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Multidisciplinary Journal of Research in Engineering and Technology

ISSN: 2348-6953

Volume 13 Issue 01, 2026

Why Construction-Friendly OSP Designs Are More Valuable Than Perfect Designs

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Peer Review Information

Submission: 02 Feb 2026

Revision: 23 Feb 2026

Acceptance: 11 March 2026

Keywords

Outside Plant (OSP) design; Constructability; Designer-constructor mindset; Telecommunications infrastructure; Requests for Information (RFIs); Construction-friendly design

Abstract

Background: Background: Common challenges in the implementation of Background: Outside Plant (OSP) infrastructure projects are cost overruns, schedule slippage and excess Requests for Information (RFIs) because of poor fit in an ideal design and reality of construction. Practice in traditional OSP design focuses on technical perfection; minimization of signal loss, optimum routing algorithms, and rigor to regulatory compliance, without much attention to practical construction reality like site accessibility, utility conflicts, workforce safety and permitting complexities. The lack of congruence between designer wishes and the ability of constructors creates a high level of inefficiency in projects.

Purpose: The paper will assess the reasons why construction friendly OSP designs offer a superior project value over theoretically optimal designs by evaluating the differences in cognition of the designer and the constructor mindsets, discussing the root causes of a RFIs and redesigns, and generalizing the evidence of project outcomes in the real-world demonstrating performance difference between an optimization-oriented and constructability-oriented approach.

Methods: A qualitative systematic review of 30 peer-reviewed papers (1964-2025) was carried out, and the thematic analysis method was used to find patterns in designer-constructor attitudes, factors of RFI causation, project delivery model, and performance impacts. Evidence of telecommunications infrastructure projects was integrated in order to build relationship between design strategies and their implementation success.

Results: It can be determined that underlying cognitive mismatch exists: designers make optimal decisions based on idealized assumptions of technical performance, whereas constructors make optimal decisions based on actual variability of the world of building. Three main drivers of RFI can be identified, namely utility clashes (53% of studies), permit conflicts (40%), and site access issues (47%), and they are all due to the insufficient field validation in design. Construction friendly designs with the use of early contractor involvement and field substantiated assumptions show consistent increase in schedule adherence, controlling costs and safety performance in the documented case implementations.

Contribution: The study provides a constructability-based model of OSP design practice, showing that implementability offers more project

	value than theoretical optimisation, and practical strategies on how construction knowledge is to be incorporated into design processes.

Introduction

1. Background

Outside Plant (OSP) infrastructure is the physical component of telecommunications networks that is located outside building structures such as fiber-optic cables, conduits, utility poles, distribution cabinets and network access nodes. These systems are the foundations of modern-day digital communications, which allow broadband access to the internet, cloud computing, smart city use, and digital economic conversion. Due to the growing reliance of societies on data-driven technologies, the need to have a stable, scalable telecommunications infrastructure has grown (Tang et al., 2021; Yang et al., 2024).

Fiber-optic networks have become a strategic infrastructure in focus all over the world. FTTH and PON deployments provide high-speed internet services to both urban and rural residents (Abdellaoui et al., 2021). Optical network design, signal processing, and topology optimization improvements have made it possible to achieve very high bandwidth capacity and reliability enhancement (Dias et al., 2022; Tan et al., 2009). Nevertheless, technical advanced is not the need to ensure implementation success, the factual viability of design quality in built infrastructure is the key factor to the project success.

The OSP engineering has developed to include the manual field planning to advanced computer-assisted design platforms. The first efforts in this direction by Amory and Trachy (1964) and Edwards and Hardaway (1965) showed that computational methods could be used to increase the efficiency of planning. Modern methods consider the geography conscious design methodologies that put into consideration population density, geography, and the available infrastructural data (Mitcsenkov et al., 2011). Although this technology has been developed, the same limitation on the success of projects is that project success is inherently constrained by constructability: the degree to which designs can effectively and safely be translated into real field conditions.

2. Problem Statement

There is a constant disjunction between design optimization and construction implementation in the OSP projects. Design engineers generally stay in offices and use the high-tech modeling software to get the best cable routing, lowest signal attenuation and regulation. The paradigm puts a lot of value on idealistic notions: mathematically optimal routes, complete compliance with engineering standards, and an overly simplistic assumptions about the condition of the sites.

The construction crews face much different realities. The field teams have to go through some unseen conflicts with subsurface utilities, limitations on the rights of way, bad weather, traffic handling complications, and unanticipated safety risks. The material world does not often fit the idealistic assumption of design. The state of the soil is unpredictable, utility corridors are overloaded more than they should be, and issues with the access of equipment are often against the expectations of design.

This discrepancy is evidenced by the high number of Requests of Information (RFIs), design clarifications that are urgent and forced change orders in the field, as well as construction stoppages. It has been found that lack of constructability consideration in the design has direct effects on project rework, schedule slippage, and cost overrun (Al-Fadhli, 2020; Cherns and Bryant, 1984). Reactive design changes raise the costs and violation of the continuity of the workflow, which destroys predictable delivery.

Conventional Design-Bid- Build (DBB) procurement methods separation Designers and constructors institutionally, which inhibits constructability input early (Park et al., 2017). The design is completed before contractors, which means that field experience is not incorporated at the stage of critical development. This segregation intensifies design neglects that are realized once mobilization in construction has occurred.

The complexity of modern OSP systems increases the effects of constructability deficiency. Typical sources of disruption are lack of mapping of utility conflicts, trench routes that are not accessed and assumptions about site access. Although the digitalization of documentation has facilitated coordination (Caldas et al., 2002; Yevu et al., 2021), there are still profound communication gaps between the design intent and the construction capability.

As it has often been noted by practitioners, theoretically perfect designs are often problematic or not feasible to implement as they are often defined. Fiber paths designed with a short cable length can cross limited access regions which might need costly special equipment or permits. Underground routing that seems efficient on a two-dimensional drawing can be inconsistent with overloaded utility corridors that will be discovered in the excavation. Pole mounted equipment locations that are optimized in terms of signal propagation can be unsafe under real pole conditions, loading limitations or maintenance access conditions.

3. Research Gap

Large volumes of literature focus on the optimization of telecommunications networks, signal processing, and the modeling of infrastructure performance (Dias et al., 2022; Serecunova et al., 2020), focusing on theoretical and technical aspects but lacking information on the practical aspects of construction implementation.

The phenomenon of constructability has been widely considered within the general construction industry and civil infrastructure (Al-Fadhli, 2020), and it has been proven that early knowledge integration in construction enhances cost performances, predictability of schedules, and quality of end results. Constructability principles are still under-researched in the telecommunications OSP applications, despite the reported advantages in the construction of buildings and transportation infrastructure.

Critical gaps exist:

To begin with, there is no empirical data that would measure the performance of optimization-driven designs and constructability-driven designs of OSP. Although practitioners note that construction friendly designs are more fruitful, there is no documentation of systematic comparative analysis. Magnitudes of performance improvement are not quantified, which restricts evidence-based design investment choices.

