construction projects were managed like sport teams, what position would you be playing?*”

The responses to the question, shown in Figure 3.26, reveal that most participants see themselves in strategic or supportive roles within construction projects. The most selected position was the Coach (37%), indicating a strong inclination toward leadership and planning. The Defender and Midfielder roles followed closely (26% each), reflecting a balanced focus on quality assurance and coordination. Interestingly, no one identified as a Goalkeeper, suggesting a potential gap in reactive problem-solving or crisis management. With only 11% selecting Striker, quick-fire problem-solving is not a dominant self-perception among respondents. This distribution highlights a team dynamic that values structure, foresight, and control over speed or reactive responses.

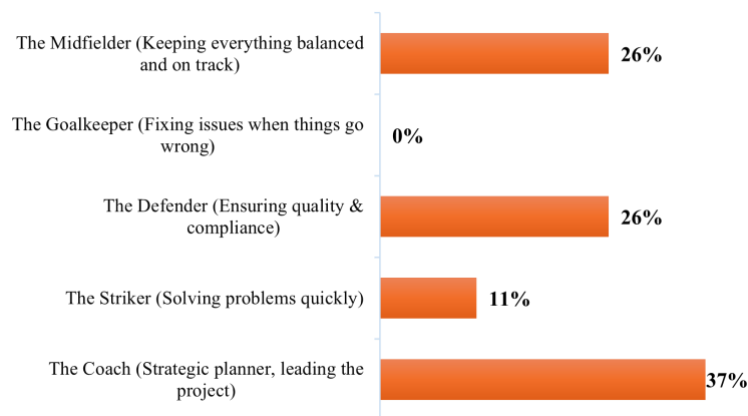


Fig. 3.26 - Respondent Roles if Construction Projects Were Managed Like Sports Teams

Respondents were given a chance to share any other thoughts about their company's approach to constructability. Most had no further comments, but a few remarks echoed the above cultural observations:

- *"Companies still lack the urge to address constructability during the project design stage,"* one noted, reinforcing that many firms do not prioritise it unless required.
- *"Our company always mentions the importance of constructability but needs to take more action on activating it and involving relevant parties,"* said another. This again shows the gap between talk and action. Culturally, management might acknowledge it in words, but practical steps (like early contractor involvement, formal reviews, etc.) are not taken.
- One respondent noted reliance on external subconsultants for constructability, leading to minimal internal knowledge retention. Culturally, this implies that constructability is outsourced and not ingrained in the company's own staff or process, which is an internal barrier to learning and improvement.

The human and cultural dimension revealed by the survey emphasises that soft skills like communication and teamwork are critical to implement constructability effectively. The industry could benefit from valuing these skills more, as technical solutions alone (tools, processes) are not enough without a collaborative culture. Moreover, how constructability is perceived internally can range from a collaborative hero to an ignored voice. Achieving the former status (team player) in more organisations will likely require deliberate cultural change: training, management buy-in, and celebrating constructability successes so that the "genius" is no longer overlooked.

3.2.15. CHANGES DESIRED IN PROJECT MANAGEMENT

Throughout the survey, respondents identified issues and implicitly and explicitly suggested ways to improve constructability implementation and project management in general. These insights, coming from their direct experience, align with best practices the industry literature often advocates, but here they are grounded in real-world context.

One question asked: "If you could change one thing in how construction projects are managed, what would it be?" Another similarly asked what they would change in how their own company operates. The responses to these questions converge on a few key recommendations:

- Enhance early collaboration among all stakeholders: The most common suggestion was earlier involvement of all parties, designers, contractors, clients, even end-users. Respondents urged breaking silos: *“early integration of all stakeholders during the planning phase,” “better communication with project design teams,”* and *“enhance internal knowledge sharing and collaboration across departments.”* Many noted that constructability issues arise from teams working in isolation. Joint planning, integrated teams, and regular coordination meetings were implied as solutions.
- Streamline decision-making and reduce bureaucracy: Several respondents were frustrated with slow, hierarchical processes. They called for *“less approvals,” “reduce time for decisions for each stakeholder,”* and *“more decentralised decisions.”* One noted that state-run organisations often have slow decision cycles, which need to change. Faster decisions help avoid delays and allow the timely adoption of constructability suggestions.
- Better planning and upfront investment in early design: Many highlighted the need for more time and resources during conceptual and early design phases. *“More investment in conceptual phases and decision-making process,”* one wrote. Early constructability input was essential for rational planning and avoiding rework, echoing the “measure twice, cut once” principle. This recommendation aligns with the adage “measure twice, cut once”, thorough upfront planning saves time and money later. It directly supports the need for early constructability analysis.
- Innovation and flexibility: Respondents wanted more openness to new methods: *“be more agile,” “more focus on Research and Development (R&D),” “adopt technology,” “move away from rigid hierarchies,”* and *“introduce digitalisation from the design stage.”* Others called for improving *“automatic tools (including AI).”* This suggests a modern constructability approach (leveraging digital tools, encouraging new construction methods) would be welcome. It also indicates that the framework should be flexible and modern, not a static old checklist
- Improve communication (internal and external): Communication issues were frequently raised. Respondents mentioned *“a more streamlined and formal communication with project design teams,”* and one wrote *“communication,”* implying it’s a major pain point. *“Face-to-face meetings rather than processes”* was a notable suggestion; many preferred direct interaction over bureaucratic exchanges.
- Selectivity and strategic focus: One respondent advised, *“adopt a more selective approach when bidding for projects... focusing on the right fit... to improve success rates.”* Poor project alignment was seen as a risk to constructability, suggesting the need for upfront assessments of project suitability and internal capability. The framework could include an initial assessment of project complexity and whether additional constructability expertise is needed, aligning with this strategic view.
- Adopt design-build approaches where suitable: One respondent advocated design-build contracts for their ability to *“force constructible solutions”* by aligning design and construction responsibility. Design-build was viewed as a structural way to enable early collaboration and flexibility when challenges arise. It suggests that shifting more projects to design-build or integrated delivery could inherently improve constructability outcomes.

Tying these recommendations back to the earlier findings, they aim to resolve the identified contradictions. Early collaboration addresses the lack of contractor involvement; streamlined decisions and better planning address slow responses and rework; using technology and training addresses the lack of expertise and process; improved communication addresses cultural and knowledge gaps. Respondents advocate for a more integrated, agile, and learning-oriented industry.

3.3. SURVEY 2 - BRIDGING THE GAP: CONSTRUCTABILITY IN REAL-WORLD PROJECTS

3.3.1. DATA DESCRIPTION, ANALYSIS, & DISCUSSION

A second targeted questionnaire (Survey 2) was conducted to delve deeper into how constructability principles are applied in actual projects, aiming to bridge the gap between theoretical best practices and on-site execution. This follow-up survey was built upon the insights from Survey 1, which highlighted a discrepancy between the recognised importance of constructability and its practical implementation. Survey 2 was distributed to 25 industry professionals who participated before and were expected to have direct project experience with constructability integration, and 16 responded (a 64% response rate). The purpose of Survey 2 was to capture concrete examples, challenges, and suggestions from ongoing or completed projects, thereby informing how a constructability framework can be practically embedded into project management processes.

The findings combine quantitative breakdowns and qualitative narratives, reflecting how industry professionals perceive and implement constructability across different project phases. Respondents held various roles, including project managers, site engineers, BIM managers, quality/sustainability leads, and senior executives, and possessed extensive industry experience ranging from approximately 6 to over 20 years.

3.3.2. EARLY INTEGRATION OF CONSTRUCTABILITY IN PROJECTS

One of the fundamental questions to discuss in initial engagement is whether constructability (or buildability) is considered during the early stages of a project. The question to explore is: when a brand-new project arrives on your desk, would you prioritise constructability/buildability as one of the initial tasks to address within the first month of the project? About 11 out of 16 participants responded that they incorporate constructability evaluations or thinking within the first month of a new project, indicating that most respondents consider constructability from the beginning. Many of these responders emphasised the importance of early constructability input in preventing downstream problems. *"Yes, constructability... should be assessed early, ideally within the first month, to optimise design, reduce risks, and enhance efficiency in execution,"* for example, was stressed by one participant.

This opinion aligns with industry best practices, which support integrating construction issues throughout all stages, starting with feasibility, conceptual and design. Several respondents described their initial steps, such as checking site conditions and available local resources, and engaging stakeholders immediately to identify potential building challenges. One of the respondents mentioned the importance of gathering all key stakeholders (designers, engineers, contractors), which aligns with Survey 1 about the importance of getting the team together from the beginning. These early actions illustrate a proactive approach, echoing another respondent's view that *"constructability should be considered from the start to ensure efficient design, cost-effectiveness, and smooth execution."*

However, a significant minority (5 out of 16) do not prioritise constructability in the first month. These individuals tend to push constructability reviews to later stages (e.g. after schematic design or even after initial planning tasks). For example, one senior engineer admitted, *"No, probably this subject will be important after a lot of other things in the project have been initially developed."* In some cases, the deferral depends on project context: *"The answer... is based on the complexity of the building; if the building is complex, I prefer to start with constructability at the initial level."* Another respondent from a speciality subcontractor perspective noted that for their trade, *"we do not start thinking of constructability within the first month. Usually, after the concept design is set, we start the constructability task as part of a holistic exercise led by the project manager."* These responses suggest

that while early constructability involvement is widely viewed as beneficial, practical constraints (such as needing a firm concept design first or perceiving other startup tasks as higher priority) can delay its introduction.

To explore the topic further, participants were presented with an open-ended question: “I start thinking about constructability/buildability early in the project. What are the first methods or ideas you implement?” They were asked to describe how they incorporate constructability in the early stages. As shown in Figure 3.27, the responses consistently emphasised collaborative and proactive planning methods. Common initial actions included conducting constructability review meetings or workshops with the project team, performing design reviews (often using BIM tools) to identify potential construction issues, and considering site logistics and sequencing early. Some respondents mentioned engaging in stakeholder consultations; for instance, involving construction site teams and subcontractors in reviewing design drawings for feasibility. Others emphasised checklists or early feasibility checks (such as verifying access, material availability, and local constraints) as practical methods. Respondents tend to implement structured reviews and interdisciplinary brainstorming to uncover and address issues pre-emptively when constructability is considered from the outset. This practice aligns with the dissertation theme by illustrating that integrating constructability early is an exercise in proactive risk mitigation and collaboration between design and construction domains.

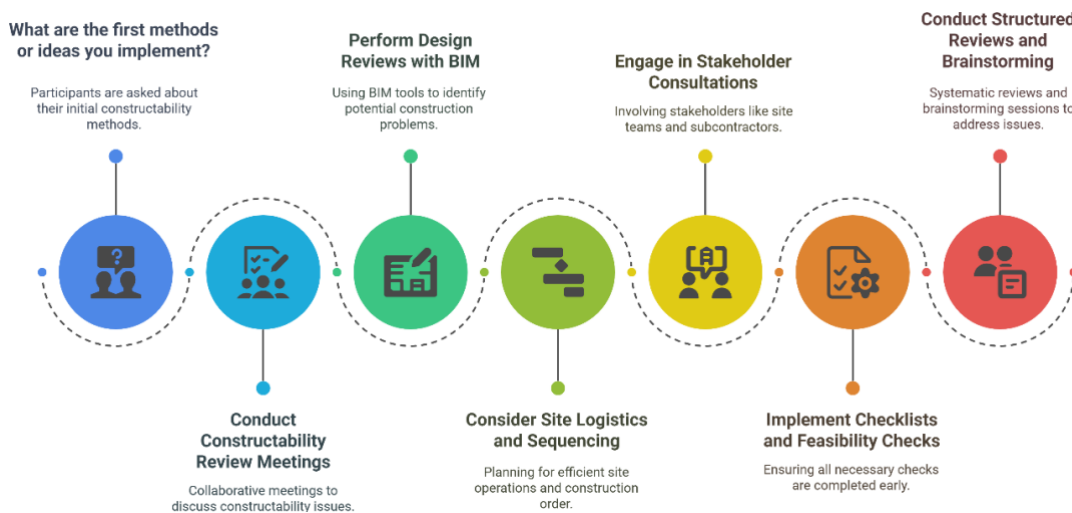


Fig. 3.27 - Early Constructability Implementation Process

3.3.2.1. Timing: Before or During Design?

Interestingly, when asked pointedly whether constructability should be considered before the beginning of the design phase, 62.5% of respondents answered “Yes.” This indicates a strong belief among most participants that constructability should be embedded in the project before formal design work begins, essentially during feasibility or conceptual planning. Yet, 37.5% of respondents answered “No,” implying that constructability can wait until or during design. The split reflects a tension between ideal practice and current practice: many know it should happen early (and some are doing so), but a substantial group still works in environments where early constructability input is not routine. Those who said “Yes” are effectively advocating for constructability input at the project inception or conceptual phase, for instance, involving construction expertise during feasibility studies or concept design to influence fundamental decisions (site layout, major structural schemes, etc.). This viewpoint is consistent with modern best practices that promote ECI for improved constructability. On the other hand, the respondents who said “No” often clarified that constructability should at least coincide with

the design phase (starting from early design but not necessarily before any design work). None of the respondents suggested constructability should wait until after design, which indicates universal agreement that the very latest it should begin is during design, reinforcing that considering constructability only in construction is far too late. The majority “Yes” vote here underlines a key theme of this dissertation: early integration of constructability (even at pre-design stages) is viewed as beneficial by practitioners.

When asked, “What early constructability factors should ALWAYS be assessed before design begins?” Respondents who believed in pre-design constructability provided examples of such factors. The factors, illustrated in Figure 3.28, frequently mentioned include site conditions and constraints (topography, access routes, local infrastructure limitations), availability of materials and regional resources, construction method feasibility (whether proposed structural systems can be built with available equipment/labour), and health, safety, and environmental constraints that could affect the construction approach. Essentially, one should assess anything significantly impacting the project's development before design. One respondent succinctly suggested “*always design with the builder in mind*,” implying that the team should consider the means and methods the builder will use before drawing plans. These responses highlight a proactive mindset: by evaluating key constructability factors (logistics, resources, methods) up front, the subsequent design can be better tailored for buildability. This approach mirrors practices in IPD where early involvement of constructors informs critical design decisions. Professionals feel that a set of fundamental constructability considerations (site, materials, methods) should predetermine the design process to avoid later rework.

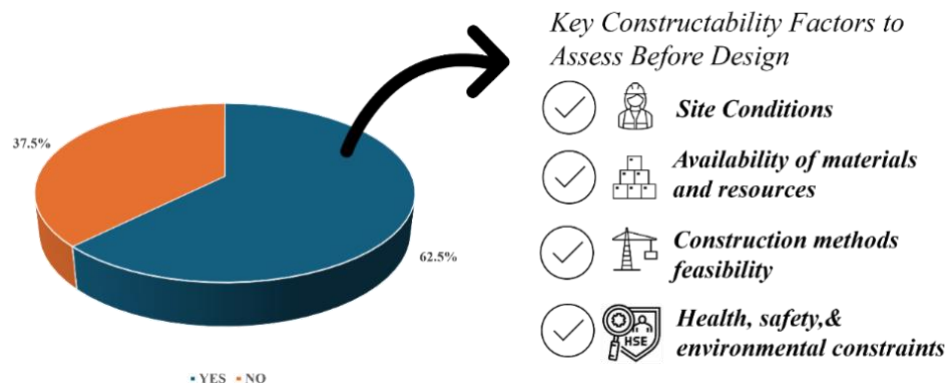


Fig. 3. 28 - Key Constructability Factors to Assess before Design cited by Respondents

3.3.2.2. Assigning Constructability Responsibility

So, when do you think constructability should be assigned? This question, closely related to the above, further probes when a constructability review responsibility should be allocated in a project. Many respondents interpreted this as reinforcing their earlier answers: constructability should be “*assigned*” or “*kicked off*” at project launch or the project planning stage. A common sentiment was that a constructability champion (whether a person or a team) should be identified as soon as a project is conceptualised or at least by the time design work starts, rather than waiting until later. Some answers implied that constructability is an ongoing responsibility (“*assigned throughout the project*”), meaning it’s not a one-time task but a role that persists. Overall, the responses suggest that the industry professionals believe accountability for constructability must be established very early, either by

assigning an individual (e.g., a constructability engineer) or by making it a clear deliverable in the early project plan.

Figure 3.29 illustrates this journey of constructability responsibility, from being unassigned or overlooked to being fully integrated across the project lifecycle. It visually underscores the importance of assigning constructability early (at conceptualisation) and maintaining it as an ongoing priority.

