Implementing Systems Engineering in the Construction Industry: Literature Review for Research Alignment

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***Abstract*— The purpose of this paper is to prepare for the execution of a research project assessing the success of Systems Engineering in complex Norwegian construction projects from a technical subcontractor perspective. We examine a sample of 33 papers considering Systems Engineering in construction projects worldwide and elaborate on the context and design of the upcoming research project.**

From the literature, we learn that construction projects' current discipline-oriented silos lead to sub-optimal interfaces and verification and validation challenges. The construction industry differs fundamentally from the manufacturing domain, emphasizing the design of the work rather than the system's design in its system engineering effort. The implementation of Systems Engineering is highly dependent on the level of competence among employees in the projects.

The Norwegian construction industry is in an early phase of the implementation of Systems Engineering methods. With this project, we hope to illuminate some challenges and solutions for the Norwegian construction industry. Moreover, we look for lessons the Norwegian construction industry can learn from the construction industry globally to help mitigate challenges and accelerate the implementation of Systems Engineering methods.

Keywords—Systems Engineering, construction project

I. INTRODUCTION

The construction industry is one of Norway's largest business sectors, generating an annual revenue of 625 billion NOK [1]. We find actors like the client and commissioner, the design/consulting firms, the contractors, and subcontractors within the construction industry. All these actors work together to design and build infrastructure and buildings. While other land-based industries in Norway have had a 30% increase in productivity between 2000 and 2018, the construction industry has had a 10% decrease [2]. There is also a high conflict level in the industry. Some of the reasons for conflict are; delay, cost overruns, and quality problems. Decreasing productivity and these factors may be inter-related.

A. Systems Engineering Definition

The International Council on Systems Engineering (INCOSE) defines Systems Engineering as "*an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Performance, Test, Manufacturing, Cost & Schedule, Training & Support, Disposal. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.*" [1, p. 11].

B. Systems Engineering Implementation.

The Norwegian construction industry has started implementing the Systems Engineering approach, under the name "Systematic Completion", to mitigate the industry's challenges. Johansen and Hoel define Systematic Completion as "an assurance that the project fulfills all functional requirements within the set time-, cost- and quality requirements, planned and verified by a structured process which is managerially driven from design and planning to handover." [2], [3, p. 9]. Whether the approach fulfills these promises "is not well documented yet" [2].

Beste [2] "provides a starting point into analyzing the effect of Systematic Completion." proposing further studies with more data, also from an international perspective, to complement the research. Furthermore, according to Beste, taking the design team, contractor, or customer's perspective would improve insight. Partnering with Bravida, we will build on Beste's recommendations and analyze Systematic Completion from other perspectives, namely the technical subcontractor point of view. A fundamental difference between the work done by Beste and this study is that we treat Systematic Completion as Systems Engineering. Using Systems Engineering as the primary reference perspective will also enable us to add an international perspective, as numerous studies are exploring Systems Engineering in the construction domain abroad.

As the Systems Engineering effort in the construction revolves around designing the work of a complex group of independent companies, we argue that it is Systems-of-Systems Engineering, despite the fact that many of the resulting physical systems are not able to fulfill any purpose independently.

We organize the remainder of the paper as follows: First, we introduce our upcoming study's context and research design. Second, we introduce Systems Engineering in construction. Third, we discuss our preliminary findings from the literature review. Finally, we sum up the paper and draw preliminary conclusions.

II. RESEARCH CONTEXT

Norway is a small country. It is sparsely populated, has a low population growth rate compared to the world average, but was ranking number six on GDP per capita in 2019 [4]. Relative rough weather conditions during wintertime and

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emerging pressure on sustainability perspectives translate into strict building regulations and new construction techniques.

A. Bravida

Bravida is a large Nordic technical contracting company covering electronics, information and communication technology infrastructure, heating, ventilation, air conditioning (HVAC), plumbing, and security installations. Bravida is involved in a wide range of technically complex construction projects, in several sectors, both with single discipline engagements and multi-discipline engagements. Many of these projects utilize Systems Engineering. The main author is currently employed in the department for interdisciplinary projects at the Oslo offices of Bravida in Norway.

B. Healthcare Building Construction

Building construction, in general, is getting more complex. There is an ever-increasing amount of technology integrated into new buildings. Healthcare building construction projects are especially complex, both in terms of integrated technology (e.g., rooms for magnetic resonance imaging), requirements related to quality (e.g., seamless redundant power supply), and the long list of stakeholders interacting both with the projects and the end-product. For the research project, we will examine three projects Bravida is involved in within the healthcare building construction domain, to limit the study by context.

C. Contractual Regimes

Traditionally, projects within the Norwegian construction sector have a design phase and a building phase. In the design phase, the client hires a consulting/design firm to plan the construction project and prepare design documents. At the end of the design phase, the client uses the prepared documents to run a tender competition that results in the client hiring contracting companies to build the project. This regime is known as design-bid-build (DBB). In a DBB regime, the risk related to design documents is the client's risk.

Another popular contractual arrangement is the design-build (DB) regime. In a DB regime, the client hires a contracting company responsible for both the project's design and construction. The DB tender often uses documents produced in a pre-project conducted by the client as a basis. Some of the contracting companies design themselves. Others hire a design firm to do the design. The risk related to design is the risk of the contractor in a DB regime.