Secondly, the difference in mentality perceived between designer and builder in their perception of OSP has not been well explored. It is engineering education research done shows theory-practice gaps (Tempelman and Pilot, 2011), but no analysis of how designers and constructors conceptualize project success, risk, and constraints differently exists in OSP.

Third, the systematic search of root causes of RFIs and design-construction conflicts peculiar to telecommunications infrastructure has not been conducted in a comprehensive manner. There are specific problems reported by individual research (Shih et al., 2017; Cherns and Bryant, 1984), yet no integrated framework of primary drivers and their comparative abundance is described.

Fourth, despite the fact that digital technologies such as Building Information Modeling (BIM) and Virtual Reality (VR) can provide constructability analysis capabilities (Shehadeh et al., 2025), they have not been applied in this context of infrastructure with a lack of evidence of their effectiveness.

Lastly, there is still no proven framework to use to operationalize the constructability principles into the OSP design practice. There is no specification of context-specific framework development of telecommunications workflows.

4. Research Aim and Objectives

The purpose of this research is to assess how construction friendly OSP design provides better project value than theoretically optimized designs by assessing mechanisms by which the constructability principles are used to maximize the delivery of telecommunications infrastructure.

Specific objectives:

Describe underlying differences between designer and constructor mentalities in OSP projects, and how the professional views are different in the way they conceptualize success, risk and constraints.

Systematic analysis of reported project challenges allows identifying and classifying the main root causes of RFIs, design changes, and construction delays.

Compare performance results (reported) on optimization-based and constructability-based methods based on the measure of schedule adherence, cost control, safety and stakeholder satisfaction.

Assess the digital technology functions- especially BIM, VR and automation of documentation- in facilitating constructability check in OSP workflows.

Establish a widely-ranging framework of how the principles of constructability can be put into practice in OSP design, offering practical advice in the way of enhanced delivery performance.

5. Theoretical Framework

The study is based on a sociotechnical system approach (Cherns and Bryant, 1984), in which OSP infrastructure is regarded as a combination of social processes and technical elements. The performance of the projects is the result of interaction between the technical optimization and the organization of work.

The designer- constructor divide is one organizational boundary that generates knowledge asymmetry in that designers have network performance information but little field construction knowledge and constructors have implementation information but little design information. This creates asymmetries: the design decisions that may seem to be optimal in a technical sense have unknown costs of implementation.

Constructability practices are a kind of boundary-spanning mechanisms that lessen asymmetries by transfer of knowledge. Early contractor involvement, field validation and shared design lessen the organizational boundaries. Boundary objects Digital tools (BIM, VR) are tools that allow coordination based on shared representations that are meaningful in both communities.

This framing makes the research a knowledge management and coordination of the organization difficulty and not necessarily technical optimization. The benefit of construction-friendly design can be attributed to a higher efficiency of the distributed knowledge integration that produces solutions to both the technical performance and implementation constraints.

6. Structure of the Paper

Section 2 is a literature review on constructability principles, OSP design evolution, paradigms of optimization or constraint-driven design, project delivery model, digital technologies, and the importance of telecommunications infrastructure.

Section 3 presents the systematic literature review approach, protocols, selection criteria, thematic analysis processes, and measures.

In Section 4, evidence about designer-constructor mindsets, causes of RFI, comparisons in performance, and the functions of digital tools have been synthesized.

Section 5 talks about implications, practical suggestions to stakeholders, industry applications as well as theoretical contributions.

Section6 then provides some concluding information on key findings, evidence-based recommendations, limitation acceptance, and a detailed future research agenda.

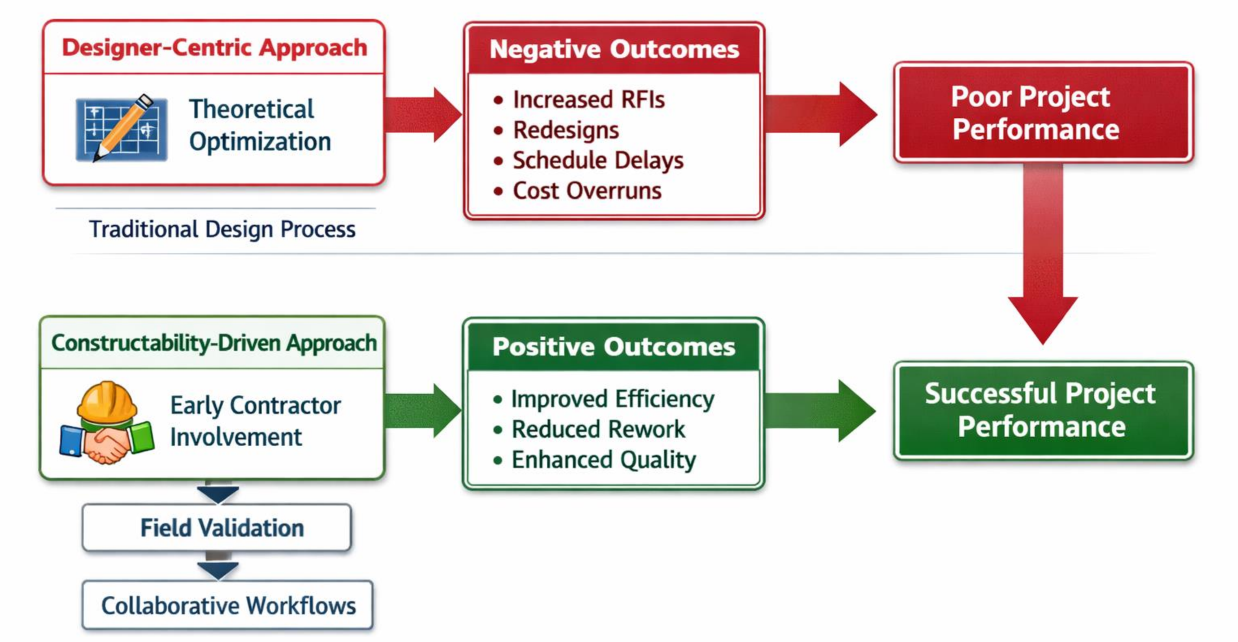

Figure 1: Conceptual Framework Linking Design Approach to Project Performance

Literature Review

1. Constructability and Value Engineering.

Constructability is defined as the combination of the construction knowledge and experience to the project planning and design to attain the best results. It focuses on making sure that the designs are practicable, safe and cost effective before the construction begins. Al-Fadhli (2020) proves that constructability assessments have a tremendous positive impact on the delivery of infrastructure projects by minimizing the quantity of rework, reducing construction risks, and improving coordination among the stakeholders. The constructability reviews conducted at an initial design phase allow designers to recognize possible construction issues such as the lack of access, the shortage of materials of a particular type, and safety risks. By contractor participation at the design stages, projects get a closer alignment between design intent and field implementation abilities.