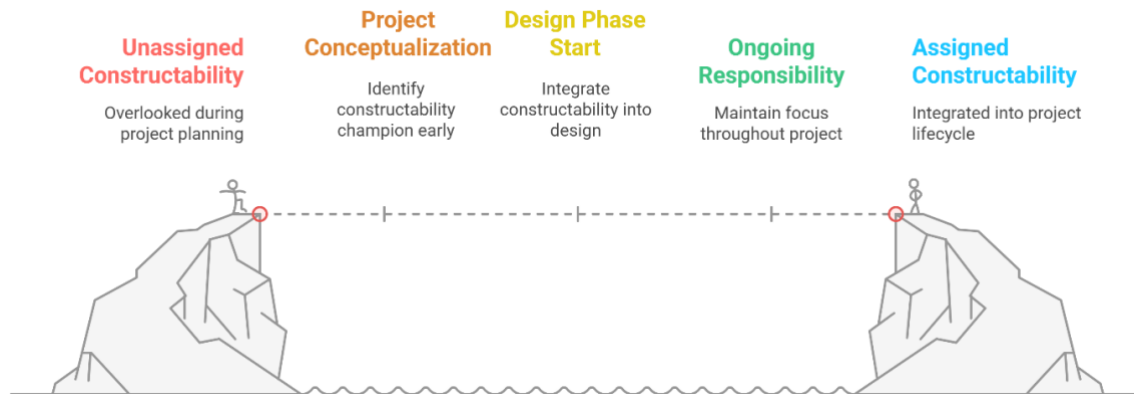


Fig. 3.29 - Constructability Engagement Across Project Phases

3.3.3. CONSTRUCTABILITY IN ORGANISATIONAL PRACTICE

The degree to which constructability is formally integrated into organisations' project management frameworks emerged as a critical theme. Responses revealed that explicit constructability processes or roles are rare. When asked if their company has a department or specific people that handle constructability/buildability, exactly half of the respondents (8 out of 16) answered that this was "*not necessary*", as shown in Figure 3.30, in their view or their company, effectively saying no dedicated role exists and they don't see a need for one. 4 respondents said their company is "*planning to implement*" such a role or department, implying an acknowledgement that the current gap should be filled in the near future. Only 4 respondents indicated "*Yes*," their company already has specific personnel or a department focusing on constructability. This could include, for example, a constructability review team, a "*methods planning*" group, or designated constructability champions embedded in project teams. The prevailing "*Not necessary*" response suggests that many organisations still rely on ad-hoc or integrated roles (e.g., project engineers or managers) to handle constructability issues rather than formalising it as a separate responsibility. This is a significant divergence from recommended best practices. CII and other industry bodies have long promoted formal constructability programs to institutionalise the "*optimal use of construction knowledge and experience in planning, design, procurement, and field operations*" (CII, 1986 apud Kifokeris, 2019, page 2) [77]. This lack of a dedicated constructability team could imply that constructability considerations are diffused among various roles, potentially leading to accountability gaps.

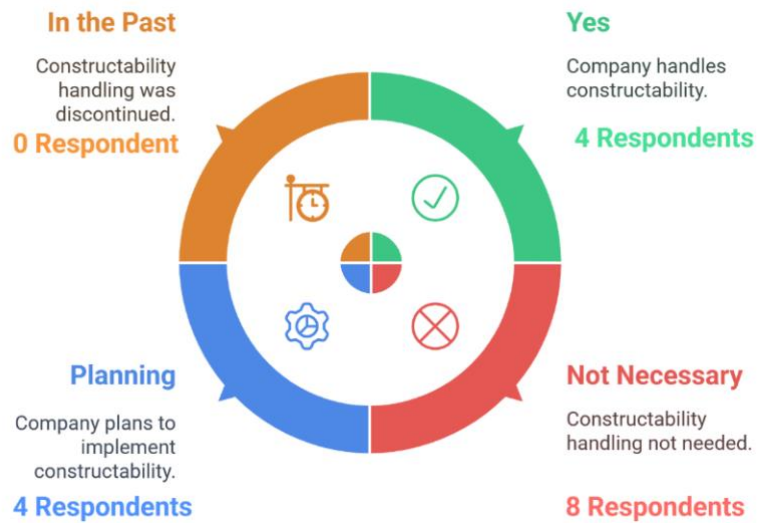


Fig. 3.30 - Respondents' Perspectives on Company Handling of Constructability/Buildability

The informal handling of constructability is reflected in how rarely the term surfaces in day-to-day discourse at companies. The survey examined how deeply constructability is embedded in each organisation's culture; for instance, they were asked how often the term "constructability" (or "buildability") arises in serious discussions within their companies. Although precise frequency data was gathered, qualitatively, the respondents indicated that constructability is not yet a routine topic in many companies. The responses varied widely, revealing a split between organisations that actively foster a constructability mindset and those that address it only reactively.

About 31% of respondents said the term is used "*all the time*" in their company, indicating a strong, ingrained culture of constructability. An equal number (31% of respondents) chose "*occasionally*," suggesting constructability is recognised but not constantly emphasised. On the other end of the spectrum, 19% of respondents said the topic arises only when demanded by a client or upper management, and 13% of respondents admitted it's discussed "*only when something goes wrong*." Tellingly, 1 person said it's "*never*" brought up in a serious conversation at their workplace. As illustrated in Figure 3.31, this distribution highlights a cultural gap: while roughly one-third of the organisations have constructability as a regular part of their language and thought process, the rest either treat it as a special-case topic or ignore it until problems occur. This distribution indicates that constructability is not yet a standard or established part of the project terminology in many companies. It tends to emerge primarily in response to specific issues or external prompts.



Fig. 3.31 - Frequency of Constructability Discussions Within Respondents' Companies

The survey explored whether companies have formal structures or processes to implement constructability, such as written guidelines. The findings indicate that formalisation of constructability is still relatively uncommon. As was discussed previously and seen in Survey 1, the presence of formal guidelines or a defined process for constructability is rare. In survey 2, an overwhelming 14 participants reported that their company does not have an official constructability guideline or process document, which supports the Survey 1 result, and it aligns with the literature that the primary goal of constructability guidelines is to enhance efficiency, safety, and risk management by formal review and knowledge sharing. Merely 2 respondents said “Yes”, indicating that fewer than 1 in 8 organisations in this sample have codified how constructability should be done. Those two who answered “Yes” described their systems briefly: one mentioned their company’s “*golden rules for the construction process*,” and another explained that “*the main goal is to establish a robust process that will tackle all risks and opportunities facing the construction phase*.”

These descriptions suggest that where guidelines exist, they serve as high-level principles or frameworks to ensure that construction knowledge is systematically integrated (e.g., through “*golden rules*” or risk-management processes). Most companies’ absence of formal guidelines underscores a key challenge: constructability is often handled informally, without standardised checklists or stage-gate reviews. This finding suggests that many firms have yet to institutionalise best practices or lessons learned into formal frameworks regarding constructability integration into project management. Instead, any constructability review might depend on individual initiative or project-specific requirements rather than a company-wide protocol.

Let’s be real: If constructability is considered too late, what’s the most common excuse you hear? This question elicited some candid and telling responses about project culture. The most common “*excuses*” reported were related to time and schedule pressure. For instance, respondents noted hearing that teams were “*rushing to meet deadlines*” or “*we’ll address it later due to a tight schedule*” as justifications for not doing constructability earlier. Another excuse mentioned was that each discipline assumed constructability was someone else’s responsibility, e.g., “*the design team thinking the contractor will sort it out, and vice versa*”. The recurring refrain was: “*We didn’t have time for it.*” This reveals that the project schedule urgency is often used to rationalise skipping constructability reviews, ironically, a decision that can lead to greater delays later. Some respondents also hinted at a lack of awareness or training (“*people didn’t know its benefits*”) as an excuse, i.e., if the team does not fully understand constructability’s value, they may not prioritise it. These excuses connect the broader dissertation argument by demonstrating a cultural and managerial challenge: constructability tends to be neglected under pressure without a strong leadership emphasis. Figure 3.32 visually captures this attitude: tight deadlines and poor responsibility assignment often result in sidelined constructability.



Fig. 3. 32 - Excuses for Late Constructability Consideration

Another aspect of culture is knowing from their experience who pushes for constructability improvements within projects. The survey allowed multiple selections for who “actually pushes” for constructability. As shown in Figure 3.33, the results highlighted the construction team and project management as the primary drivers. The construction/site teams were cited by the most respondents (selected by 11 respondents), and project managers were close behind (10 respondents). This indicates that those directly responsible for delivering the project (contractors, site engineers, and project managers) most often champion constructability because they face the real-world consequences of design decisions. Clients were also a significant force (mentioned by 6 participants); in some organisations, the client or owner’s requirements might mandate constructability reviews or improvements (especially if the client has a strong engineering or project control background). The design team was selected less frequently (5 out of 16), suggesting that designers are not typically pushing for constructability unless the company integrates it explicitly into the design process. One respondent even noted that “no one” pushes for constructability in their experience, highlighting that the initiative might fall through the cracks unless explicitly assigned in some projects.

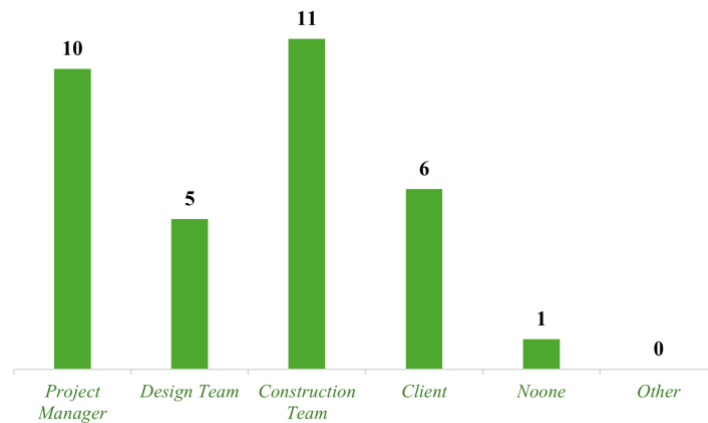


Fig. 3.33 - Respondents' Views on Who Actually Pushes for Constructability Improvements

Survey 1 and Survey 2 explore stakeholder roles in constructability, but from different angles. Survey 1 examines who influences constructability decisions, while Survey 2 investigates who pushes for constructability improvements in practice. This distinction between decision-making power and proactive initiative reveals valuable insights into organisational dynamics and cultural gaps. Survey 1 revealed that design engineers are perceived to have the most significant influence on constructability decisions, followed by project managers. At the same time, Survey 2 showed that construction teams and project managers are the primary drivers actively pushing for constructability improvements. This contrast highlights a disconnect between decision-making authority and on-the-ground initiative, suggesting that those who implement the work often lead constructability efforts, even if they lack formal influence.

3.3.4. PROJECT PHASE AND TIMING OF CONSTRUCTABILITY

In Survey 1, most practitioners agreed that constructability should span the full project lifecycle. Survey 2 asked participants to describe how their companies structure construction project phases to gain deeper insights into how this concept integrates into workflows. While answers varied slightly in terminology and granularity, a clear pattern emerged. Most describe project life cycles that align with well-known frameworks (often implicitly referencing models akin to FEP, the RIBA Plan of Work stages, or PMI process groups). For example, several broke projects into conceptual or strategic planning, design (frequently broken into sub-stages such as schematic, detailed, or even fabrication-level design),

procurement and/or mobilisation, construction or execution, and finally handover or close-out as per the client's procedure of work to follow. Some companies do not adhere to this but follow the client's request. One respondent mentioned, *"The client usually defines this, but it typically revolves around Pre-Assessment, Masterplan, Concept Design, and Detailed Design."*

As with the earlier subset, many respondents described a conventional sequence of stages: concept or feasibility, design, procurement, construction/execution, and handover or close-out. However, when responses were analysed through the lens of constructability, it became evident that not all organisations actively embed constructability considerations within or across these phases. Several participants explicitly or implicitly referenced constructability as an integrated concern. Several examples are illustrated in Figure 3.34 to provide insights. One respondent described it as an *"overarching process"* in the planning stage, influencing everything from construction methods to procurement and supply chain decisions. Another noted that constructability is considered during bidding and planning, with reassessments made during operations in response to changes or unforeseen challenges. Such responses suggest a proactive, systems-oriented approach where constructability informs decision-making across multiple phases and revisits earlier assumptions as needed. Some responses were purely descriptive, outlining stages such as *"master planning, concept design, detailed design, shop drawings,"* or *"project development, project analysis, sitewide coordination."* While most organisations appear to adopt a lifecycle framework in their phase structuring, only a subset actively aligns this framework with constructability best practices. This gap reinforces the key insight from Survey 1, as shown in Figure 3.13.

These thorough examples illustrate how constructability should ideally be a continuous thread that runs through all stages rather than a one-time checkpoint, precisely the strategy that industry frameworks support (i.e. ensuring construction input from concept through commissioning).

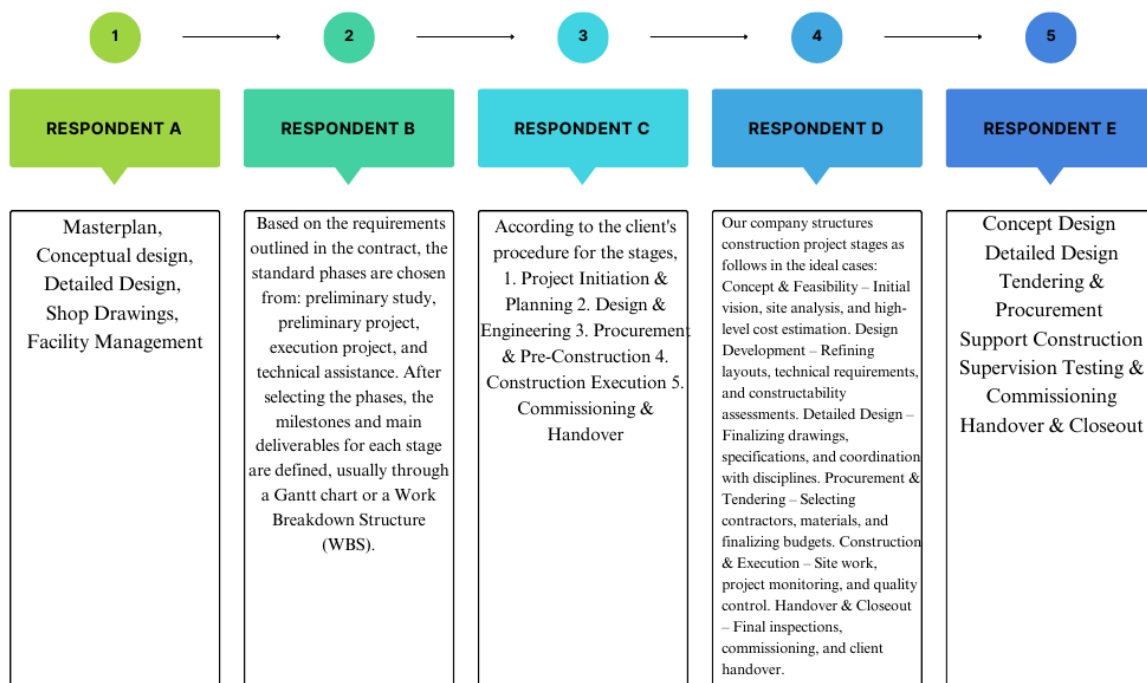


Fig. 3.34 - Illustrative Examples of Project Phase Structuring Among Respondents

Every company has its way of defining the phases of a construction project. The participants were asked to break them down. These questions invited respondents to outline their project lifecycle phases. Some responses reflected highly formalised approaches, such as aligning project phases with milestones and deliverables as defined in contractual documents (e.g., "*specifications*"), with feedback loops involving client approval before advancing to the next phase. Several broke projects into conceptual design, detailed design, tender/procurement, construction, and handover stages. A few mentioned stages are less commonly highlighted, such as viability studies, preliminary analysis, or sitewide coordination. While one respondent explicitly stated their company does not engage in construction-phase projects, and two others did not provide a substantive answer (responding "N/A"), the overall data set is robust enough to draw patterns.

Interestingly, specialised trades such as electrical services reported a dependency on the project manager's framework, underscoring the hierarchical and often discipline-specific nature of phase structuring within large multidisciplinary projects. This highlights the importance of cross-disciplinary alignment in constructability planning, a theme implied in Survey 1 and further evidenced here.

A particularly detailed response broke the execution phase down further into discrete construction activities, from site preparation and system installations to finishes and final inspections, emphasising the operational granularity often involved in complex builds. Similarly, several practitioners acknowledged sub-phases within design, such as schematic, developed, and fabrication design, reflecting how the evolving level of detail supports downstream constructability. In other words, many companies confine constructability reviews to a one-off check late in design, rather than an ongoing practice. This tendency reflects the traditional "review fallacy" identified by CII [31]: when construction personnel are invited to review designs only after they are largely complete, their input is limited to minor tweaks because significant changes at that late stage would be too costly or disruptive.

In Figure 3.35 below, some responses are mentioned and cited regarding how they defined their company structures in the context of construction project stages and phases.

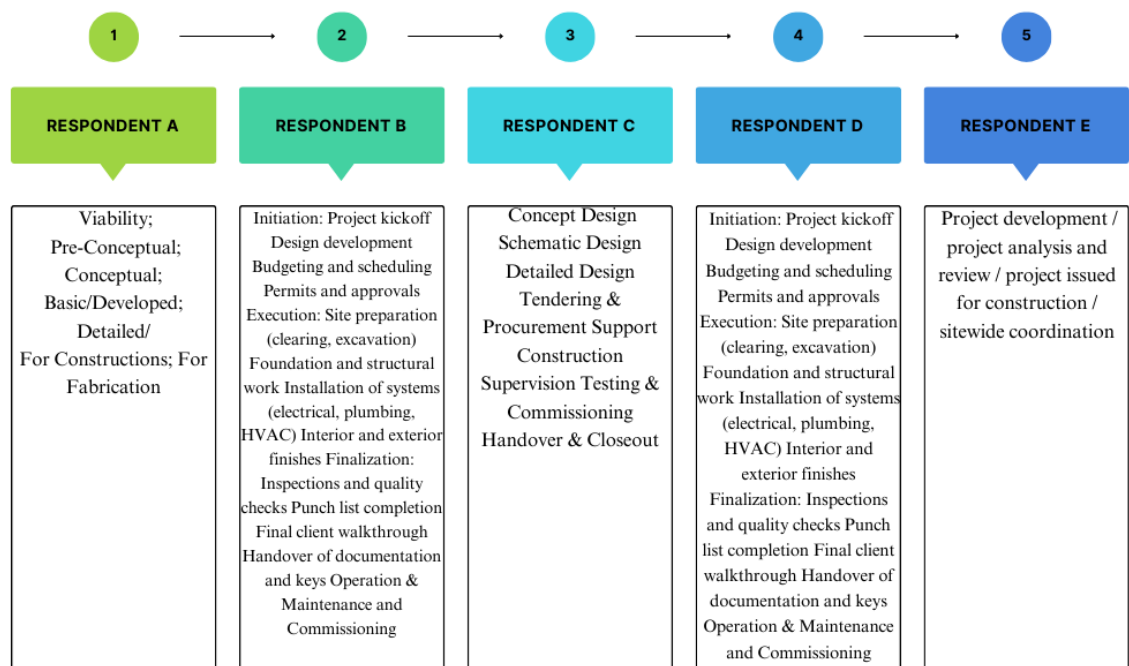


Fig. 3.35 - Detailed Descriptions of Project Phases in Respondents' Companies

However, most respondents' experiences fell short of that ideal. When explicitly asked at which project stages their company formally considers constructability, answers varied widely. A few participants indicated that constructability is reviewed during design stages (e.g., schematic or detailed design milestones) and again in pre-construction planning, aligning with the common practice of holding constructability reviews during design development. One respondent noted constructability is addressed "*from the design phase and continuously throughout procurement and construction,*" implying an integrated approach. Another stated that constructability is "*embedded in all stages,*" even if not formally singled out, with particularly intense analysis during early commercial planning.

These cases suggest that some organisations, likely those executing large or complex projects, have internalised constructability as a guiding principle across phases (even if they don't use the term explicitly at every stage). Yet, several others admitted that no formal constructability consideration occurs at any specific stage in their process. Responses like "*None of them,*" or "*constructability isn't a major concern of our workflow,*" were reported, indicating that constructability is at best an implicit and minor factor in those organisations. More commonly, respondents pinpointed a single phase where constructability is given attention, most often during the design phase (e.g. "*halfway through detailed design*" or "*after the concept design stage*").

In other words, many companies confine constructability reviews to a one-off check late in design, rather than an ongoing practice. The survey data underline that this reactive model persists. Some practitioners only see constructability addressed when design is nearly finished, which often reduces the effectiveness of any suggestions due to resistance or sunk design costs. One respondent said, "*The design was already too advanced, and changes would be costly or time-consuming,*" encapsulating the common excuse for bypassing late constructability feedback. This supports Survey 1, which indicates that constructability input should be considered at every project lifecycle stage. The divergence here is critical: while the recognised frameworks and literature call for early and continuous integration of constructability (ECI, collaborative design development, etc.), current practices in many firms still relegate constructability to a belated check or ignore it entirely. This misalignment suggests that, without organisational frameworks or client requirements enforcing constructability reviews (as, for example, some public infrastructure clients or progressive contractors do), many teams rely on ad-hoc consideration at the discretion of project managers or designers.

In response to the question, *why is constructability not considered at the stated stages (or at any other stages)?* The most recurrent reasons echoed cultural and organisational barriers: "*management doesn't recognise its importance,*" "*it's not one of the main focuses,*" or it's seen as "*irrelevant to design.*" Where constructability was overlooked, it was often due to leadership and designers prioritising other aspects (cost, aesthetics, schedule) under tight timelines, or simply due to inertia, "*never been considered so far.*" One respondent noted that their company would only consider constructability "*by client input,*" implying that unless a client contract mandates a constructability review, it might not happen. Furthermore, a lack of involvement occurs if contractors or construction experts aren't included in the planning phase and in the design phase, which was cited as a barrier in both literature and by our respondents (one complained of a "*lack of experts' involvement*" when constructability issues arise). One respondent later in the survey candidly stated that constructability is often viewed as "*an added task rather than an integral part of the process*" and that some teams "*focus more on meeting deadlines and budgets*" at the expense of constructability.

Several respondents repeatedly mentioned the lack of communication, information, and inclusion of constructability from the beginning of the project. This suggests that when constructability is omitted

from phase workflows, it is usually not due to a belief that it's unimportant, but instead due to entrenched processes that fail to incorporate it.

Shifting from current to ideal practice, respondents were asked to choose from their perspective which stages/phases should be applied where they believe constructability should be integrated. Nearly all (14 respondents) agreed that it should be applied in the Design phase, reinforcing that design is the critical window for constructability input (before decisions are locked in). Notably, many argued for even earlier integration: many selected the planning and briefing stages (often termed Strategic Definition or Master Planning & Asset Brief).

Several participants indicated that constructability should start from the beginning of a project's conceptualisation. Concurrently, about half of the respondents also believe constructability should be addressed during the Construction phase & close-out, meaning not only should it start early, but it should also continue to be considered during execution (for example, via ongoing constructability reviews or adaptability of methods). Only a few respondents considered limiting constructability to a single phase; most favoured a multi-phase application. This perspective aligns well with constructability as a continuous process throughout the project lifecycle. It demonstrates that professionals recognise the need for integration at all significant stages: from initial concept, design, and construction. As earlier answers show, the challenge is making this ideal a reality.

3.3.5. CONSTRUCTABILITY CHALLENGES

A central part of the survey explored the real-world challenges respondents encounter due to insufficient constructability and how these issues are dealt with. Most professionals acknowledged that their companies experience constructability-related issues throughout the project life cycle. When asked whether their companies encounter problems related to constructability during this period, as shown in Figure 3.36, 6 respondents answered "Yes," while 10 answered "No." To follow up, the 6 respondents were asked to describe the kind of problems or issues that are most recurrent. These problems most commonly manifest during construction execution as errors, delays, or rework that trace back to design or planning shortcomings.

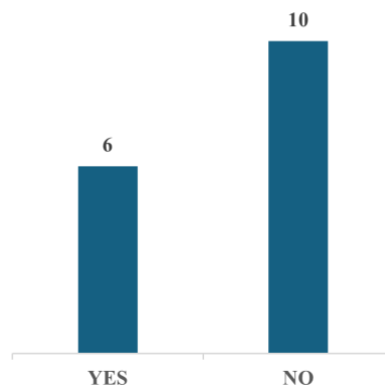


Fig. 3.36 - Respondents Reporting Constructability-Related Issues During the Project Lifecycle

For instance, one respondent described frequent “*damages or deviations that occur during construction by others*”, essentially on-site errors or changes, which they attributed to earlier planning issues. Another pointed to “*planned methods that perform poorly and need to be adapted/changed*” once in the field, meaning the construction approach envisioned during design did not work as intended under real conditions. Such occurrences align with well-documented consequences of neglecting constructability

in design: late design changes, constructability conflicts, and resultant cost/schedule overruns are classic symptoms. A recurring specific issue raised was the lack of construction expert input during design. One junior engineer lamented that many problems could be traced to a “*lack of experts’ involvement*” early on, resulting in designs that did not fully consider practical means and methods.

Other respondents highlighted economic and schedule pressures as root causes: value-engineering decisions or cost-cutting can introduce constructability problems (e.g. *choosing a cheaper design option that is harder to build*), and tight deadlines can lead to incomplete coordination of design details. In projects involving existing structures or constrained sites, unique difficulties were noted (e.g. “*ancient construction methods*” and modifications in refurbishment projects proving troublesome). These insights reinforce what the literature has identified: that constructability problems are multifaceted, ranging from technical design flaws (like inadequate detail or ignoring site logistics) to procedural and contractual issues (like fast-tracking and cost-driven changes). As summarised in Table 3.2, these problems range from on-site rework and misfitting methods to procedural errors stemming from poor design assumptions, exclusion of expert input, and deadline-driven compromises.

Table 3.2 - Constructability Problems and Underlying Causes Identified by Respondents

Observed Problems	Common Causes
On-site errors or rework	Lack of expert input during design
Poor performance of planned methods	Design assumptions not aligned with field conditions
Cost/schedule overruns	Fast-tracking, value engineering, and tight deadlines
Misfits in renovation/refurbishment projects	Overlooked site constraints or historical construction issues

When such problems arise, the respondents indicated they employ a variety of reactive solutions. Typically, the project team will analyse the issue on a case-by-case basis and convene relevant stakeholders to brainstorm a fix. One manager explained that solving unexpected constructability problems involves the “*senior project leaders*” taking charge to “*handle and resolve*” the issue, potentially mobilising subject matter experts or redesign efforts as needed. Another described a structured approach: “*assess the issue, collaborate with stakeholders, consult experts, revise the design if needed, adjust timelines/resources, and prioritise safety.*” This mirrors general problem-solving best practices and shows that when constructability issues surface, companies rely on the experience and improvisation of their teams to mitigate impacts. The fact that teams must frequently resort to late-stage design adjustments or method changes suggests earlier constructability reviews were either not performed or not effective enough.

3.3.6. DESIGN ISSUES

The survey also delved into the specific design-phase aspects of constructability. Respondents were asked whether design mistakes are identified during constructability studies and what types of mistakes are most common. Twelve participants answered “Yes,” while four said “No.” Those who answered “Yes” cited a variety of common mistakes as shown in Figure 3.37. In open responses, several key issues recurred.

- The most frequent was a lack of coordination between disciplines: five respondents mentioned problems like designs that don't align, unclear scopes, or clashes between architectural, structural, and MEP plans.
- Another frequent theme was overly complex or impractical designs: multiple answers noted that architects sometimes create “*overly complex*” or “*impractical*” solutions that are hard to build.
- Other mistakes included unrealistic construction sequences or schedules, inadequate access or logistics planning (poor site access, “huge” window designs with no maintenance consideration), and inappropriate material choices (such as specs not available locally).
- Several noted the knock-on effects: delays, rework, and cost overruns often ensue when such issues are discovered later. One cited, for example, “*Poor access planning, material conflicts, unrealistic construction sequencing, inadequate space for utilities, and structural coordination issues. Cost-related issues as well.*”
- Indeed, several participants indicated that 3D BIM models and design reviews are a primary method to vet constructability early. This allows them to visualise and spot design conflicts or impractical elements before they hit the field. This practice reflects an industry trend where constructability reviews are increasingly intertwined with BIM coordination processes.

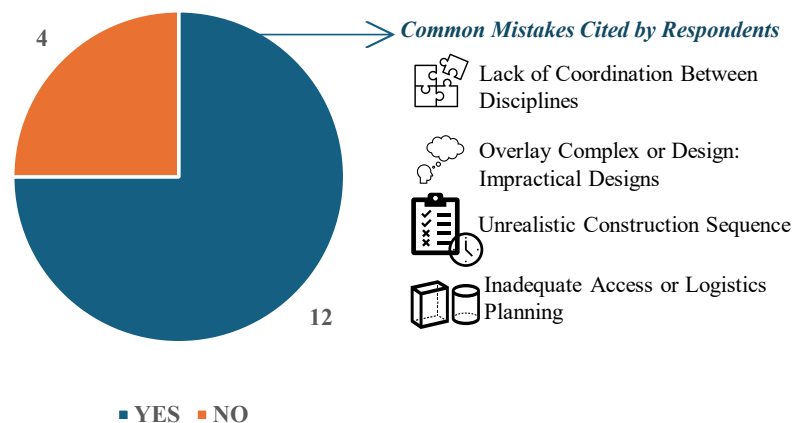


Fig. 3.37 - Respondents Acknowledging Recurrent Constructability Mistakes in Their Projects

The 4 who answered “No” indicated they do not typically find design mistakes, often stating insufficient project complexity or informally handling issues as they arise. A question was addressed to them asking “who is involved in constructability discussions during design”, revealing that in most cases, the participants are internal project stakeholders, typically the design team members (architects/engineers) and the project management team. A few respondents explicitly mentioned the “*project manager and discipline leaders,*” or “*the engineers of each speciality and the project coordinator,*” convening for constructability considerations. In some cases, the client is also involved in these discussions, as shown in Figure 3.38, especially if the client is intensely interested in ensuring a smooth project (for example, a client’s project manager might push for constructability as part of design reviews).

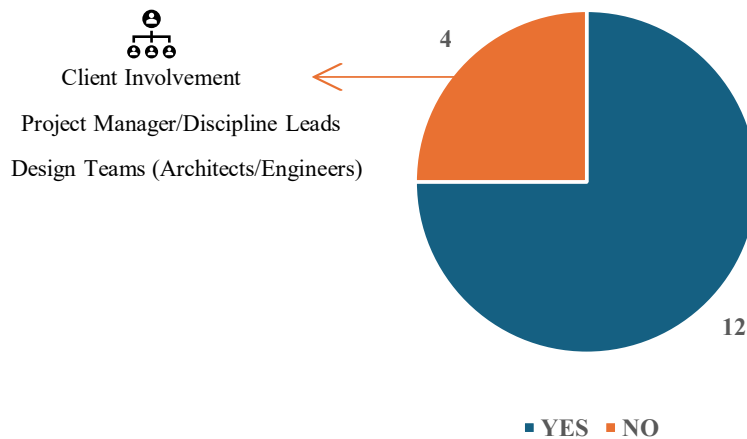


Fig. 3.38 - Respondents Indicating Absence of Recurrent Design Mistakes

Notably absent from most responses was the routine involvement of external constructors (contractors) during design. Only one or two respondents hinted at early contractor input. For instance, one mentioned “*Early Contractor Input*” as a method they try to implement early, and another indicated that in their context, the commercial/bidding phase involves a first constructability review (implying contractor involvement at the bid stage). However, according to the survey, contractor involvement in design-phase constructability is often not prevalent unless the project delivery approach (such as design-build or a two-stage tender with ECI) expressly permits it. This is a crucial result because it demonstrates that constructability for many traditional projects depends more on the client's demands or the design team's own construction expertise than it does on direct feedback from the project's builders.

Literature on ECI has demonstrated that involving contractors early can “*enhance constructability*” and yield better project outcomes. The survey responses support this: companies incorporating contractor or construction team input during design tended to report constructability as an ongoing, embedded process and faced fewer late-stage issues. In contrast, those without such integration often saw constructability as something “*we hope the contractor will handle later*”, an attitude encapsulated by the excuse “*It isn't in the designers' scope; the contractor on site should take care of it,*” reported by one respondent. This suggests a shift toward more collaborative delivery models, or at least structured interim constructability reviews (with construction expertise present) during design, is needed to improve constructability. It also ties into recognised frameworks like the PMI's emphasis on stakeholder engagement: engaging the construction stakeholder during design is crucial.

As illustrated in Figure 3.39, the ECI process involves early contractor engagement, collaborative design development, and continuous coordination practices, which respondents said contributed to smoother execution and fewer constructability problems downstream.