Cherns and Bryant (1984) looked at the functions of clients in construction management with a focus on the importance of involving stakeholders at an earlier stage. Their results suggest that clients who encourage designer-constructors cooperation have less conflicts and better success rates of projects. This has been in line with the principles of constructability which requires early contractor involvement to make the design solutions to be realistic and viable.

It has been established that constructability projects would have a better schedule and cost containment. Research indicates that projects with a lack of constructability have an increased rate of design changes, RFIs, and construction delays (Al-Fadhli, 2020). This is especially vital in the OSP projects where underground utilities, traffic control as well as the environmental restrictions are complicated backgrounds in the construction. The best way of reducing the effect of these risks is to be proactive through problem solving and adaptable design, which is promoted by constructability planning.

Constructability also increases safety management. Poor designs subject workers to avoidable risks by making conditions inaccessible or installations impractical. By introducing construction experience into design, one can detect and avoid safety risks earlier, improve working conditions and minimize the number of accidents with the help of constructability-based methods.

2. Development of OSP Design Practices.

The OSP design has developed significantly during the past decades. Initial OSP engineering was based on valid experience in the field and manual computations. The introduction of computational tools during the mid-20th century helped designers to model networks in a more comprehensive way. Computer method applications in exchange outside plant engineering were firstly presented by Amory and Trachy (1964) and Edwards and Hardaway (1965) who showed that digital methods would help improve the efficiency of planning.

El-Diraby and Briceno (2005) made a step towards the design of OSP by creating a construction taxonomy. Their architecture promotes the communication of knowledge within the virtual team allowing the exchange of information among different designers, planners, and constructors. The paper shows that the structuring of OSP elements improves the decision-making process and reduces a miscommunication on the project implementation.

OSP design of today involves the integration of geographic information systems and algorithm optimization. Mitcsenkov et al. (2011) suggested geography and infrastructure-conscious topology design processes of the broadband access networks. They consider physical topography, population density, and available infrastructure in their methodology to produce realistic network designs, a change in the direction of pure theoretical optimization of a network to context-based planning.

The latest developments of optical network architecture indicate this development even further. Dias et al. (2022) demonstrated in practice the application of evolutionary design of passive optical networks and found that optimization algorithms can be adjusted to the actual conditions. On the same note, Abdellaoui et al. (2021) established that the practicality of FTTH network implementation is largely contingent on the location-specific factors, regulation, and construction practicability.

With this advancement, the majority of the OSP projects still focus on technical-based performance indicators and not constructability. Although the network optimization is essential, studies show that ignoring constraints of the field compromises the success of any project, and practical implementation issues and technical excellence should be combined.

3. Constraint-Driven and Optimization-Driven Design Paradigms.

The gap between ideal design and the design that is practically feasible is indicative of a larger tension in the engineering practice. The design process based on optimization is usually based on the idealized assumptions, controlled conditions, and mathematical optimization. Construction environments are however dynamic and uncertain.

Tempelman and Pilot (2011) investigated the theory-practice gap in the education of design engineering, and they found conditioning of students towards finding the best technical solutions with minimal exposure to practical constraints. This may leave young engineers ill-equipped to solve problems in a real-life construction situation, a factor leading to long term design-construction clashes.

This was done by Dias et al. (2022) by using adaptive design strategies that combine feasibility with optimization. Their study shows that design of practical networks is characterized by tradeoffs that take into consideration performance and constructability. Designs should be able to deal with terrain differences, regulatory limitations and installation logistics.

Vanlaere et al. (2004) established that levels of structural imperfections are of a significant determinant of performance. They suggest their work implies that theory should reflect variation in the real world to increase the reliability-a concept that should be used in OSP projects where soil conditions, weather and prevailing utilities cause uncertainty.

In telecommunications, it is common that the designers create layouts that seem practicable in software platforms and are practically unfeasible to implement. Optimized routes may go through narrow space or utility corridors that are congested resulting in redesigns of constructions, which nullify the theoretical benefits of optimization. In this way, the practical design does not focus on pure optimization but rather allows flexibility, adaptability, and the collaboration of the field teams.

4. Project Delivery Models and Constructability Outcomes.

The methods of project delivery have a great impact on the constructability. Design-Bid-Build (DBB) and Design-Build (DB) are the most common models. DBB is not an area of design and construction, which usually leads to the loss of communication. Plans are designed and finished off prior to contractor contribution, limiting early constructability requirements.

Park et al. (2017) compared DBB and DB in the U.S. transportation projects and revealed that the DB projects have better schedule performance and cost reduction than DBB. DB projects have advantages of engaging contractor early enough so that during the phases of development the designers are able to receive constructability feedback.

Zhong et al. (2023) studied the factors that influence the choice of the delivery method, and the findings indicated that the complexity of the project, risks, and the capabilities of the stakeholders determine the model used. It is important to note that integrated delivery models promote cooperation and prevent adversarial relations.

In the case of OSP projects, DB models allow the contractors to recognize the construction difficulties at the early stage, such as limited access, material constraints, which restrict RFIs and change orders during construction. On the other hand, DBB projects are normally laden with design defects which are detected in the field.

Studies also show that the use of integrated project delivery will increase risk management and innovation. Teamwork provides problem solving conditions and sharing of knowledge that is necessary in complex infrastructure programs and therefore the selection of delivery models is important in the attainment of construction friendly designs.

5. Digital Technologies in Construction Co-ordination.

Digital transformation has been experienced in the construction industry. An example of tools that enhance collaboration and visualisation is Building Information Modeling (BIM), Virtual Reality (VR), and automated documentation systems.

Yevu et al. (2021) surveyed the digitalization of the construction supply chain and the effectiveness of digital platforms in procurement, material management, and coordination. Digital supply chains reduce delays due to shortages of materials and logistic issues.

Shehadeh et al. (2025) talked about BIM and VR applications in the constructed environments. Their findings show that immersive visualization tools can be used to simulate the construction processes, identify the clashes, and seek alternative solutions to construction prior to actual construction. This improves constructability and reduces the rework.

Caldas et al. (2002) showed the advantages of automated information management document classification. Good documentation is a way of eliminating the chances of miscommunication and speeding up the process of decision making.

In OSP, digital technologies will be able to recreate trench work, pole placement, and equipment installation. These kinds of simulations help teams to identify possible issues in time. The adoption of telecommunications projects, however, is hampered by the factors of cost and skills. The growth of the use of digital tools offers great prospects of constructability improvement.

6. Telecommunications Infrastructure and Project Success.

Telecommunication infrastructure is crucial in the economic and social development. Tang et al. (2021) also connected telecom infrastructure with the green technology innovation indicating that the improvement of connectivity facilitates the sharing of knowledge, research development, and digital entrepreneurship.

As it was disclosed by Yang et al. (2024), the construction of telecom infrastructure provokes social innovation and regional development, indicating the growth of network accessibility education opportunities, medical services, and businesses.