Fig. 3.39 - Key Strategies for Enhancing Constructability Through the Project Lifecycle

The survey highlights that during the planning and design phases, the main challenges are a lack of formal process, limited involvement of builders in design, and the persistence of design errors that could have been prevented. Participants see the value, and many say constructability “should be applied from pre-design through execution,” but their accounts of recurring issues show that current practice doesn’t always meet that ideal. This gap between knowing and doing is a focal point for discussion: while practitioners conceptually understand constructability (as evidenced by some very insightful responses and analogies), practical constraints and siloed roles hamper its full realisation.

3.3.7. CONSTRUCTABILITY IN PROCUREMENT

Procurement decisions, such as material selections, contracting strategies, and supplier choice, frequently affect constructability. When asked, and as presented in Figure 3.40, “Have you ever faced constructability issues due to procurement decisions?” 7 of 16 respondents said “Yes”, and 9 said “No.”

- The seven respondents were asked to describe the impact on cost, schedule and quality, and one respondent working on international projects shared that specific designs did not account for local market procurement limitations; for example, specifying materials or equipment that were not readily available or had extremely long lead times in that region. The result was that procurement could not meet the design requirements, forcing late design changes and project delays. This situation exemplifies a common constructability error: not adapting the design to the resources, a principle frequently emphasised in constructability best practice guides.
- Another respondent described the fallout from selecting inappropriate materials through procurement, choices that seemed acceptable on paper but were “*incompatible*” or significantly delayed deliveries. This caused extended timelines and rework, impacting both schedule and cost.
- A third described “*poor judgment in subcontracting*” as a procurement-related constructability issue, where hiring subcontractors without adequate vetting led to technical problems on site, delays, cost overruns, and even reputational damage to the contractor.

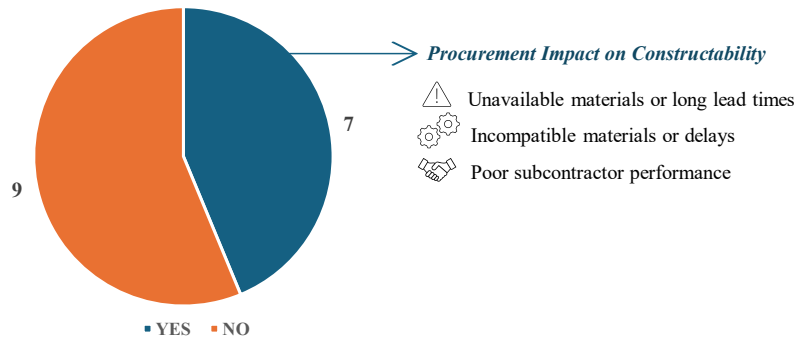


Fig. 3.40 - Respondents Indicating Constructability Issues Faced

These examples underscore that procurement is not merely a commercial process but a deeply constructability-relevant phase: decisions made in procurement can either enhance constructability (by ensuring methods and materials align with what was planned) or undermine it (if, for cost or other reasons, procurement deviates from constructability needs).

Despite the impact of procurement on constructability, few organisations have formal strategies to align the two. Those who said that they didn't face constructability issues due to procurement decisions, when asked if any procurement strategies are in place to improve constructability, out of 9, only one respondent said "Yes," and the rest said No. This suggests most companies lack formal procurement measures for buildability.

Those who implemented strategies provided a best-practice template, as shown in Figure 3.41 below:

1. They follow early material selection (choosing key materials early with constructability in mind).
2. Supplier involvement (bringing suppliers or fabricators into the discussion to ensure that what is designed can be supplied/fabricated efficiently)
3. Flexible schedules (building some buffer for critical procurement items to avoid forcing design compromises later),
4. Value engineering (continuously evaluating alternative products or methods for easier construction), and ongoing procurement monitoring to catch issues early.
5. Answers also included engaging contractors early, analysing tender alternatives, redesigning parts to accommodate available materials, and emphasising constant planning review. In one case, a respondent cited having a "company golden rule" to list such strategies.

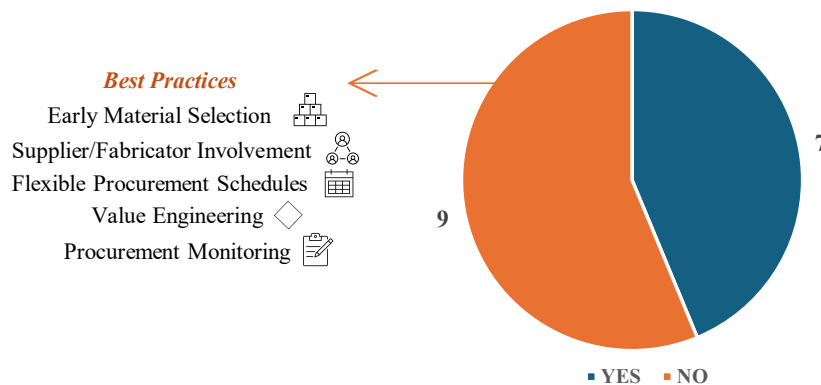


Fig. 3.41 - Respondents Indicating Best Practice Strategies

These tactics align with suggestions made in the literature for combining constructability and procurement; for instance, early procurement input is similar to ensuring that "*module/preassembly designs and material choices facilitate fabrication and installation*" and that "*designs are configured to enable efficient construction.*"

3.3.8. CONSTRUCTION PHASE

Once the project moves into the construction phase, the survey responses illuminate whether the earlier constructability planning (if any) translates to the field. A direct question was posed: "Are the construction methods developed during design-phase constructability studies maintained during construction?" The answers were split for those with such strategies: out of 8, about half said Yes, the methods and plans made during design were carried through, and half said No, typically, contractors ended up changing those methods in the field.

Conversely, those who saw methods changed on site (an open question about why contractors often change methods) cited pragmatic reasons such as local availability of materials, safety considerations, or simple time and budget pressures. For example, one noted that the pursuit of cost savings (contractors finding cheaper ways to build), material availability issues (needing to substitute methods because certain specified techniques or equipment are not available or affordable at execution time), site conditions differing from assumptions, and labour or productivity considerations (contractors might use methods that better suit their crew's skills or the available labour).

Safety concerns and improved techniques were also noted, for instance, a contractor might change a method to a safer alternative or because a new technique has since emerged. One respondent summed it up: "*Common reasons include cost, material availability, site conditions, labour efficiency, safety concerns, and improved construction techniques.*" In simpler terms, contractors will deviate from the design-phase plan if they see a more advantageous way to do the work in reality or if circumstances force their hand. Another respondent said changes are due to "*financial and deadline*" pressures; if the project is running late or over budget, contractors might innovate or shortcut on methods to catch up, regardless of the original plan. These insights align with general industry observations that even a good constructability plan can be undermined by evolving project constraints or if the plan is unrealistic.

It also reflects a potential shortcoming in some constructability studies. If contractors (who are implementation experts) were not involved in creating the plan, they may not buy into it or may have their own preferred methods once they take over. Figure 3.42 captures this contrast. On the left, Figure 3.42 shows the optimism and structure of the design phase, where construction methods are carefully documented. On the right, the reality of field execution emerges, characterised by deviations due to cost pressures, material shortages, site conditions, labour limitations, safety concerns, and evolving techniques. These visual elements reinforce the survey's finding that even well-developed plans can be reshaped by real-world constraints.

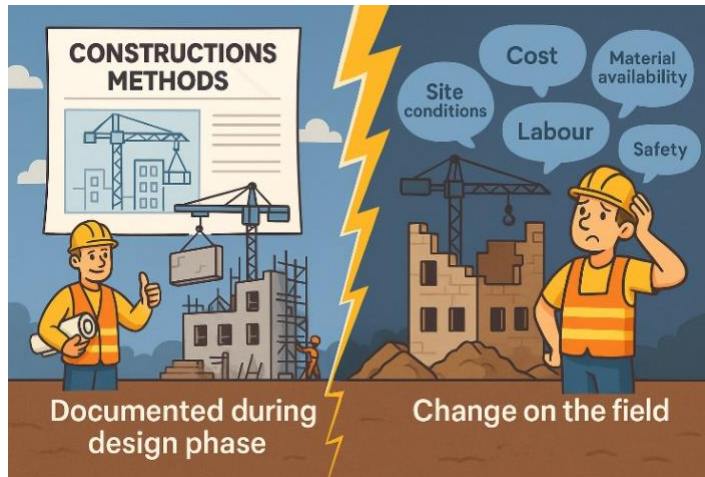


Fig. 3.42 - Design vs. Field: The Constructability Gap

Unexpected site problems also highlighted gaps. When asked, “For unexpected construction problems on-site, do you have a specific plan, guide, or team in place to address them?” 9 of 16 said “Yes”, and 7 said “No.” Respondents who had plans in place described generally ad-hoc but organised approaches. The common pattern was to analyse each issue case-by-case: one said they “*study the problem, find the root cause, and then solve it with minimum cost,*” another mentioned that “*senior leadership and company leadership provide the necessary oversight to tackle such issues,*” implying a reliance on seasoned managers to make judgment calls.

Many mentioned assembling the project team (coordinator, contractors, engineers) to reassess schedules, adjust resources, and prioritise safety. Those without formal plans admitted to solving problems reactively. In all, the procurement/materials responses show that external constraints (vendors, contracts, materials) are a source of real constructability risk: about half of respondents have faced issues, few have formal preventative strategies, and resolution usually relies on expertise and negotiation as problems arise. These descriptions highlight that problem-solving during construction is mainly reactive and heavily reliant on human expertise. This is not unexpected, even with robust constructability planning, construction is dynamic, and some surprises will occur, so having competent teams is crucial. However, the difference a formal process can make is in speed and documentation: companies that treat unexpected issues as part of their constructability program tend to document the cause and solution (turning it into a lesson learned) and have predefined roles for addressing it (which can save time).

Survey 2 procurement and construction phase analysis reveals that while constructability considerations certainly play out in these later stages (for better or worse), there is often a disjointedness due to earlier omissions. Proper procurement alignment and consistent method execution can yield the cost, schedule, and quality benefits celebrated in literature, and some respondents achieved these. Yet many had to adapt on the fly, which, while showcasing the industry’s resilience and problem-solving capability, also points to preventable inefficiencies. The findings reinforce the need for an integrated constructability approach that explicitly links design decisions with procurement reality and construction execution.

3.3.9. LESSONS LEARNED, COMMUNICATION AND REVIEW PROCESSES

When asked if the respondent's company formally documents constructability lessons learned, approximately half said their company formally documents constructability lessons learned, whereas the other half do not.

Those who do describe various mechanisms: some have an official portal or database where project teams upload lessons at the end of the project; others include constructability insights in the overall project closure reports or post-mortems. For example, one participant noted that lessons learned (including constructability-related ones) are recorded as part of the internal project closure process and stored in the project directory or a company knowledge base.

Another mentioned a *“lessons learned register, capturing challenges, solutions, and best practices for future reference.”* However, even among those who document, it wasn’t always clear if the lessons specifically feed back into future design processes; it was noted that they are archived. The respondents who said no formal documentation often skip this step. This reflects a broader industry issue: lessons learned usually go underutilised, especially constructability lessons, which might not be systematically fed into new project planning.

Another said lessons were shared on a company folder, but without context, we don’t know if they are actively referenced later. From a framework’s perspective, PMI and others emphasise the importance of lessons learned for organisational learning [30]. Many firms are missing a feedback loop that could gradually improve their constructability practices. Encouragingly, one respondent did point out that at closeout, *“a Lessons Learned process captures challenges and achievements that provide valuable lessons on what worked and what didn’t,”* and crucially, *“these will inform future constructability analyses and proposals.”* That statement exemplifies the ideal: feeding real execution insights back into FEP of subsequent projects, closing the loop in the project management framework to achieve continuous improvement in constructability.

The reaction to formal constructability review meetings also sheds light on organisational attitude. When asked how they react when a *“constructability review”* is scheduled, most respondents expressed positive or at least neutral attitudes, which is encouraging. Common reactions included being *“happy”*, *“welcoming it”*, or seeing it as an opportunity to *“discuss and learn more.”* A few even said they would respond with *“Great”* or *“Finally!”*, the latter implying they had been waiting for such a review to happen, perhaps indicating that, in their context, constructability reviews are too rare, and their scheduling comes as a relief.

One participant remarked, *“This is too early,”* which may reflect a cultural context in which constructability reviews are typically delayed, making early scheduling seem unusual. Another respondent offered a simple *“OK,”* which could be interpreted as a neutral or mildly indifferent reaction. Still, some responses pointed to profound reflections on the review's importance. For example, one participant said, *“Revise, contact stakeholders, and try to resolve.”* At the same time, another noted, *“Could be helpful to the design, and would be better to know with more time than during construction.”* These comments underscore the value of holding constructability reviews early and regularly.

Overall, no one openly dismissed the value of a constructability review; even in cultures where it’s not routine, individuals seem to recognise its importance when it does occur. This suggests that, at the personal level, professionals are generally receptive to constructability practices, but organisational habits and priorities differ, affecting how often these practices are executed. The importance of conducting constructability reviews within organisations was also emphasised in Survey 1. These reviews are crucial for establishing a well-defined management structure that can support projects and help prevent delays. Participants were previously asked about the tools they recommend, and constructability reviews were among their suggestions.

Respondents were asked to gain insights into the efficiency of constructability meetings: *“If you had to eliminate one useless discussion from constructability meetings, what would it be?”* Answers varied considerably. Two participants indicated they could not think of any (*“I don’t know”* or *“Can’t think of*

one”), while among the rest, cost-related discussions emerged as a point of criticism. Specifically, two respondents identified “Cost” or “Cost estimates” as wasteful topics. However, in complex projects, where strict client budgets must be respected, constructability is crucial in ensuring that the design and execution strategies remain within the financial parameters. Rather than being dismissed outright, cost discussions may need better focus to align with actionable outcomes rather than speculative or redundant debates.

Others highlighted vague or theoretical discussions: for instance, “*overly theoretical or vague ideas*,” especially aesthetics that don’t impact buildability, or “*subjects with minimum impact on cost/time*.” One answer was cryptic (“*Mistakes responsibility*”), and a couple touched on scope issues. The most common theme was eliminating non-actionable debate: comments like “*discussing overly theoretical ideas that have no practical feasibility*” appeared. In summary, respondents tended to single out discussions that lack direct build impact (cost debates, aesthetics, finger-pointing) as candidates for removal.

What’s the #1 thing that makes a constructability review actually useful? As presented in Figure 3.43, the responses to this question are clustered around a few critical success factors for constructability reviews.

- By far the most frequently cited factor was “*Open collaboration when people are listening and collaborating*.” Roughly 7 respondents highlighted this as the top factor. An effective constructability review, in their view, is one where stakeholders (designers, engineers, contractors, etc.) engage in honest, ego-free dialogue and truly consider each other’s input.
- The second most cited factor was having “*Hard data - real numbers, not opinions*.” About 3 respondents emphasised that bringing factual information (such as cost data, productivity rates, or evidence of past issues) makes reviews productive rather than based on conjecture.
- Two respondents each mentioned “*Early timing before designs are locked in*,” meaning a review is most useful if done early enough to influence the design (this ties back to early integration).
- Another two mentioned “*Budget saver cost reduction*,” implying that focusing on constructability changes that significantly cut cost makes a review feel valuable to stakeholders (it gets buy-in if it saves money).
- Two respondents highlighted “*A tough moderator, someone who keeps things real*,” i.e., having a facilitator or chair in the meeting who can challenge ideas, prevent side discussions, and ensure the team faces the constructability issues head-on.

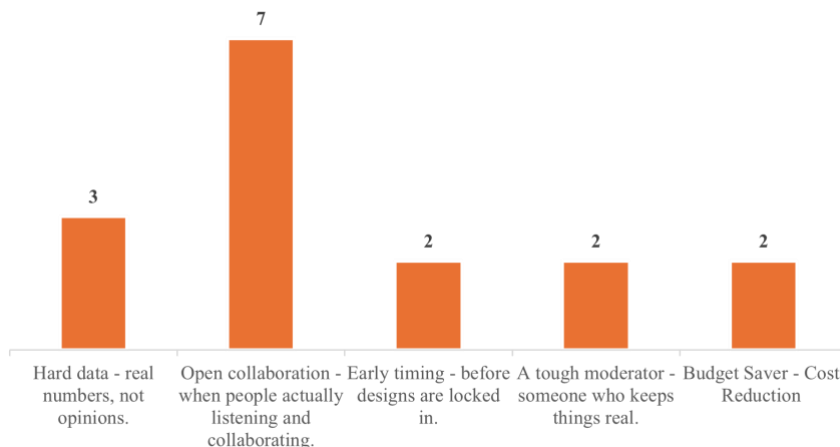


Fig. 3.43 - Factors Identified by Respondents for Effective Constructability Reviews

Synthesising these, the usefulness of a constructability review hinges on timing, data, collaboration, and leadership. The review will likely yield tangible improvements if held early, guided by evidence, with a cooperative team and a strong facilitator. These insights are reasonably practical; they match literature, which says multidisciplinary teamwork and factual analysis are key to successful constructability programs. Notably, collaboration came out on top, reinforcing that constructability is as much a social process (people working together) as a technical one.

3.3.10. DIGITAL TOOLS AND FUTURE DEVELOPMENTS IN CONSTRUCTABILITY

We probed the role of technology with both fanciful and practical questions. To introduce the topic, respondents were asked: “If you had to explain constructability to a new engineer, which tool would you use?” This question was framed to identify which educational or illustrative tools practitioners favour for conveying constructability concepts. Respondents could select multiple options from a list of tools, as shown in Figure 3.44. The most commonly chosen tools were BIM-based design reviews and checklists.

- Specifically, “*Design review BIM-based (reports and/or workshops)*” was chosen by many (by 7 responses), as was “*A checklist practical and effective*” (also by 7 responses). These two tools represent complementary approaches: BIM visualisations help see and simulate the project (making it easier to spot constructability issues), whereas checklists provide structured guidance ensuring no key aspect is forgotten.
- The following popular choices were “*Good old paper sketches I trust my brain over software*” (selected by 6), indicating that some experts still find value in hand-drawn sketches or diagrams to explain and solve constructability issues; and “*BIM: seeing is believing*” (5 responses), reinforcing the importance of 3D visualisation.
- Also mentioned by 5 respondents was “*4D simulations because time matters,*” highlighting the use of 4D (time-sequenced) models to demonstrate how a project will be built step-by-step to a new engineer.
- Only one respondent wrote in “*Dialogue is usually the most engaging tool,*” emphasising conversation and mentorship as an “other” option.

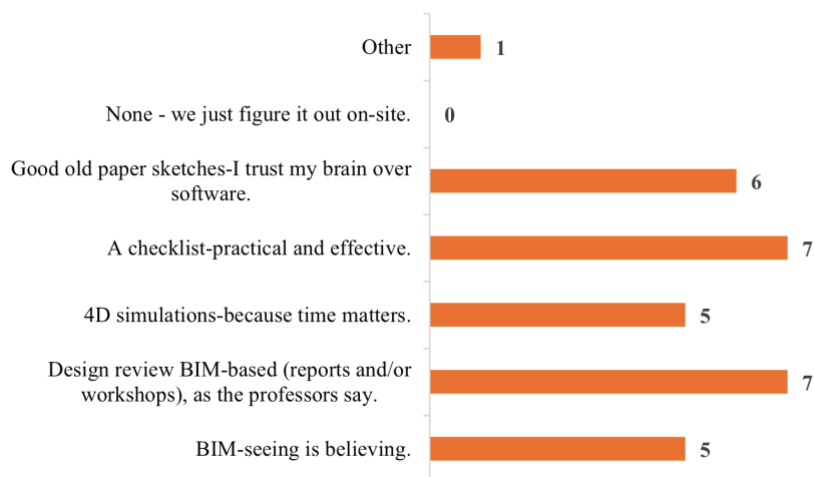


Fig. 3.44 - Tools Preferred by Respondents for Explaining Constructability to New Engineers

This mix indicates that experienced engineers still rely heavily on manual methods (sketches) to teach or communicate constructability, but many also value BIM visualisation and simulation. Notably, no one identified a perfect tool; answers suggest that multiple tools (analogue and digital) are helpful depending on context.

Which of these ‘fancy’ digital tools has actually made a difference in constructability for you? (Multiple selections allowed) This question probed the real-world impact of modern digital technologies, often touted for improving constructability. The results (visualised in Figure 3.45) show a clear winner:

- 3D visualisation through BIM solutions was chosen by 9 respondents, indicating it has significantly helped them address constructability issues.
- The second most impactful tool was 4D scheduling (time-sequenced simulations), selected 6 times, showing that the ability to simulate the construction timeline in a 3D model is highly valued for planning and detecting sequencing problems.
- Collaborative information management via BIM (common data environments, etc.) was next with 5 selections. This suggests that simply having a shared BIM platform where all disciplines can see integrated models helps uncover and resolve constructability issues (like clashes) early.
- Other tools had more modest impacts: AI-powered clash detection (3 selections) and drones for site assessment (3 selections) have helped some, but are not as universally impactful yet.
- 2 respondents selected digital twin technology, and Augmented Reality (AR)/Virtual Reality (VR) for constructability reviews by 1 respondent, indicating these are either less widely used or not as effective yet in practice for the participants.
- Interestingly, “None” was also selected by 2 respondents, meaning a couple of individuals felt that none of the high-tech tools have made a real difference for them, possibly they rely on traditional methods or have not had access to them.

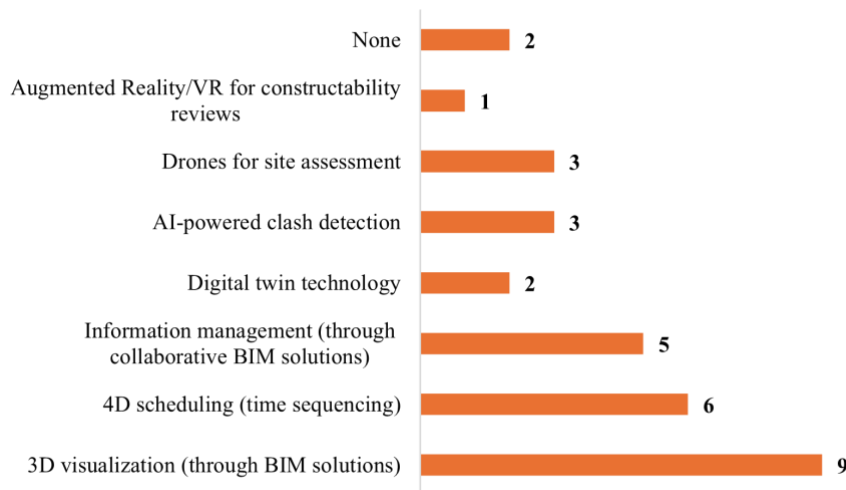


Fig. 3.45 - Digital Tools Reported to Positively Impact Constructability~

The overall takeaway is that BIM, especially 3D/4D modelling, has proven its worth in constructability, validating the industry’s investment in these technologies. Cutting-edge tools like AI and AR/VR are still emerging in impact. This informs the dissertation that while technology is a great enabler for

constructability integration (by improving visualisation and coordination), its adoption and effectiveness vary, and it complements but does not replace the need for process and collaboration.

Looking forward, respondents were imaginative about ideal tools. In the blank-check question “If I gave you a blank check to develop the perfect constructability tool, what would it do?”, many answers centred on AI and integration. For example, one respondent envisioned “*an AI-powered planner that analyses project designs, identifies potential constructability issues early, suggests alternative solutions, and automatically updates the plan/schedule.*” Others described a “*real-time 3D/4D BIM integrated with AI clash detection, enabling automated issue identification, cost and time impact analysis, and suggestions for optimisation.*” Another theme was automation and integration: the perfect tool would bring together design models, schedule, cost, procurement databases, and even lessons learned, to provide a one-stop environment for constructability analysis. Summarising these visions: the ideal constructability tool would dramatically bridge the gap between design and construction by using advanced technology (AI, simulations, data) to ensure the design is buildable, optimised, and risk-mitigated, all before ground is broken.

3.3.11. HUMAN FACTORS, MINDSETS, AND PROFESSIONAL ADVICE

Beyond the technical and procedural aspects, the survey delved into practitioners' cultural perceptions of constructability. One question asked: “Let’s be honest: what’s the biggest reason constructability isn’t taken seriously in some projects?”. Answers repeatedly pointed to a lack of knowledge or awareness and schedule/budget pressures. Many respondents said people don’t understand its importance or consider it secondary. For example, one answer was “*all those involved are not aware of its importance,*” another cited “*lack of knowledge from team members,*” and several mentioned that constructability is “*considered an added task*” rather than an integral part of work. Others blamed time pressure or tight budgets (“*Not enough time,*” “*Budget constraints,*” “*rush project*”) and conservative culture (“*we prioritise speed over thorough review*”). In short, respondents blamed a combination of cultural mindset (not valuing constructability or offloading it to others) and pragmatic excuses (schedules, budgets) for it being taken lightly. This indicates a practical gap: even when people conceptually agree that constructability matters, real-world pressures and mentalities often relegate it to an afterthought.

To probe a related mindset, we asked, “If constructability were treated as seriously as health and safety, what would change?”. The answers were optimistic, as shown in Figure 3.46: most respondents envisioned more predictable, efficient projects. Many predicted fewer surprises and delays: comments included “*fewer delays and cost overruns,*” “*smoother, safer, more cost-effective projects,*” and “*more feasible designs.*” Others pointed to better planning and coordination. One said it would require “*someone looking at it*” (analogous to a safety officer), leading to a lower probability of mistakes. Another noted higher satisfaction for all stakeholders. Respondents believed that if constructability were considered a safety issue, projects would see stronger early validation, rigorous planning, and accountability, yielding tangible improvements in time, cost, and quality.



Fig. 3.46 - Practitioners' Views on the Potential Impact of Treating Constructability Like a Safety Priority

Constructability could be better if only... (Finish the sentence!) This prompt garnered many insightful completions, and a clear consensus emerges that constructability would improve if considered earlier and with greater collaboration. The most frequent themes were early integration and stakeholder involvement.

- For instance, respondents finished the sentence with: “...*was considered during the design stages,*” “...*applied early in the project,*” and “...*done at early project stages,*” all emphasising timing.
- Collaboration came through in answers like “...*if only design teams collaborated more closely with contractors from the start to identify practical solutions,*” and “...*if everyone involved is aware of its importance and truly involved in the process.*” Another wrote “...*if it was taken more seriously by project managers,*” suggesting leadership emphasis is key.
- Resource and knowledge aspects also appeared: e.g., “...*if only there were unlimited resources,*” and “...*if only everyone had understood its meaning,*” indicating sometimes constructability is hindered by resource constraints or lack of understanding. One answer, humorously trailed off as “*First, I have to know more about that...*” underscores a point: constructability could be better if people were educated about it.

Aggregating these responses, one can say: Constructability could be better if only it were prioritised from the earliest project phases, embraced collaboratively by all stakeholders (designers, contractors, clients), and supported by organisational commitment and knowledge sharing.

The survey responses strongly validate that professionals see earlier and more integrated application of constructability as the path to better project outcomes.

We also collected candid, creative reflections. For example, on “What’s the worst constructability mistake you’ve ever seen (or had to fix)?”, the answers illustrated real failures: examples ranged from “*designs that couldn’t be built (requiring major fixes) and huge delays*” to “*wrongly chosen materials causing huge delays*” or “*designs with no plan for lifting/maintenance.*” Each answer visualised in

Figure 3.47 (15 unique ones) described an actual project calamity: e.g. a contract “*where crane requirements were not considered,*” or “*non-local materials specified that held up the project.*” These anecdotes confirm that neglecting constructability can lead to severe consequences.

Similarly, when asked to imagine a warning label for constructability, respondents chose different choices, where “warning labels” and a clear favourite emerged.

- The majority (9 respondents) chose: 🚧 “*Requires early attention, do not ignore!*” This fictional warning encapsulates a critical point: neglecting constructability is dangerous for a project. It humorously mirrors how a hazardous product might have a warning here, but the hazard ignores constructability.
- The next most common label (3 respondents) was a cautionary phrase like ⚠️ “*Handle with care, neglect at your own risk!*” which similarly implies that if you mishandle constructability (or treat it lightly), the project will suffer.
- Two respondents chose 🛑 “*Warning: May cause project delays if overlooked!*” explicitly stating the consequence (delays) of ignoring constructability.
- Interestingly, two respondents responded with a mock-confused label: ❓ “*What’s constructability again?*” This satirical label suggests that in some projects, people act like they’ve never heard of constructability, pointing to the lack of awareness or attention.

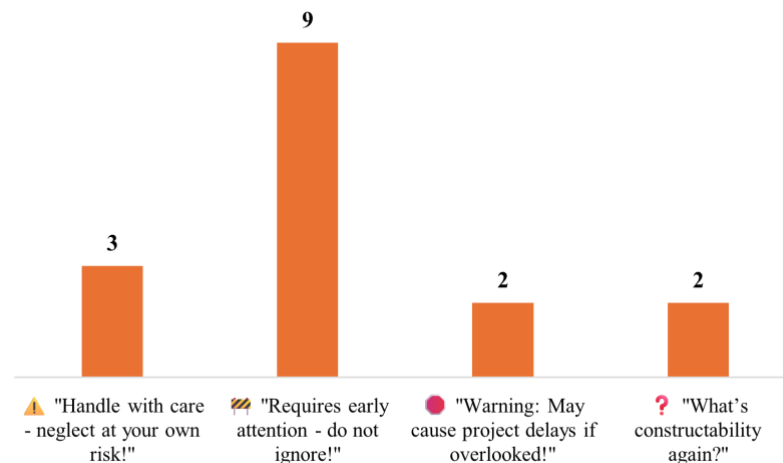


Fig. 3.47 - Fictional Warning Labels for Constructability: Respondents’ Creative Reflections

These “labels”, while humorous, strongly highlight the consensus that early and serious attention to constructability is necessary. The fact that so many independently came up with “*Requires early attention*” as a warning message underscores how pivotal timing is, echoing the serious answers given elsewhere in the survey. It also indicates a degree of frustration: if constructability came with a warning, perhaps people would pay heed to it like they do for safety warnings. This supports the notion, often made in literature, that constructability should be treated with the same rigour as safety in project management.

We also explored personality metaphors. Asked “If ‘constructability’ had a personality, what would it be?” This creative metaphor question yielded three recurring characterisations: the Detective, the Wise Old Engineer, and the Ghost, illustrated in Figure 3.48.

- By far the most popular choice (9 responses) was describing constructability as “*a detective, uncovering hidden construction risks.*” In this personification, constructability is the sleuth on the project team, diligently investigating the plans to find any clues of trouble

(risks, errors, inefficiencies) before they become big problems. This implies that respondents view constructability as an investigative process that brings problems to light (which aligns with the function of constructability reviews to identify issues).

- The second persona, mentioned by 4 respondents, was “*a wise old engineer who always warns you about mistakes.*” This presents constructability as the expert in the room, providing wise advice and caution derived from extensive experience, even if others sometimes ignore him. It suggests that constructability carries knowledge (often from past lessons) and that its advice can prevent mistakes, but perhaps it’s not always heeded by the younger or more hurried team members.
- The third persona, from 3 respondents, was more pessimistic: “*a ghost everyone knows it exists, but no one sees it in meetings.*” This ghost metaphor indicates that constructability is present in theory (everyone knows it’s an important concept), but in practice, it’s invisible; it doesn’t have a voice or presence in actual discussions. This reflects the earlier finding that the word is not used often, and sometimes there’s no dedicated person for it. The ghost image poignantly captures the integration gap: constructability’s potential influence haunts the project rather than actively participating.

These personifications, detective, wise mentor, or ghost, all shed light on how constructability is perceived as a crucial problem-finder (detective/mentor) or as an overlooked spirit. They reinforce that when given attention, constructability helps solve mysteries and impart wisdom, but when ignored, it’s like a ghost in the room with warnings unheard.

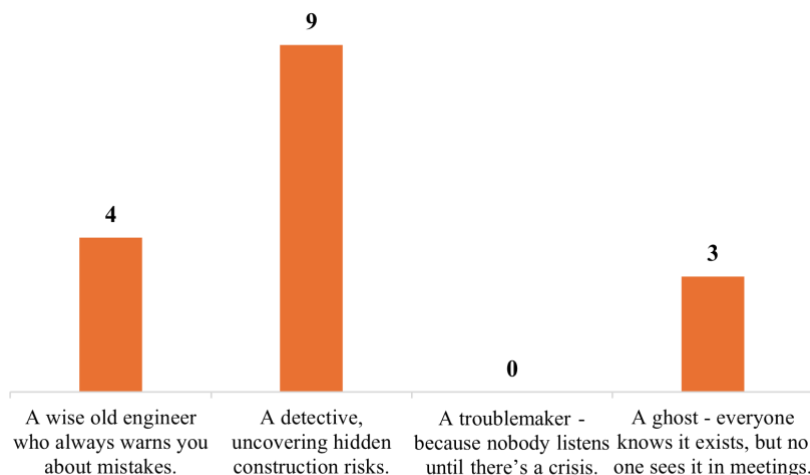


Fig. 3.48 - Respondents' Confidence in Their Ability to Explain Constructability to Others

If constructability issues were a recurring character in a TV show, they would be: Here, respondents' choices were narrative archetypes as shown in Figure 3.49.