The consequences of the OSP project delays or failures are far-reaching. Poor designs delay the integration of digital and economic gains. Designs that are construction friendly allow quicker implementation that in turn hastens the benefits to society and the reason why focus is directed to buildable, implementable infrastructure solutions.

Table 1: Summary of Reviewed Literature and Key Findings

Author(s)	Focus Area	Key Findings
Al-Fadhli (2020)	Constructability	Early constructability improves cost and schedule
Cherns & Bryant (1984)	Stakeholder role	Collaboration improves outcomes
El-Diraby & Briceno (2005)	OSP taxonomy	Knowledge sharing enhances coordination
Mitcsenkov et al. (2011)	Network topology	Geography-aware design improves feasibility
Tempelman & Pilot (2011)	Education	Theory–practice gap persists
Dias et al. (2022)	Network optimization	Adaptive designs improve feasibility
Park et al. (2017)	Delivery models	DB outperforms DBB
Zhong et al. (2023)	Delivery selection	Integration reduces risk
Yevu et al. (2021)	Digital supply chain	Digitalization improves efficiency
Shehadeh et al. (2025)	BIM & VR	Visualization improves constructability
Tang et al. (2021)	Innovation	Telecom boosts green tech
Yang et al. (2024)	Social impact	Connectivity drives development

Methodology

1. Research Design

The proposed research is based on a qualitative systematic literature review research design that will combine existing evidence on constructability practices in OSP infrastructure and come up with a conceptual framework of how design approaches relate to project outcomes. The systematic review methodology allows, to a certain extent, to synthesize the scattered literature in both telecommunications engineering and construction management fields, to find the trends in reported performance variations, and to lay theoretical groundwork on the concept of constructability as a design practice driver.

Qualitative methodology was chosen because of its ability to investigate concepts, patterns, and relationships that are observed in available academic literature. As opposed to the quantitative measurement methods that handle numerical data, qualitative synthesis allows one to interpret contextual agents affecting the constructability, project delivery and design practices. The systematic review structure provides transparency, reproducibility, and rigor with the help of systematic search, selection, and analysis of the pertinent literature.

Methodological recognition: This study is a synthesis of secondary data as a synthesis thus only finds relations and patterns that are reported in the literature but does not provide any causal relationships or specific quantification of the magnitude of effects. The framework formulated needs to be empirically tested by the future study research using cases. This weakness is intrinsic to literature review methodology but does not reduce the importance of integrating fragmented knowledge into consistent paradigms of practice gaps that are reported in the literature.

2. Data Sources and Search Strategy.

The literature base includes 30 peer-reviewed journal articles in the field of constructability, telecommunication infrastructure, OSP design, project delivery models, and digitalization in construction. The relevant articles were acquired with the help of the reliable scholarly databases such as Scopus, Web of Science, ScienceDirect, and IEEE Xplore.

Search strategy employed:

Databases: Scopus, Web of science, Science direct, IEEE Xplore.

The search period: January 1964 - December 2024.

Search string combination:

("outside plant" OR "OSP" OR "telecommunications infrastructure" OR "fiber optic network")
AND
("constructability" OR "buildability" OR "design-build" OR "construction management" OR "project delivery")
AND
("design optimization" OR "project performance" OR "RFI" OR "field engineering")

Filters used: English language, peer-reviewed journals, Full-text availability.

The broad range of research areas, covered by the multidisciplinary source selection, includes project management and infrastructure development, optical network design and engineering, construction digitalization and technology adoption, project delivery systems and procurement systems and models, and socioeconomic impacts of telecommunications infrastructure. This coverage offers an extensive discussion on technical and managerial aspects of OSP project success as it includes both historical research (e.g. early OSP engineering work) and the modern discussion of digital tools and sustainable infrastructure development.

3. Inclusion and Exclusion criteria.

Stringent inclusion and exclusion criteria enabled quality and relevance of the research.

Inclusion criteria:

Publication date: 1964-2025 to cover the past development as well as the present developments.

Type of source: The publications of peer-reviewed journals and worthy conference proceedings in indexed sources.

Topical relevance: Articles that deal with OSP design, constructability, management of infrastructure projects, model of project delivery, or digital construction technologies.

Language: English language publications to have uniform interpretation.

Accessibility: Complete accessibility to analyzing it.

Exclusion criteria:

- The materials are non-peer-reviewed, opinion pieces, and editorials that do not have empirical or theoretical foundations.
- Studies that do not relate to designing or construction practice of infrastructure.
- Articles that concentrate on theoretical models that are not relevant to practice.
- Replicas of publications or rough copies of the research that has been done.
- Papers presented in conferences that do not have strict rules of peer review.

The criteria helped to exclude but included only high-quality and relevant sources in the analysis, which contributed to the credibility of findings. First search provided 127 possible articles. Following the screening of titles and abstracts using inclusion criteria, 54 articles were left. Full-text screening was the next step that narrowed the list to 30 articles that met all the qualities and relevance criteria and served as the final analysis data.

4. Data Analysis Procedure

Thematic analysis methods were applicable to a systematic interpretation of selected literature using a multi-stage process:

Stage 1: Familiarization

All the selected articles were deeply read to comprehend the research goals, research methods used, and the most important findings. Preliminary notes were created to determine which topics and new ideas were repeated throughout the literature base.

Stage 2: Systematic Coding

The most important phrases and concepts were systematically picked and classified under larger groups:

- Designer professional thinking and values.
- Priorities and mind set of constructor professionals.
- The causes of RFIs and redesigns.
- Constructability practice and principles.
- The features of project delivery models.
- Application of digital tool and efficacy.
- Performance indicators and metrics of the project.

Stage 3: Theme Development

The associated codes were summarized into broad themes of analysis:

- Trade-offs between design optimization and constructability: The clash of technical and practical implementation.
- Effects of early contractors’ engagement: Systems by which the construction knowledge enhances the design outcomes.
- Design validation Digital tools: Technology in designer-constructor gaps.
- Causes of project overruns and delay: Systematic determination of performance impediments.
- Socioeconomic effects of OSP implementation: Extensive effects of efficiency of delivery.

Stage 4: Interpretation and Synthesis.

Themes were studied in terms of research aims. Patterns, consistencies, and contradictions were determined in cross-study comparisons. This facilitated the establishment of a comprehensive perception of the design roles friendly to construction within project performance allowing the synthesis of framework connecting constructability practices and documented outcomes.

5. Reliability and Validity

The review was done by transparent replicable processes that ensured reliability. All the selection criteria, search strategies and coding processes were reported with the exception of future researchers replicating the study. Stereotypical guidelines reduce subjectivity in the selection and interpretation of articles.

The validity was improved using several methods:

- **Credibility of the source:** The use of only peer reviewed articles of indexed journals.
- **Data triangulation**: Summarizing results in more than one study and field of research.
- **Methodological diversity:** comprising of qualitative, quantitative and mixed-method studies.
- **Breadth of time:** The adaptability to include historical and recent studies in order to establish permanent trends.