- The top answer (9 respondents) was “*The underdog - ignored but important.*” This casts constructability issues as a character who doesn’t get attention initially (much like an underdog in a story) but ultimately proves crucial to the plot. This echoes a recurring theme: constructability concerns often don’t get the spotlight until later, when they become critical.
- Another popular answer (5 respondents) was “*The detective -revealing hidden project flaws.*” Like the previous question, this frames constructability issues as the investigator character in a drama, constantly popping up to expose something others missed.
- A few unique choices were “*The sidekick - helpful, but never the main focus,*” and “*The villain - always causing chaos.*” The sidekick analogy aligns with the idea that

constructability supports the hero (the project manager or designer), offering help but rarely getting credit or centre stage.

- The villain characterisation, mentioned by 1, frames constructability issues as the antagonists that continuously create conflict in the story (in other words, the recurring problems that the heroes must overcome each episode).

Taken together, these TV character metaphors emphasise that constructability issues have a persistent presence in project narratives: sometimes undervalued (underdog/sidekick) and sometimes only appreciated when they cause trouble (villain), but ideally, they should be like the detective who, if listened to, helps resolve the plot.

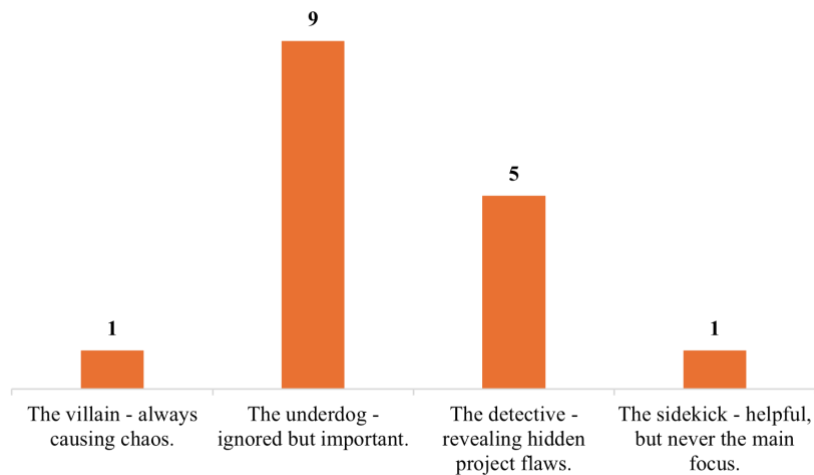


Fig. 3.49 - How Respondents Personified Constructability Issues as TV Show Characters

Practically, respondents offered straightforward advice. The “golden rule” question, “What’s your golden rule for constructability?” yielded tips like *“always think from the builder’s perspective.”*

- One wrote, *“Always design with the builder in mind,”* which concisely captures this principle.
- Many highlighted early planning and simplicity: e.g., *“Keep it simple and practical, avoid overly complicated solutions when a straightforward one works,”* and *“Plan thoroughly and consider site conditions and sequencing from day one.”*
- Involving others was another rule: *“Involve the entire project team early and often,”* emphasising multidisciplinary collaboration, and *“Know the site and local rules!”* underscoring context awareness.
- Safety and patience also appeared, with one saying *“Patience,”* hinting that rushing can undermine constructability, and another advising *“- gather information; analyse the important topics; develop a methodology,”* which is a methodical approach.
- A particularly vivid advice was: *“Imagine it being built, visualise the method, means, and timeline. See it in your mind, then challenge the design with that vision.”* This encourages newcomers to simulate construction as they work on designs mentally.
- Another put: *“Follow procedures,”* implying adherence to any constructability processes or checklists.

Collectively, these golden rules convey to new engineers that constructability is about practicality, foresight, and collaboration.

Tell me about an experience you had in which constructability saved (or ruined) a project. Here, respondents recounted narratives, which underscore the stakes of constructability.

- One positive example: a participant shared that early planning of construction crane locations on site influenced the design phasing, ultimately saving the project from major logistical issues.
- Another described how a constructability review of a complex curved glass façade at an airport identified that the proposed design would be complicated to install; by catching this early, the team was able to redesign certain elements and avoid a potentially project-ruining problem, in this case constructability saved the project from disaster by flagging an issue with “a complex façade that would have been impractical to build as originally conceived.”
- On the flip side, several recounted negative experiences where lack of constructability ruined aspects of the project: “*Problem in design, bad implementation, bad site management and scheduling caused delay and failure for some time,*” wrote one, essentially listing a cascade of constructability neglect consequences.
- Another mentioned a project part “*impossible to build, requiring a late redesign,*” a clear case of constructability issues coming too late and causing turmoil. A respondent talked about constructability being done too late in design, discovering an impossible element, and having to construct something completely differently at a higher cost.

There were also simpler admissions like “Don’t remember a good example,” or “I don’t have sufficient knowledge on this topic,” which might indicate some haven’t consciously tracked such experiences. However, the shared stories align with broader industry knowledge that early constructability efforts can pre-empt major problems (saving projects), whereas ignoring them can lead to significant delays, cost overruns, or even project failures.

Finally, about future trends (“Looking ahead, what will change most in the next 5 years?”), Opinions were split as presented in Figure 3.50. The largest group (6 respondents) predicted that AI and automation will take over constructability tasks. Another 5 respondents foresaw digital tools dominating, making manual checks obsolete. A quarter thought that the most significant change would be that constructability is planned earlier in projects. Only 1 chose “*Digital tools will make it easier to apply constructability.*” This shows some optimism that technology (especially AI) may transform constructability and hope that organisational practice will evolve (planning earlier). The diversity of answers suggests uncertainty but reflects the broader theme: respondents see either a technological leap or a shift in culture as needed to advance constructability.

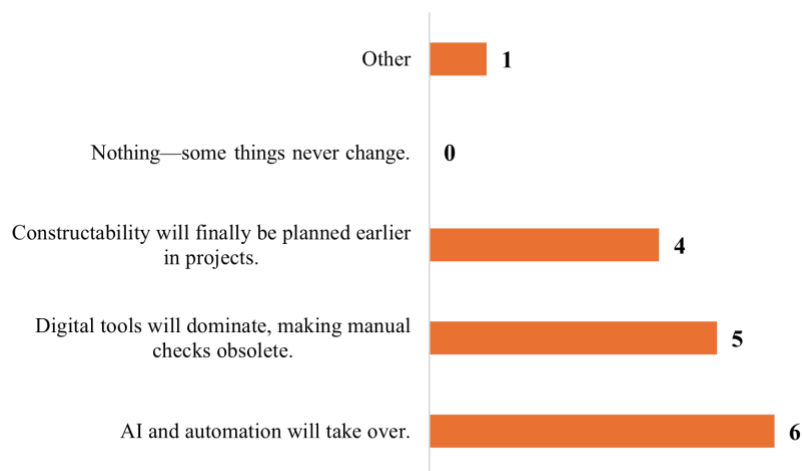


Fig. 3.50 - Respondents' Predictions on the Future of Constructability in the Next 5 Years

4

RESEARCH OUTCOME & CONCLUSIONS

4.1. A PROPOSAL FOR A CONSTRUCTABILITY-INTEGRATED CONSTRUCTION LIFECYCLE (CICL)

4.1.1. CICL'S CONCEPTS & OVERVIEW

The Constructability-Integrated Construction Lifecycle (CICL) is an approach that aims to embed constructability principles throughout all stages of a project's life cycle, from inception through design and into construction and operation. It aligns the project's design and construction processes by integrating construction knowledge at each phase, improving feasibility, efficiency, and risk management. The following subsections clarify the terminology and components of the proposed CICL framework in a formal, structured manner.

4.1.1.1. Project Lifecycle Stages Overview

The CICL framework follows a project lifecycle stage envisaged and presented in Figure 4.1, with constructability integrated at each step. Below is an overview of all lifecycle stages, each clearly defined:

- **Stage 1-Strategic Definition (SD):** The Strategic Definition Stage sets the foundation for a successful project by establishing its fundamental purpose, viability, and alignment with the client's vision. It defines the project's aims and why, forming a clear Strategic Brief that guides all future phases. It includes gathering and synthesising macroeconomic data and conducting trend and gap analyses at the regional or national level.
- **Stage 2-Master Planning & Briefing (MPB):** During this stage, the project brief is refined, and preliminary planning is performed. Site information is gathered, and constraints are identified; an initial project execution strategy, including scope, budget boundaries and schedule (often including a feasibility study), is formulated to guide the upcoming design phases.
- **Stage 3-Concept Design (CD):** The project's design concept is developed by exploring alternative solutions. Major spatial layouts, massing, and technical concepts are proposed and evaluated for constructability, ensuring that the selected concept is feasible to build and aligns with project objectives and site constraints. It allows for the preliminary distribution of assets, delineating the public realm, and identifying supporting infrastructure requirements. The concept master plan defines the development parameters and provides a spatial framework for the project in terms of architecture, structure, and sustainability.
- **Stage 4-Design (D):** This stage is divided into two substages:
 - **Stage 4A-Developed Design:** In this stage, the preferred concept is detailed across all disciplines: architecture, structure, MEP, sustainability, and special requirements. The

design is fully coordinated, and technical solutions are refined. Ongoing constructability reviews ensure that systems, materials, and interfaces remain practical and cost-effective. This stage finalises space layouts, finishes, structural systems, and equipment through schematic drawings and outline specifications. It is essential for tendering in design-bid-build projects. In design-build schemes, tendering may occur at the end of this stage or earlier, with the contractor completing the design if tendered at the concept stage.

Stage 4B-Detailed Design: The design is finalised with full technical specifications, detailed drawings, and integrated engineering systems. All coordination issues (clashes, tolerances, etc.) are resolved, and Issued-for-Construction (IFC) documents are prepared. Constructability considerations are fully integrated, meaning the design is optimised for efficient construction, and any remaining risks or uncertainties are addressed with mitigation plans.

- **Stage 5-Mobilisation & Construction (MC):** The physical building work is carried out in this stage. Construction teams execute the project according to the plans and specifications, while management processes monitor methods, safety, quality and progress. Ongoing constructability feedback is provided (e.g. through periodic buildability reviews) to ensure that any issues encountered on site are fed back and resolved in collaboration with the design team.
- **Stage 6-Commissioning, Handover & Close-out (CHC):** The completed facility is tested and verified, and the project is prepared for handover to the client or end-users. Systems commissioning is conducted (e.g. MEP systems are started up and tested), defects are rectified, and operation and maintenance documentation is finalised. The outcome is a fully functional asset handed over with all requisite certifications, manuals, and training delivered.
- **Stage 7- Use & Operation (UO):** The facility enters the operational phase after handover. Post-project evaluations (such as performance monitoring or post-occupancy reviews) may be conducted to capture feedback on how the facility performs and to identify lessons learned. Although outside the core delivery stages, this phase provides valuable data on whether early assumptions were valid and offers insights for future projects (closing the loop on constructability learnings).

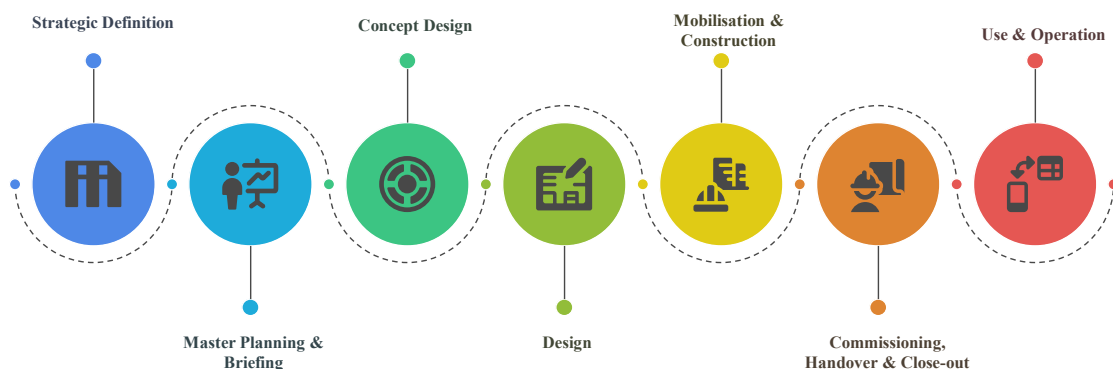


Fig. 4.1 - Project Lifecycle Stages

4.1.1.2. Key Actions and Terminology in CICL

In the CICL BPMN, two important term's structure the transition between phases:

- **Stage Kick-off:** This is the official start of a new project phase. Usually, a stage kick-off happens right after a gate decision to move forward. It is distinguished by establishing the stage's team, goals, and scope. A kick-off frequently consists of a kick-off meeting or workshop where roles are given and the strategy for the following stage is confirmed. A Stage Kick-off is held at the beginning of the Concept Design stage to set design parameters and ensure all disciplines are on the same page regarding the stage objectives. A clear mandate and a common knowledge of constructability goals initiate each phase. Figure 4.2 illustrates the process throughout the project lifecycle.

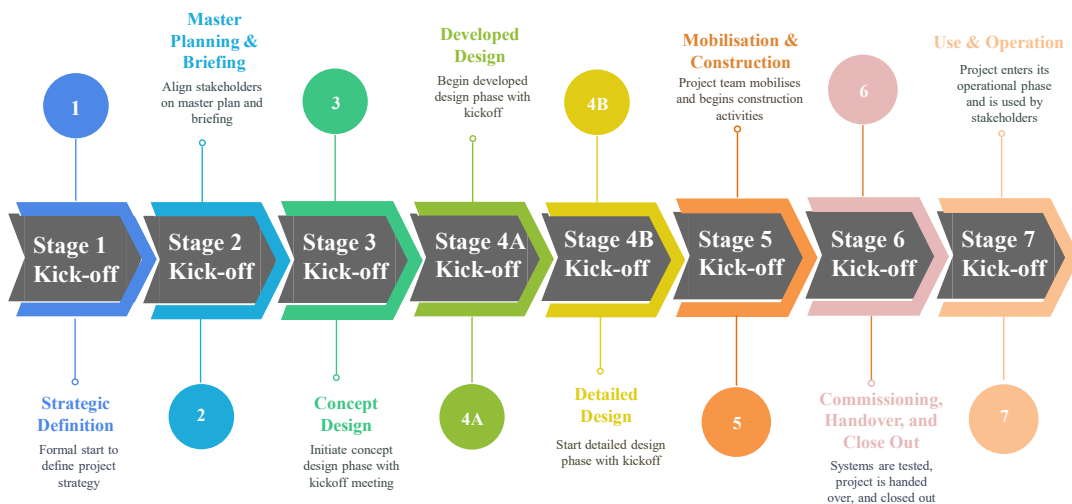


Fig. 4.2 - Project Lifecycle Stages with Kick-off Milestones Across the Construction Process

- **Stage Gate Review:** Also known as a phase gate or gateway, this is a formal checkpoint after a stage. During a Stage Gate Review, stakeholders assess whether the project stays aligned with its goals and whether the stage deliverables satisfy predetermined standards. Decisions are made about whether to move forward, make changes, or, in the worst situations, halt or end the project. Each gate ensures strict control: permission to proceed is granted only when the project is ready, and the outputs of the completed stage are verified, including constructability characteristics. Before permitting the project into Developed Design, a Stage Gate Review may verify that the Concept Design is feasible and within budget, as presented in Figure 4.3. Between phases, this gated process introduces responsibility and quality assurance.

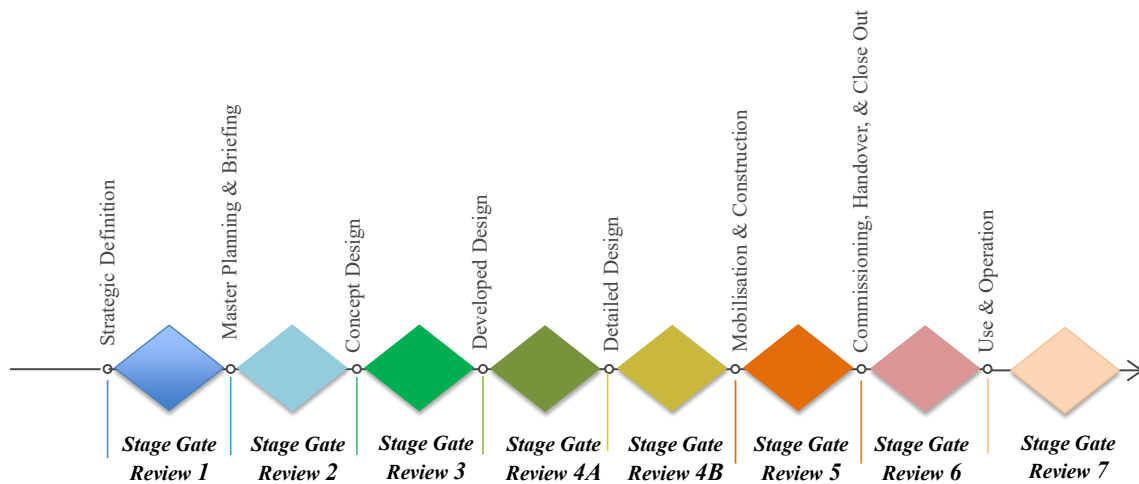


Fig. 4.3 - Construction Project Lifecycle with Stage-Gate Reviews

CICL also involves a series of recurring actions. Each key verb from the CICL process (as depicted in the BPMN diagram shown in Appendix A) is defined below in context.

- **Align:** Shows that two elements have been brought into alignment. For instance, to guarantee uniformity and agreement across all criteria, project plans or briefs align with stakeholder requirements, cost limitations, or location constraints.
- **Analyse:** Denotes an extensive examination being conducted. Data, designs, or site circumstances are analysed to comprehend the consequences for construction, cost, or feasibility (e.g., site access, utility routes, or design possibilities are studied).
- **Archive:** Signifies that documents or records are stored for long-term reference. At project close-out, all project documentation is archived in the client's repository, ensuring a formal record for future use and lessons learned.
- **Assess:** Means that conditions or requirements are evaluated. For instance, a site or a design is assessed to judge its readiness, feasibility, or completeness.
- **Assign:** Implies that tasks or responsibilities are allocated to specific parties. For example, actions or deliverables are assigned to team members (such as assigning responsibilities to a contractor or assigning corrective tasks to engineers) to establish accountability.
- **Begin:** It is used to signify the start of a period or activity. "Begin" denotes the official start of a project stage, such as the start of the construction phase, following the completion of all previous permissions.
- **Brief:** Shows that a team is formally receiving information. A team is briefed on specific plans or goals; for example, the site team is briefed on the logistics and constructability goals.
- **Close:** Denotes that a process or set of items is formally concluded. For instance, contractual and financial items are closed out at the end of the project, meaning all contracts are settled and any open issues are resolved to close the project phase or the project itself officially.
- **Complete:** Signifies that requirements finish a deliverable or task. A document or process is completed; for example, a draft planning application is completed (finalised), and the project budget is agreed upon.

- **Conduct:** Indicates that an activity is carried out or performed, often referring to meetings, tests or reviews. For example, a detailed survey or a constructability review workshop is conducted with all disciplines.
- **Confirm:** Means that something is verified or formally acknowledged as correct. For example, stage objectives or design decisions are confirmed, indicating that stakeholders have reviewed and agreed.
- **Consider:** Implies that alternatives or factors are contemplated. Design or construction options are considered (e.g., different construction methods are considered) by the team.
- **Coordinate:** Denotes elements brought into a common framework or kept in sync. For instance, design interfaces are coordinated among disciplines, meaning that architectural, structural, and MEP designs are checked and adjusted to fit together.
- **Define:** Means that parameters or boundaries are established and articulated. For example, the project scope and budget boundaries are defined early in the project.
- **Deliver:** Signifies that an item is handed over or presented to the intended recipient. For instance, documentation or a physical deliverable is delivered, including a building user guide and compliance documents, to the owner.
- **Develop:** Indicates that something is created or progressively elaborated upon. A plan, design, or baseline is developed; for example, a cost and time baseline is developed, or design drawings are developed to the next stage.
- **Engage:** Means that participants or stakeholders are actively involved. For example, the full design team is engaged in the process, implying that they are brought in to participate in discussions or reviews (e.g., engaging an early contractor in design review).
- **Establish:** Denotes that a foundation or system is set up. A procedure, methodology, or routine is established, for instance, daily management routines are established on site.
- **Execute:** Indicates that a planned task or contract is carried out. It often refers to the implementation of work according to plan; for example, construction works are executed in sequence as per the method statements, or a construction contract is executed (put into effect).
- **Finalise:** Signifies that a deliverable or process is brought to a final or approved state. For example, handover deliverables are finalised, meaning all necessary documents (as-built drawings, manuals, etc.) are completed and reviewed for handover. This term is used when something undergoes final adjustments or approvals, indicating it is ready for closure or delivery.
- **Freeze:** Indicates that a particular aspect is locked and no further changes are allowed.
- **Hold:** In this context, a meeting or session is convened. For example, a cross-disciplinary design review or weekly coordination meetings are held during construction.
- **Identify:** Means that specific items are recognised or pinpointed. For instance, high-risk constructability issues are identified early in design, or critical constraints are identified during planning.
- **Implement:** Denotes that a plan or procedure is put into practice. For example, control routines or corrective measures are implemented on-site.
- **Include:** Indicates that a person, group, or element is part of something. For example, the cost planner and constructability coordinator are included in the design team. This ensures that their expertise is part of the process.
- **Initiate:** Means to formally start or launch a process or phase. For instance, a planning phase is initiated after approval, or the commissioning stage is initiated once construction is substantially complete. Using initiate indicates an official commencement, the action or

phase is kicked off according to the project's governance (often following a stage-gate decision to proceed).

- **Integrate:** Denotes that one element is combined with or incorporated into another. In the CICL context, constructability insights are integrated into project deliverables, meaning constructability considerations (risks, opportunities, best practices) are woven into planning documents, design decisions, or schedules.
- **Issue:** Means formally releasing or submitting something, typically a document or request. For instance, if a design clarification is needed, an RFI is issued to the design team, or a Practical Completion Certificate is issued at project completion.
- **Mobilise:** Refers to preparing and deploying the necessary workforce, equipment, and resources to the site. When the construction stage begins, the site team and subcontractors are mobilised.
- **Monitor:** Means to observe and check the progress or quality of something over time. For example, compliance with method statements is monitored daily, and any deviations are noted.
- **Obtain:** Indicates that something is acquired or secured from another party. For instance, the FM representative obtains a sign-off at handover.
- **Perform:** Denotes that tasks or activities are carried out as instructed. For example, construction tasks (groundworks, structure, MEP installations, etc.) are performed according to the plan.
- **Prepare:** Means to produce or set something up in advance. Documents or materials are prepared; for instance, testing documentation is prepared before commissioning, or a site setup plan is prepared during mobilisation.
- **Provide:** Denotes that something is supplied or made available. For instance, support documentation (warranties, procedures, manuals) is provided to the end users and the facilities team.
- **Rank:** Means that options or alternatives are ordered based on set criteria. For example, design options might be ranked using constructability and cost criteria.
- **Record:** Means that information or data is documented for the official log. For example, test results are recorded and defects are tagged during commissioning.
- **Release:** In the context of CICL, release refers to the action where financial securities or contractual hold-backs are formally let go after all obligations are met.
- **Review:** Denotes that an examination or critique is performed on a deliverable or situation. For instance, a long-lead procurement strategy is reviewed, or design documents undergo constructability review.
- **Select:** Indicates that a choice is made among alternatives. For example, a preferred design option is selected because it offers the highest feasibility and strategic fit.
- **Submit:** Means that a document or deliverable is formally sent for approval or record. For instance, weekly progress and constructability reports are submitted to project management.
- **Track:** Denotes that ongoing progress is measured against a plan. For instance, construction progress is tracked against the baseline program; this means data on completed work is collected and compared with scheduled milestones.
- **Update:** An existing document or plan is revised with new information. For example, a risk register is updated with constructability inputs, or a 3D coordination model is updated after clash detection.

- **Validate:** Denotes that an item is checked for correctness or compliance through analysis or testing. For example, a project brief is validated to meet client requirements, or material deliveries are validated against the planned sequence.
- **Verify:** Similar to validate, it means to confirm the truth or completion of something, often through inspection or evidence. For example, close-out documentation and punch lists are verified at the end of construction, confirming that all required tasks are completed and all issues resolved.
- **Walkthrough:** Refers to an on-site review conducted by physically walking through the work area. In CICL, a walkthrough is performed to visually inspect and demonstrate that the constructed facility aligns with operational needs and familiarise stakeholders (like facility managers or owners) with the installation.

4.1.1.3. Constructability Workshops Across the Project Lifecycle

A consolidated overview of constructability workshops is presented in Figure 4.4 below. It captures the typical inputs, tools & techniques, and outputs that characterise constructability workshops throughout the project lifecycle (from early planning to project handover).

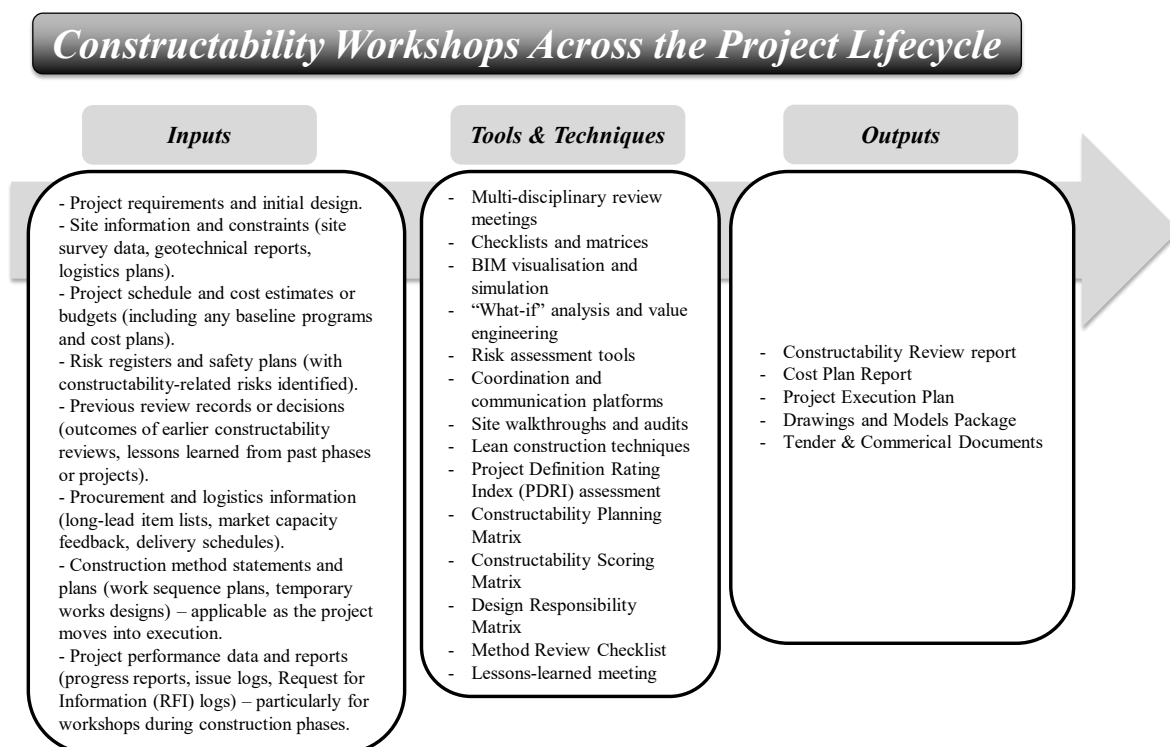


Fig. 4.4 - Constructability Workshops Across the Project Lifecycle: Inputs, Tools & Techniques, and Outputs

4.1.2. BUSINESS PROCESS MODEL AND NOTATION (BPMN) OF CICL

Business process mapping can be done using a standardised graphical language called Business Process Model and Notation (BPMN) [99]. It creates understandable process diagrams for all stakeholders using symbols resembling flowcharts, such as events, activities, gates, and swimlanes [99]. BPMN removes uncertainty from process descriptions and assists teams in coming to a consensus on "who does what, when" in a complicated workflow by graphically representing the order of actions and decision points.

BPMN functions as a process blueprint in construction project lifecycles, outlining each project phase, essential decisions and activities, and participant interactions in a single integrated model [99]. In a field where projects are drawn out, complex, and entail numerous disciplines, this offers the following advantages:

- **Clarity and Communication:** When discussing the project process, owners, designers, contractors, and managers can use a single language thanks to a BPMN diagram [99]. For instance, it is possible to visualise the complete building lifespan from early design to handover, allowing all stakeholders to see how their contributions fit into the overall scheme of things.
- **Better Planning and Constructability:** Organisations can examine and enhance their project delivery process by using decision gateways to map the project as a sequence of steps [99]. For example, incorporating an early constructability assessment assignment into the design phase guarantees that possible build concerns are identified when making modifications is simpler and less expensive.
- **Engagement of Stakeholders:** BPMN's graphical format promotes involvement. Clients and contractors can align expectations by going through the BPMN lifecycle diagram together during the early stages of project preparation. Roles are defined, and scope gaps or overlaps are avoided by clearly defining tasks for each swimlane (e.g., "Design Team," "Contractor"). In addition to capturing institutional knowledge for upcoming projects, the visual workflow facilitates process training for new team members [99].
- **Lifecycle Feedback and Improvement:** BPMN's support for feedback loops is arguably its most significant feature. It depicts iterative flows and information loops while modelling a project's linear progression. Lessons from later phases (building, commissioning, and operation) are incorporated into earlier stages of subsequent projects in a constructability-integrated lifecycle.

Each stage corresponds to a typical project phase (from strategic inception to operation) and describes its purpose, main activities/decisions, constructability measures, key tools/templates, outputs, stakeholders, and how feedback or lessons learned are captured. This structured approach aligns with standard frameworks (such as PMI process groups and RIBA plan of work stages) but with an enhanced focus on constructability and collaboration at every step.

4.1.2.1. Contextual Flexibility in Project Delivery

The BPMN model presented here is intended as a comprehensive baseline. In practice, however, the workflow must be tailored to each project's context and delivery approach. Key factors that may require adjustments include:

- **Project Delivery Model:** Different delivery methods alter the workflow. For instance, a traditional Design-Bid-Build (DBB) sequence enforces a clear separation between design and construction phases (with a discrete bidding step and separate contractors). In contrast, a Design-Build (DB) or Public-Private Partnership (PPP) approach integrates design and construction under one contract, often involving early contractor input. In DBB, the BPMN should explicitly show a handover from design to construction; DB or PPP should show merged roles and parallel processes for design and construction activities.
- **Contract/Procurement Type:** The contract structure (lump sum, cost-plus, EPC, etc.) affects risk allocation and decision points. For example, an Engineering-Procurement-Construction (EPC) contract may shorten approval cycles by bundling procurement with

execution, while a unit-price contract may trigger more detailed early estimating and scheduling steps. Each contract form may add or remove specific gateways or tasks (such as detailed bid evaluation in DBB or joint review workshops in PPP).

- **Stakeholder Structure and Ownership:** Projects with many stakeholders (e.g. government projects, urban developments, or community-backed initiatives) often require extra review and consultation loops. Public-sector ownership typically brings regulatory approvals, public consultation meetings, or oversight committees that must be reflected in the process (e.g. adding a “Regulatory Review” swimlane or gate). In contrast, purely private projects may streamline these steps.

The BPMN diagram should be treated as a template. Project teams should customise swimlanes, tasks, and gateways to match their specific organisational chart, decision-makers, and legal requirements. Although the generic model covers most cases, practitioners are encouraged to add or omit elements (e.g. extra milestone reviews or parallel tracks) to fit the project’s delivery method, contract terms, and stakeholder environment.

4.1.2.2. Strategic Definition (SD)

In the SD stage, the project is defined at the highest level and foundational decisions are made. The BPMN model, presented in Appendix A, shows this stage beginning with tasks such as Define Business Objectives and Strategic Requirements, which means the project’s purpose and value proposition are formally documented. One necessary process here is the Conduct Feasibility Study, which is critical because it evaluates whether the project objectives can likely be met given the site conditions, budget, and timeline.

Feasibility studies are a central component of this stage. These include a preliminary business case analysing the financial and technical viability of the project, supported by early cost estimates and a review of possible funding or procurement methods. A parallel site feasibility study identifies potential risks, such as access restrictions or geotechnical issues, that could impact constructability. Importantly, constructability constraints are identified and documented early, such as limited crane access or the potential need for off-site fabrication, allowing these issues to inform design and delivery strategies from the beginning.