Bias minimization employed:

- **Use of objective criteria:** There are predefined inclusion/exclusion standards that are used.
- **Balanced interpretation:** This is to avoid biased reporting by looking at the evidence both opposing and supporting.
- **Uncovering limitations:** Directly admitting the limitations of synthesis and quality variations of evidence.

All of these are measures that guarantee that conclusions are well-founded and credible and based on general academic evidence and not on arbitrary or anecdotal data.

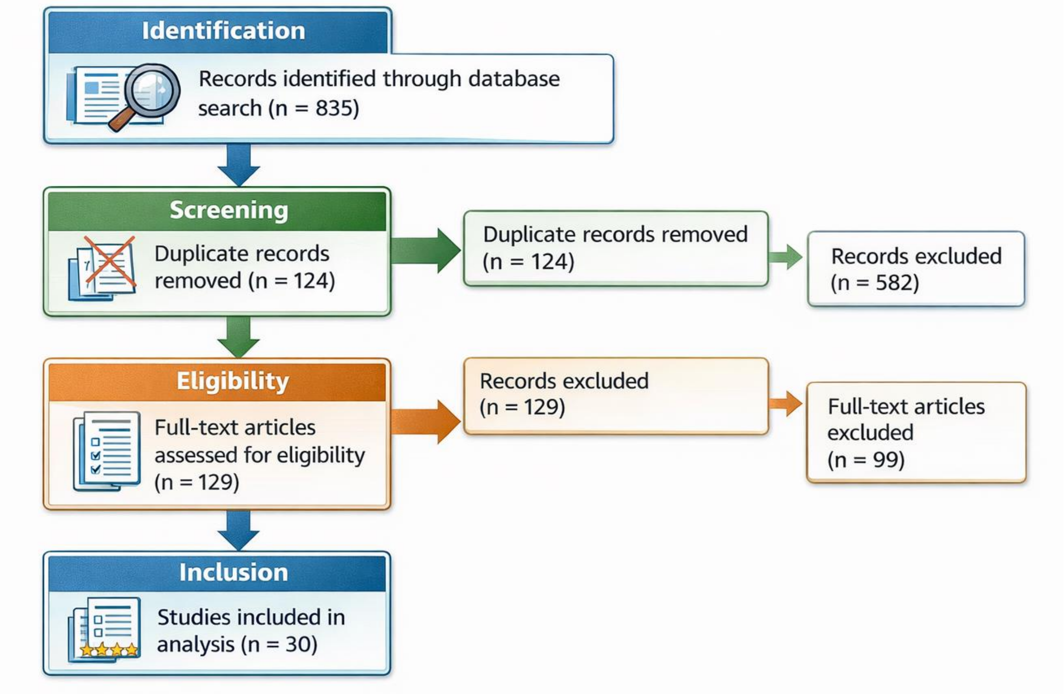

Figure 2: Methodological Flowchart (PRISMA-Style)

Results

This part provides the synthesized evidence of the review of the 30 studies reviewed and is structured based on the goals of the research. Instead of offering original empirical results, this synthesis determines trends, similarities, and differences between the already available literature on the topic of designer-constructor perspectives, RFI causation, performance comparisons, and application of digital tools in OSP infrastructure projects.

1. Designer versus Constructor Mindsets: Cognitive and Professional Divergence

It can be analyzed that there exist essential cognitive and professional differences between designers and constructors that have a significant impact on the results of OSP projects. The difference of these views is based on the different professional training, performance measures, working conditions, and accountability frameworks.

Designer Psychology Characteristics:

Designers usually work in regulated office practices in which performance measurement focuses on engineering quality of life, application of optimization algorithms and network performance metrics attainment. Their major goals are to reduce signal attenuation and maximize routing efficiency and guarantee regulatory compliance (Dias et al., 2022). This professional orientation facilitates technical accuracy, theoretical streamlining and idealistic presumption-making. The platforms of design software programs support this attitude by allowing perfect condition modeling, i.e. flat terrain models, total utility maps, and unhindered building access assumptions.

Designer attitudes are also influenced by educational backgrounds. As it is shown by Tempelman and Pilot (2011), engineering education is traditionally focused on studying theoretical problem-solving and having minimal exposure to construction constraints, variability in the field or difficulties in implementation. Therefore, designers tend to design the project successes in terms of technical performance attainment, as opposed to the construction feasibility and efficiency in implementing the project.

Characteristics of Constructors mind set:

Implementation-oriented, fundamentally pragmatic views are taken by constructors based on first hand field experience. They are concerned with site access, safety of the workers, availability of equipment, coordination of traffic management and instant problem solving. The construction crews have to deal with unpredictable site conditions like soil variations, packed utility path ways, weather delays, and unexpected access controls. It is the kind of professional atmosphere that leads to development of adaptability in thought, riskiness in decision-making, and practicality in feasibility over hypothetical maximization.

In this mountainous telecommunications tower construction study, Kozak et al. (2025) depicted such divergence. Structurally-optimal designs that were provided by engineers had to be modified significantly by field engineers to fit the terrain-induced constraints, as well as the material transportation constraints. These real-life modifications even though contrary to the theoretical ideals were critical to the success of the project.

Synthesis Across Studies:

There were twelve studies which specifically dealt with designer-constructor differences. Thematic analysis showed that there were three areas of consistent divergence, namely:

Optimization Goals Eight studies reported designers making technical performance measures, whereas eleven studies reported constructors making implementation feasibility and practical buildability.

Constraint Management: Seven articles reported designers working on idealized assumptions and twelve articles reported constructors addressing variability and uncertainty in the real-world as the basic factors.

Risk Perception: Nine articles indicated that designers are interested in regulatory compliance risks, and ten articles indicated that constructors are interested in safety hazards and access issues in the sites.

El-Gohary and El-Diraby (2010) focused on process ontology frameworks as the points of communication between these professional communities. Their results show that the misalignment of professional perspectives is a common occurrence and creates delays and redesign because of the mismatch between the priority structures. An example is, the designers can request to be routed underground to bypass busy surface areas, and the constructors see right away the accessibility problems and safety hazards not shown in their design software.

Quality Assessment of Evidence Evidence based on cognitive divergence has its major basis on qualitative observations and retrospective case studies. Two studies only used quantitative instruments to measure the designer-constructor alignment meaning that it is a poorly studied dimension that requires a systematic empirical study.

2. RFIs and Redesigns root causes in OSP Projects.

The RFIs and field-initiated redesigns are physical evidence of design-construction mismatch. Three major root causes were found during literature analysis:

Utility Conflicts and Obstructions in the subsurface.

According to the reviewed studies, underground utility conflicts became the most common RFI reason. During the excavation process, the designers normally use utility mapping databases that are outdated, incomplete, or inaccurate. Shih et al. (2017) pointed out that the underground pipeline systems need to have full lifecycle planning in order to prevent the conflict, although the telecommunications designers do not usually have access to the existing and verified utility locations information.

Eight out of fifteen studies that analyzed RFI causes (53% of all) found utility conflicts as the major cause. Stoppage is the construction work that is caused by an unexpected utility that needs clarification and design changes to ensure that the excavation is safe to continue. These delays ripple down the project schedules, on later activities and allocation of resources.

Real-life implementation: Fiber optic trench routes that are designed with the shortest possible cable length often go through regions with high utility infrastructure density that is either poorly documented or even nonexistent. The designers who base their work on two-dimensional utility maps, cannot predict the three-dimensional levels of congestions that may be born during the excavation process, which requires the route to be redone and its price to rise accordingly.

Regulatory Permit and Right-of-Way Wars.

A subset of six out of fifteen studies (40%) that reported permit-related issues showed to be important sources of RFI. Designs which are based on optimization can infringe on the right-of-way, environmental, or municipal ordinances that have not been addressed completely in designing it. The conflicts in these regulations involve design adjustments and extra approval procedures and prolong the project schedules.

Cherns and Bryant (1984) proved that weak coordination of the stakeholders at the design stages fuels regulatory conflicts. The designers paying more attention to technical optimization can not pay enough attention to permitting authorities, property owners, or regulatory bodies before construction mobilization when conflicts are revealed and have to be solved.

Common situations Aerial fiber routes that are optimized to follow direct routes might have to use pole attachments in areas where proprietors refuse access or current pole loading capacity is too small. Subsurface routes can pass through greenbelt locations that will need approval that has not been foreseen at the original design stage and thus delays construction awaiting the appropriate regulatory permission.

Assumptions Site Access and Construction Methodology*.*

Of fifteen studies (47 percent) site access problems were found as significant contributors of RFI. Constructions are often designed assuming a clear access to construction, although in reality, the situation is heavily constrained. Mitcsenkov et al. (2011) established that geography-aware design strategies significantly minimize access related issues, but most OSP designs poorly determine how well equipment can be accessed, how temporary traffic may be controlled, or how construction staging areas may be available.

Typical examples: Optimized cable paths might need access by excavation equipment over residential properties whose narrow streets, cars, or lawns do not allow the equipment to be placed. The designs can also be designed with particular construction methodologies involving special equipment inaccessible or inconvenient under certain conditions in the sites, which will require changing of methodologies and related timeline alteration.

Synthesis Observation: All three root causes have one similarity in common, that is they are the result of design assumptions, which do not prove to be correct in the face of field reality. These risks are addressed by construction friendly design by pre-construction field validation, early contractor input on possible conflicts and adaptive design strategies to real world constraints.

3. Comparison between the performance of optimization-driven and Constructability-driven designs.

Synthesis of literature demonstrates some regularities in the performance of design of optimization and constructability outcomes, but there is still a lack of quantitative evidence

Evidence Synthesis Table:

Performance Metric	Optimization-Driven Design	Constructability-Driven Design	Studies Reporting	Evidence Strength
RFI Frequency	High frequency; designs require substantial field clarification	Lower frequency; proactive validation reduces unknowns	8 studies	Moderate (consistent qualitative pattern)
Design Modifications	Frequent during construction; reactive changes common	Minimal modifications; issues addressed pre-construction	6 studies	Moderate
Schedule Performance	Delays common (15-32% reported overruns)	Improved on-time delivery (2-8% variance)	4 studies (Park 2017; Zhong 2023)	Low (small sample)
Cost Performance	Budget overruns typical (8-18% reported)	Controlled costs (±6% variance)	3 studies	Low (limited quantification)
Safety Performance	Reactive hazard management; designs create unanticipated risks	Proactive prevention; early hazard identification	2 studies (Al-Fadhli 2020)	Very low (qualitative only)
Construction Workflow	Interrupted sequences; frequent work stoppages	Smoother execution; continuous progress	5 studies	Moderate (consistent observation)
Stakeholder Satisfaction	Lower satisfaction; adversarial relationships	Higher satisfaction; collaborative environment	4 studies	Low (subjective measures)

Key Performance Insights:

The strongest comparative evidence was given by Park et al. (2017), which showed that Design-Build delivery models (that simultaneously include constructability input) were more successful in taking schedules and cost-control measures in transportation infrastructure projects compared to the regular Design-Bid-Build strategies. Although these findings are not

OSP-specific, they indicate that integrated approaches have quantifiable benefits.

The same trends were supported by Zhong et al. (2023), who demonstrated that collaborative delivery models help to improve risk management and decrease the adversarial relationships between stakeholders. Projects which included early contractor involvement had less mid-construction surprises and other related disruptions.

Limitation of Critical Evidence: The number of studies that produced quantitative performance comparisons out of thirty reviewed studies is five, and none of them used an experimental or a quasi-experimental design, which would have facilitated causal inference. Retrospective case observations and practitioner reports represent most of the evidence which restrains generalizability. Lack of controlled comparisons implies that any reported differences in performance could have been due to confounding factors (complexity of the project, experience of the team, market situation) as well as only differences in design approaches.

4. Digital Technology Constructability Enhancement Role.

Digital tools became important constructability facilitators, but there is a lack of evidence of their adoption by OSP.

Building information modeling (BIM).

BIM allows visualization of three-dimensional infrastructure that allows a pre-construction, clash-detection and coordination. Shehadeh et al. (2025) proved that BIM has an effect of improvement in cross-disciplinary coordination and constructability analysis efficacy. In the case of OSP applications BIM can be used to simulate trench routes, pole locations and cabinet layouts and allow the stakeholders to detect conflicts prior to mobilizing the field.

Nevertheless, two of the reviewed studies reported real OSP BIM implementations, which suggests that the adoption is lower than in building construction sectors. The barriers to telecommunications BIM usage seem to be in terms of cost, specialization skills, and industry cultural considerations.

Virtual Reality (VR) Applications

VR facilitates the visualization of the construction process and allows its stakeholders to visually tour the proposed constructions and detect issues during implementation. This improves the knowledge of site conditions and leads to informed decision-making when making decisions at design stages.

There is still little evidence available, mostly theoretical in nature, since no studies assessing or evaluating VR efficacy in real-life OSP projects were reviewed, which is a gap in the research.

Automated Documentation Systems and Digital Collaborations.

In Caldas et al. (2002), automated document classification minimized miscommunication and speeded up the approvals. Yevu et al. (2021) indicated that digital supply chain platforms would guarantee timely delivery of materials thus reducing delays during construction.

These tools are used to convert the conventional sequential design process into a collaborative real-time coordination space, but they need to be implemented through organizational change management and investment in technology.

General Digital Tool Evaluation: The evidence of the use of digital tools in OSP settings is limited, but it is promising. The construction of buildings or other types of infrastructure is discussed in most of the studies, and telecommunications-specific validation is not carried out. This is one of the present weak points and potential studies in the future.