A Constructability Kick-off Workshop (Workshop #1) is conducted, which is a pivotal process, bringing together the core team, including client representatives, designers, cost planners, contractor, and regulatory stakeholders, to align on early constructability issues. The workshop covers site access, major construction challenges, delivery strategy, sustainability targets, security, safety, vision, lessons learned from previous projects, etc. Key outputs include a customised Constructability Matrix or Checklist, and a Lessons Learned log that captures insights from similar past developments to avoid repeating known issues. After each workshop/meeting, Minutes of the Meeting (MOM) should be taken to enhance and provide insight into the success and track throughout the project.

This identifies initial risks and opportunities related to building the project. By the end of SD, key deliverables (strategic brief, business case, initial risk register) are produced and a Stage-Gate 1: Strategic Definition Review is carried out. A diamond indicating a decision point represents this gate in the BPMN. A go-ahead (proceed) at Gate 1 implies that the project’s strategic premise is sound, and the team may advance to a detailed briefing. A detailed breakdown of the Strategic Definition Stage, including its objectives, activities, constructability integration, tools, and key deliverables, is provided in Appendix A.

4.1.2.3. Master Planning & Briefing Stage (MPB)

During the MPB stage, illustrated in Appendix A, the project requirements are developed into a clear brief, and preliminary planning is performed. The BPMN swimlanes show intensive activity by the project management and design teams here. For example, tasks like Develop Initial Project Brief, undertake feasibility study and Identify & Prepare Planning Program, Legal, Environmental Constraints appear in the diagram. These indicate that the stage involves documenting the client's requirements and surveying all external constraints. A critical process in this stage is the Stage 1 Workshop: Planning & Site Strategy (noted in the BPMN as Workshop #2). This workshop is crucial because it aligns the project brief with site-specific constructability considerations. The BPMN notes using a "Custom Constructability Planning Matrix" and "Cost Matrix", an essential tool that underscores the structured approach. The outcome is an updated project brief and a preliminary execution plan. Stakeholder engagement intensifies during this stage. Client priorities, planning authority concerns, community inputs, and specialist consultant requirements (e.g. sustainability, security) are gathered to inform the design and brief.

Note: In practice, MPB & CD overlap rather than being strictly sequential. Early conceptual sketches may expose site challenges (e.g. access or utility conflicts) that feed back into the master plan. Conversely, detailed site information or stakeholder feedback from master planning can refine the emerging design concept. BPMN can show this iterative interplay; indeed, one of its strengths is depicting feedback loops and iterative flows. Some teams even illustrate a dotted-line "osmosis" between the MPB & CD stages to emphasise their fluid boundary. The key point is that insights from one phase can inform the other continuously, ensuring the final concept is both visionary and feasible.

Throughout the BPMN for Stage 1, activities feed into a Validate Project Brief task (ensuring the brief reflects feasible solutions), before proceeding to Stage-Gate 2: Initial Brief & Planning Review. That stage gate, shown in the diagram, checks that the planning phase deliverables (the brief, feasibility study, baseline estimates, etc.) are acceptable and that any major constructability issues (e.g. site access or site logistics strategy) have been addressed. Successfully passing Gate 2 signifies that the concept design stage can start with a well-founded and agreed-upon brief.

4.1.2.4. Concept Design (CD)

The CD stage, shown in Appendix A, develops an integrated architectural and engineering solution based on the approved master plan and project brief. Its core aim is to define how the project will look, function, and perform, while remaining feasible in cost and technical delivery. Architects shape spatial layouts through preliminary drawings and sketches, while engineers (structural, mechanical, electrical) define high-level systems such as structural frames, MEP routes, and plant room locations. Throughout this phase, the team conducts internal constructability self-checks, assessing aspects like standardisation, construction sequencing, and logistics to ensure early constructability alignment.

A crucial enhancement during this stage is ECI. Contractors contribute real-world insight by testing the evolving design's feasibility, developing logistics plans, identifying site access challenges (e.g. crane access, material laydown zones), and analysing build time and complexity. Design optioneering is performed collaboratively, key system alternatives such as precast vs. cast-in-place structures or stick-built vs. unitised façades are evaluated for cost, speed, and constructability, ensuring optimal decisions.

BIM supports this stage with 3D coordination and 4D simulations, allowing early detection of clashes or sequencing issues. Constructability is kept central through regular multidisciplinary meetings, with continuous contractor input. A major milestone is Workshop #3: Concept Design Buildability Review,

where all stakeholders, including Health , Safety & Environment Engineer (HSE) and cost advisors, assess the concept's compliance with site, method, and buildability constraints using a Constructability Scoring Matrix.

The team establishes milestone submission points to maintain clarity and client confidence, which are formal approval stages for deliverables like updated drawings, cost plans, and risk registers. These checkpoints enhance transparency, but are always followed by cross-disciplinary coordination meetings. These ensure shared understanding of milestone outputs and allow adjustments before proceeding, keeping the project context-aware and constructible.

VE is actively pursued during CD and is led jointly by design and construction teams. The goal is to enhance constructability/buildability and reduce costs without compromising performance. Safety-in-design is embedded through structured reviews of edge protection, access, and maintenance needs.

The stage concludes with several formal outputs: a Concept Design Report, outline specifications, an updated cost plan and schedule, and a documented constructability review. The Project Definition Rating Index (PDRI) is reassessed to track progress and reduce scope uncertainty. The final Gate 3 Review allows the client to approve the concept based on strategic, financial, and scheduling criteria, clearing the way for the Developed Design phase with a well-coordinated, buildable, and client-approved concept.

4.1.2.5. Design (D)

Developed Design

The Developed Design stage is when the approved concept is expanded into a coordinated design with all major systems and dimensions resolved. The BPMN diagram for Stage 3, presented in Appendix A, shows a Stage Kickoff where the team reviews the client requirements and the approved concept, confirming stage objectives and scope. Consistent terminology is used: tasks like Review Client Requirements & Approved Concept, Confirm Stage Objectives, and Coordination Requirements are present, indicating a thorough alignment at the start of the stage. One important process in this stage is the Multidisciplinary Design Coordination & Constructability Workshop (labelled Conduct Stage Workshop with all disciplines in the diagram). This is critical because, in developed design, multiple specialist designs (architecture, structural, MEP, ECI, cost estimator, etc.) must interface correctly.

The BPMN illustrates tasks such as engaging the whole design team / subconsultants and establishing coordination methodology (BIM level, data exchange protocols), which sets the stage for effective collaboration. During the workshop (often denoted as Workshop #4A in the model), representatives of each discipline and construction (including the constructability lead and cost estimator) jointly review the evolving design. According to the BPMN notes, focus areas include layout buildability, sequencing impacts, access and safety considerations, and early value engineering opportunities.

This process is essential to catch any interdisciplinary clashes or impractical design features while there is still time to adjust. A Preliminary Cost Plan Update task is also indicated, meaning cost and constructability feedback are integrated. Gate 4A (Developed Design Evaluation) checks that the design is sufficiently developed and coordinated, and crucially, it is buildable and within budget before detailed design proceeds. Passing this gate implies that all disciplines and contractors are comfortable with the design foundations.

Detailed Design

The Detailed Design stage converts the developed design into a fully documented set of construction instructions. The aim is to produce comprehensive construction documentation, including fully coordinated IFC drawings, technical specifications, and schedules for procurement and execution. Architects develop detailed floor plans with annotations, sections with construction detailing, and schedules for doors, finishes, and room data. Engineers finalise reinforcement layouts, steel connections, duct and pipe routing, and cable runs. Coordination checks are heightened, especially in congested areas like plant rooms or ceiling voids, ensuring all trades can install their systems without conflict. The BIM model reaches a high level of development and is suitable for fabrication and sequencing simulations.

Constructability remains a core focus, with the construction team reviewing package breakdowns, construction tolerances, and method compatibility. IFC drawings are structured around procurement packages (e.g. steel, façade, MEP) to align with contractor scope divisions. Preconstruction method statements are validated against the final design, and any remaining constructability issues are resolved. Workshop #4B, Detailed Design Constructability Review, ensures the final design is optimised for safety, efficiency, and cost. Market engagement (e.g. with suppliers and subcontractors) provides materials and methods that align with local capabilities and procurement realities. Quality and safety plans are finalised, with inspection/test points in the specifications and design notes. A detailed breakdown of the stage is provided in the Appendix A.

Specialist feedback (e.g. steel fabricators, façade subcontractors) is solicited for critical components, and late-stage constructability tools such as a Constructability Cost Interface Matrix and Market Alignment Report are used to confirm readiness. The design team ensures that access for construction, future maintenance, and safety compliance is adequately addressed in the documentation. A final constructability checklist is completed, and a detailed 4D simulation may be prepared using the IFC model to validate sequencing and communicate plans to site teams.

As Appendix A describes, key outputs include the complete IFC drawing and specification set, the final cost plan and Bill of Quantities, procurement package documents, and a suite of risk, logistics, and constructability reports, etc. Approvals and permits are also obtained at this stage. A Gate 4B: Detailed Design & IFC Review is held to ensure the project is shovel-ready. Approval confirms the design is fully coordinated, constructible, and ready for mobilisation and execution.

4.1.2.6. Mobilisation & Construction Stage (MC)

The MC stage, shown in Appendix A, is where the project is built on site. In the BPMN diagram, Stage 5 typically starts with a Stage Kick-off condition, such as IFC Drawings approved, and site mobilised (the model mentions “IFC Drawings Approved and ...” as a prerequisite to begin construction). Once construction is underway, the BPMN outlines the execution and the monitoring processes. Key tasks in the construction swimlane include Execute Works in Sequence (groundworks, structure, MEP, etc.) and Track Construction Progress against Method Statements. These indicate that the project is built in sub-steps (substructure, superstructure, services, finishes listed in the model) and that progress is continuously compared to the plan.

As the BPMN highlights, the Last Planner System (LPS) is employed as a lean planning and control approach tool. LPS is a collaborative scheduling system where the site foremen and crew (“last planners”) participate in rolling lookahead planning and weekly work plan meetings. In lookahead sessions, the team breaks the work into a six-week horizon (or as appropriate). It identifies constraints, such as missing materials, incomplete drawings, or pending permits, that could impede each upcoming

task. These constraints are removed in advance to ensure that when the weekly plan is set, each task has all its prerequisites. Weekly work planning meeting then confirms the short-term schedule and commitments for the coming week, with the goal that nearly all promised tasks can be completed on time. LPS creates a tight feedback loop between construction and planning: issues discovered during lookahead or weekly planning (for example, a last-minute design clash on-site) are immediately communicated to designers or procurement to resolve. This continuous feedback helps improve constructability in real time. For instance, if a field crew reports that a detail is difficult to install, the design team can clarify or adjust before that problem propagates. By stabilising workflow and ensuring tasks are ready to go, LPS embeds ongoing constructability checks into execution.

Ultimately, the construction stage in the BPMN concludes when the physical works are complete. This is marked by Stage-Gate 5: Physical Completion Review. At Gate 5, the model assesses readiness for the next phase (testing & commissioning), verifying all major work is done, QA/QC documentation is in order, and no open constructability issues remain. Only upon passing this gate does the project transition into commissioning and handover.

4.1.2.7. Commissioning, Handover & Close-Out Stage (CHC)

The CHC stage involves testing the constructed facility, training end-users, and closing out the project. In the BPMN, Stage 6 begins with a condition akin to Major Works Complete and site cleared for commissioning (the Stage Kick-off for this phase). The model then delineates tasks needed to hand over the project safely. Some tasks shown are Review Commissioning Schedule and Protocols, Assign Responsibilities (Commissioning Agent, etc.), Execute System Testing & Integration, and Validate Interoperability of systems. These reflect a systematic approach to commissioning, ensuring each system (MEP, fire safety, etc.) is started up and operates as intended.

A highlighted process, presented in Appendix A, is the Constructability Lessons Learned Workshop (Workshop #6, labelled “Lessons Learned / Handover” in the BPMN). This is critical because it loops back on the entire project and captures what went well or poorly from a constructability perspective. This workshop involves key stakeholders in the BPMN, including the client/owner, PM, contractor, FM, and constructability lead. This process is essential because it enables continuous improvement: the model explicitly notes the purpose of identifying design or building issues that affect performance, capturing improvement opportunities for future projects, and closing the loop on early constructability assumptions. Essentially, the team evaluates if the early constructability planning was accurate and what unexpected challenges emerged, so those lessons can be fed into organisational knowledge (the BPMN might depict this as an output going to a corporate lessons learned repository). Additionally, during Stage 6, there are numerous handover tasks charted: for example, Finalise Handover Deliverables, Prepare As-Built Drawings and O&M Manuals, Deliver On-site demonstrations and training, and Obtain Handover Sign-off from FM. These ensure the client’s facilities management team receives all documentation and is ready to operate the facility.

When complete, the BPMN likely uses document symbols and an end-of-phase marker to represent these deliverables. The stage ends with Stage-Gate 6: Official Project Closure (the diagram references a Gate 6 decision for project closure). Passing this gate means the project is formally closed, all deliverables have been accepted, and the project team can be disbanded. Including the lessons-learned workshop as part of closure is an enhancement over standard practice, ensuring that constructability insights are not lost.

4.1.2.8. Use & Operation Stage (UO)

The UO stage, detailed in Appendix A, represents the operational life of the facility post-handover, with early focus on performance monitoring, user feedback, and final defect resolution. The FM team assumes control, applying maintenance schedules from O&M manuals and managing building systems. Construction-related issues are tracked in a Defects Log and rectified by the contractor. The FM team monitors system performance, energy use, air quality, and occupant comfort and compares it against design expectations. Performance shortfalls prompt adjustments or investigations into potential design or construction causes.

Post Occupancy Evaluation (POE) is conducted to gather feedback from occupants and assess how well the building meets its intended purpose. Issues of comfort, usability, and maintainability are noted. For instance, if accessing a filter for maintenance is difficult, it may be logged as a design-for-maintenance issue. Operational lessons are compiled and compared to assumptions made during early constructability planning. Data analytics from innovative systems may reveal further insights, such as energy overconsumption due to HVAC settings or occupancy patterns not matching predictions.

As illustrated in Appendix A, Key deliverables in this stage include the POE Report, Defects Liability Closure Report, FM Performance Logs, and a final Lessons Learned Document incorporating operational feedback. Knowledge transfer processes ensure insights are fed into future projects via internal databases, updated design standards, or debriefing workshops. While the formal project concludes, the long-term value of constructability integration is validated in how efficiently the building operates, how few issues arise, and how well the design serves users over time.

4.2. CONCLUSION & FUTURE RESEARCH

This dissertation addresses a critical and persistent challenge within the construction industry: the disconnect between theoretical support for constructability and its inconsistent application throughout the project lifecycle. The study developed a comprehensive Constructability Management Framework, the Constructability-Integrated Construction Lifecycle (CICL), through a detailed investigation combining best practices presented in the literature review, through empirical survey data, and expert validation. This framework provides a structured approach to embedding constructability principles into every phase of a construction project, offering practical procedures, tools, and review mechanisms to support consistent implementation.

The findings revealed significant industry awareness of constructability's value and widespread organisational and procedural gaps in its formal application. Many companies continue to rely on ad hoc practices or informal knowledge sharing, limiting the full potential of constructability benefits. Notably, recurring challenges were the lack of early contractor involvement, the absence of formalised constructability reviews, and limited integration of digital tools such as BIM. Despite these limitations, the study identified promising practices among forward-thinking professionals, including early design-phase reviews, cross-disciplinary collaboration, and proactive use of constructability workshops.

The proposed CICL framework bridges these gaps by aligning insights from leading project management standards, PMBOK, RIBA Plan of Work, and Front-End Planning, with empirical industry feedback. Its value lies in its contextual flexibility, detailed process modelling (via BPMN), and actionable guidance tailored to real-world project demands. Finally, the framework's improvements and validation by an academic expert reinforce its relevance and feasibility.

In conclusion, this dissertation contributes both theoretically and practically to the field of construction management. Theoretically, it enriches the discourse on constructability by situating it within an

integrated lifecycle framework. Practically, it offers a scalable and adaptable tool for industry professionals seeking to institutionalise constructability within their organisations. By adopting the CICL, project teams can expect improved design-construction alignment, reduced rework, enhanced collaboration, and ultimately, more successful project outcomes.

Future research may explore the framework's application in live projects, assess its long-term impact on performance metrics, and refine its components through digital integration. As the industry evolves toward more collaborative and technology-driven delivery models, this dissertation positions constructability not as a supplementary consideration but as a central, strategic function in modern project management.

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APPENDIX A: CONSTRUCTABILITY-INTEGRATED CONSTRUCTION PROJECT LIFECYCLE (CICL)



LEGENDS & SYMBOLS