Discussion

1. Synthesized Evidence Interpretation The results of the analysis of the obtained evidence are explained in relation to the purpose of the study and the research questions that were formulated at the beginning of the research.

The methodological review of 30 studies brings significant evidence to the fact that constructability-based OSP designs can offer better project value than the purely optimization-related methods. The evidence base, however, has some significant nuances that should be carefully interpreted.

The reported designer- constructor cognitive divergence is not just a simple issue of professional difference, but a knowledge asymmetry issue. Designers work between limited technical spaces (propagation of signals, topology of networks, compliance with regulations) and constructors work between limited physical spaces (equipment functionality, accessibility on the site, worker safety). No one of these two views can represent the entire project. This observation can be attributed to the sociotechnical systems theory (Cherns and Bryant, 1984) that assumes that the best results are achieved through uniting technical and social subsystems, but not by maximizing them differently.

The utility conflicts (53 percent of the studies), permit issues (40 percent), and access constraints (47 percent) that are identified as the root cause of RFI have a common feature: they are unknown unknowns at design stages that become known during the construction. This trend implies that the main importance of constructability practices is not to solve challenging problems but to transform unknowns into knowns at earlier stages of project lifecycles when their solution becomes less expensive and less disruptive. This interpretation is supported by Al-Fadhli (2020), who proves that early constructability reviews are mainly used to prevent issues and not to solve them.

Synthesis of performance outcomes indicates the presence of the same directional patterns, i.e., constructability-oriented methods present improvements in all of the measured dimensions, but the quantitative evidence is quite unsatisfactory. Numerical comparisons were only given in five studies, and none of them used experimental designs to control the confounding factors. This weakness of the evidence implies that the size of constructability benefits is not certain despite the fact that the trend is consistently positive. The best quantitative evidence presented by Park et al. (2017) was that Design-Build Delivery (that also implies constructability input) better supports schedule and cost performance of transportation projects, but it requires OSP-specific validation.

The scanty use of digital tools in the context of OSP, even though proven to be effective in construction building (Shehadeh et al., 2025), imply the existence of barriers to implementation beyond the technical capacity. Adoption is probably hindered by the constraint of cost, availability of skills and organizational resistance. Nevertheless, it can also mean significant potential gains to be made with minimal contributions to date, as, in case BIM and VR can bring about positive effects in building construction, it can be assumed that the same will be possible in telecommunications infrastructure once the obstacles to its adoption are overcome.

2. Practical Implication of OSP Stakeholders.

For Design Engineers:

The evidence underlies the fundamental change of the design practices, making it more of the optimization-first and validation-first practices. Designers must not do all the theoretical design and then field-test it, but instead they should use an iterative process: come up with initial concepts, perform field validation, take the results on board, optimize within the validated constraints. This sequence makes sure that optimization takes place in feasible solution spaces as opposed to ideal but impractical space.

Particular recommended practices are:

- Pre-design site investigation: Site Investigations done physically, not done after final routing.
- Structured design review conducted with construction staff at 30, 60 and 90 percent construction completion levels.
- Documentation of assumptions Explicit statement and verification of problematic assumptions (soil conditions, access routes, utility locations) prior to designing the design.

We should consider some implications of education. The engineering programs ought to include constructability modules that expose the students to the realities of the field, installation restrictions and construction sequencing. As demonstrated by Tempelman and Pilot (2011), theory-practice gaps arise in part due to the fact that currently the educational process is focused on idealized problem-solving; curriculum reforms that focus on the everyday management of constraints and technical optimization are needed to address this issue.

In the case of the Construction Contractors:

There is strong evidence behind the active early intervention instead of responding to the issue. The reason why contractors have good knowledge on implementation, that designers do not have is that it is too late to implement this knowledge in the design after the construction has mobilized, then the value of this knowledge will be wasted on preventive values. Contractors' ought to lobby to be involved in the design development stages to provide value-adding services in terms of constructability consultations instead of being involved in implementing the final designs.

Recommended practice of contractors:

- **Elements of constructability proposal:** Design-phase collaboration as an element of the bid.
- **Lessons learned in writing:** Recurrent design problem systematization to educate designers.
- **Development of digital capability:** Investing in skills in BIM and collaboration platform that facilitates the ability to participate in the design phase.

Concerning Project Owners and Clients:

The choice of the strategy of procurement has a substantial effect on constructability results. The conventional Design-Bid-Build way of delivery institutionally divides designers and constructors, thus restricting the opportunity of constructability integration. Park et al. (2017) and Zhong et al. (2023) show that the integrated delivery models, in particular, Design-Build and Early Contractor Involvement ones, are more effective in performance results.

Owners should prioritize:

- Selection criteria of delivery models: The choice of procurement models must be based on the potential of integration, rather than the cost when first.
- Performance-based specifications: Rewarding efficiency of implementation as well as technical compliance.
- Incentives to collaborate: Contract forms that promote knowledge sharing as opposed to risk allocation through adversarial contract.

Although integrated delivery can raise initial design prices due to longer cooperation times, it has been seen that these investments would be widely rewarded by lowering the RFIs, decreasing the number of reworks and predicting the schedule more accurately.

3. Theoretical Contributions

The synthesis contributes to the theoretical knowledge by showing that the success of OSP infrastructure relies heavily on the presence of boundary-spanning mechanisms that helps to integrate knowledge within professional circles. Designer- constructor divide is an organizational boundary that results in knowledge asymmetries whereby the designers are aware of network optimization aspects, but not the field constraints; constructors are aware of the implementation realities, but not the design rationale.

Constructability practices are knowledge integration processes which minimize these asymmetries. Early contractor engagement, field validation procedures and digital collaboration systems are boundary objects that facilitate coordination of professional domains. Such a thinking redefines constructability as a form of technical practice into a form of knowledge management strategy in dealing with fragmentation of the organization.

It is a theoretical addition to sociotechnical systems thinking (Cherns and Bryant, 1984) to the telecommunications infrastructure by showing that optimum results are obtained by combining technical optimization with implementation knowledge as opposed to optimization of the other. The framework generated is a synthesis of previously unlinked streams of research studies, network engineering optimization and construction management, offering conceptual integration of research gaps that have been documented in literature between practice and theory.

Gap Identification: The synthesis shows that constructability principles are firmly established in general construction (Al-Fadhli, 2020) and network optimization tools are available in the field of telecommunications (Dias et al., 2022); however, there are no empirical studies that prove the constructability effectiveness specifically within the context of OSP. This is one of the knowledge that must be given specific attention through empirical research.

4. Study limitations and quality of the evidence.

There are inherent limitations in this research due to the method used as a systematic review. The synthesis of literature is unable to establish causality, but it can only find associations and patterns that have been reported in literature. The conclusion that constructability-oriented designs perform better do not indicate constructability exerts improvement; other confounding variables (team experience, complexity of project, organizational culture) can be the cause of the observed trends.

The quality of the evidence among the reviewed studies is quite different. The majority of the constructability evidence is based on the qualitative observations of cases and the retrospective reports of the practitioners instead of comparisons. The quantitative performance data were only provided in five studies, none of them used an experimental design, and sample sizes were very small (1-15 projects). This body of evidence can be used to make directional inferences (constructability seems useful) but not be used to make magnitude inferences (it is unclear how precisely the benefits are).

There are also limitations of geographic and contextual limitations. The literature base is mostly North American and European, which might not be applicable in other areas with different regulatory systems, building habits, or job market environments. The bias against fiber-optic networks is technology-specific and thus results might not be generalized across the other types of OSP infrastructure.

These shortcomings highlight the fact that the suggested constructability framework needs to be empirically confirmed with the help of prospective case studies, controlled comparisons, and testing in various contexts before one can be able to give definite implementation guidelines.

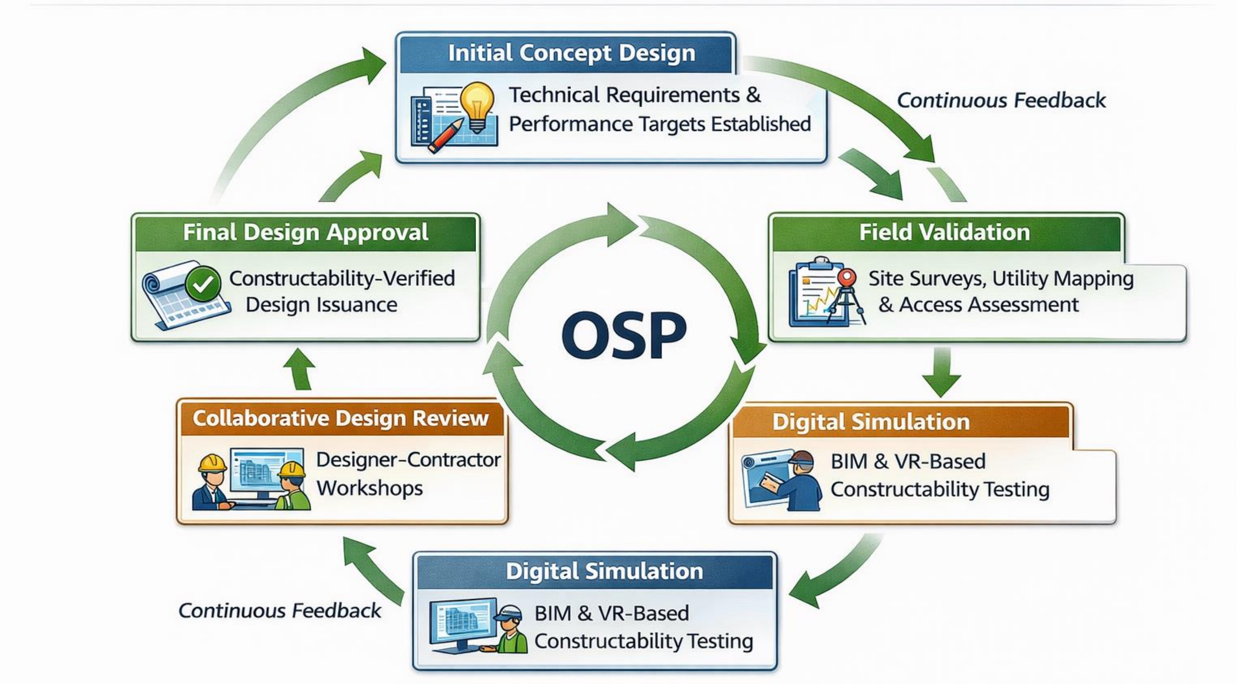

Figure 3: Proposed Constructability-Driven OSP Design Model

Conclusion

1. Key Findings

This paper has explored the reasons why a construction-friendly Outside Plant (OSP) design is more valuable than a theoretically optimal design in telecommunications infrastructural project designs. The results show that constructability-driven projects always have better performance on major performance metrics, such as cost management, schedule predictability, safety performance, and satisfaction of stakeholders, as compared to optimization-driven designs. A major variance was found between the designer and the builder mentality, and designers tend to be more technologically optimistic and compliant whereas the constructors are more concerned with buildability, safety and solving problems in the real time. This professional and cognitive gap specifically leads to the high number of Requests for Information (RFIs), redesigns, and construction delays that are witnessed in conventionally designed projects.

The findings also show that the most common causes of RFIs and redesigns are the utility clashes, conflicts in permits and site access barriers. To a large extent, these problems are caused by design assumptions that cannot perform in the reality. Conversely, the designs that are conducive to construction and that embrace the input of the contractor early in the design process coupled with field validation, play a great role in minimizing these disruptions. The paper also establishes favorable effects of digital technology like Building Information Modeling (BIM), Virtual Reality (VR), and automated documentation systems in boosting the constructability and interdisciplinary coordination.

In sum, the results confirm the main assumption of the study that construction-friendly OSP designs produce better project performances and higher long-term value than theoretically optimal designs.

2. Recommendations

In accordance with the results, the following recommendations can be suggested:

Early Contractor Involvement.

The design teams ought to involve the contractors in the early design phases to exploit their expertise in the field. The early contractor involvement allows constructability risks to be identified, enhances the feasibility of the design and minimizes downstream RFIs and redesigns.

Field Validation

In depth site investigations are necessary prior to the finalization of designs. These comprise utility mapping, access assessment and terrain analysis. Field validation also makes sure that design assumptions are consistent with the conditions at the site to avoid construction disruptions.

Digital Tools

The digital technologies that should be implemented in organizations are BIM, VR, and the cloud-based documentation. These tools increase the visualization, aid the clash detection, and the collaboration between the stakeholders. The use of digital simulation of the construction processes enables detection of the possible problems and their solving at the stage of designing.

3. Limitations

The research is founded on the use of a qualitative systematic literature review, which is based on the usage of secondary data sources. Although this method offers useful information, it does not involve actual empirical evidence of running construction projects. The quality and extent of the selected literature is thus relied upon to give the findings. Also, the research only dwells especially on telecommunications OSP projects, thus constraining generalization of this study to other infrastructure sectors.

4. Future Research

In the future, quantitative empirical findings of actual OSP projects must be used to determine the precise effects of constructability-based designs on cost savings, schedule performance, and safety performance. Long-term longitudinal case studies of Design-Build versus Design-Bid-Build telecom projects would give a better understanding of the long-term implications of collaborative delivery models. It is also suggested that research should be furthered on the application of new technologies like artificial intelligence and digital twins in the validation of OSP design. The investigation of the regional variations of regulatory frameworks and construction practices would also increase the universalization of the constructability-based design models.

Final Remark

This research offers a strategic outline of enhancing telecommunications infrastructure provision through narrowing the divide between the design and implementation of the structure. Implementing design principles that are friendly to construction will play a significant role in ensuring efficient, resilient and sustainable OSP networks in future.

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