A third contractual arrangement that is gaining traction in the Norwegian construction industry is partnering contracts. In a partnering contract (PC), the design companies, contracting companies, and the client develop the project in a joint effort. During the partnering phase, the participants develop high-level design documents and agree upon a price for a DB or DBB regime, governing phase two of the project. The PC is the regime where the contracting companies are involved earliest. Hence, we assume the PC to be best suited to facilitate successful Systems Engineering processes. A PC with a subsequent DB regime governs all three projects that are selected for our research.

III. Research Design

The effect of Systems Engineering in the Norwegian construction industry is not well documented. It is uncertain whether the approach delivers the promised results or not.

Our research will use an exploratory multi-case study approach with a triangulation of document analysis and interviews. According to Yin [5, p. 9], the case study approach increases in relevance if we try to explain some contemporary circumstances. E.g., how and why some social phenomena work [3, p.9]. The project will investigate how Systems Engineering works in the construction industry. We also use exploratory "what" questions to explore specific aspects of effective implementation and potential lessons to be learned. Hence, we conclude that a case study approach is suitable for this research. We will limit the study by context (healthcare building construction) and time (early phase of the projects). To increase our ability to draw generalizable conclusions that could apply to other cases, we will conduct a cross-case analysis from three separate single case studies [3, p.16].

The goal of the project is threefold. First, we will attempt to determine how successful the application of Systems Engineering is from the technical subcontractor perspective. Second, the project intends to contribute to establishing a shared understanding of Systems Engineering in Norwegian construction. Finally, the project aims to provide recommendations on what the industry should focus on in further implementing Systems Engineering and research.

Preparing this paper, we have conducted pre-interviews with colleagues in the industry to define the problem and examined the body of knowledge in the literature. Moving forward, we will conduct a document review of three case projects and follow up with a series of interviews. We will use findings from the literature and define propositions to guide the document review. Finally, we will synthesize findings from the literature, document review, and interviews into recommendations for further Systems Engineering efforts for the Norwegian construction industry. The present paper covers the literature review, discussed in light of our knowledge from the industry and initial understanding of the problem.

A. Research Questions

To concretize the research and contribute to documentation and clarification about Systems Engineering in construction, we will address the following research questions (RQ) that we intend to answer in our next paper:

RQ1: What can the Norwegian construction industry learn from the implementation of Systems Engineering in the construction domain abroad?
RQ2: How does Systems Engineering affect the technical subcontractor's project management performance in public healthcare building construction projects?
RQ3: What are the prerequisites to make Systems Engineering work for the technical subcontractor?
RQ4: What are the elements that contribute to effective Systems Engineering in construction?

Project management performance relates to cost, time, and quality [6]. Answering RQ1 will illuminate challenges and solutions from an international perspective and shed light on a rich body of knowledge that we assume is unfamiliar to the Norwegian construction industry. In the process of answering this question, we will mostly draw on the literature review. Moreover, the findings serve as an inspiration to develop and answer the other questions and synthesize recommendations at the later stages of the projects when we know more about what challenges are relevant in the Norwegian construction realm. Answering RQ2 will clarify whether Systems Engineering fulfills the promises given in the definition of Johansen and Hoel [3]. Exploring RQ3 will illuminate any differences in prerequisites essential for the building commissioner and the technical subcontractor's success. Finding answers to RQ4 will help us enlighten which elements contribute to Systems Engineering effectiveness in construction.

B. Literature Review

For literature review, we search the Systems Engineering journal, Systems journal, and proceedings from the INCOSE International Symposium published between 2011 and 2020. After reading all abstracts of the 79 total hits, we compile a list of 15 relevant papers. From these 15 papers, we search for secondary sources examining the reference lists. Checking for substantial relevance to Systems Engineering in the construction industry, we compile a final sample of 33 papers, which we read in their entirety.

IV. Systems (of-Systems) Engineering in Construction

The complexity in construction projects is growing [7]–[10]. Simultaneously, the industry is consistently failing in delivering what clients and users want [11]. In the past decades, Systems Engineering has gained interest in the construction industry to handle the increasing complexity [8], [10], [12]–[16].

A substantial difference between industries traditionally associated with the application of Systems Engineering principles in development efforts is that while they often manufacture the resulting product repeatedly, construction produces one-off products [7]. Aslaksen [17] states that the development process of what to be constructed only accounts for 10% of the engineering effort. The focus lies in determining how to carry out the work. Moreover, the integration process integrates various parts of the construction processes divided into disciplines [7], [17].

A system-of-systems is an assemblage of components that individually may be considered systems of their own and have both operational and managerial independence [18]. Operational independence means the component system must be able to operate usefully and accomplish its purpose on its own. Managerial independence meaning it maintains continued operational existence independent of the system-of-system. While some authors argue that the lack of a system-of-systems perspective is partially to blame for the lagging productivity growth in the industry [19], such a definition would place construction systems on the borderline between system and system-of-systems development.

Although some of the systems in a building may operate independent of the others (e.g., the electricity system is not depending on the water supply or HVAC system to provide electricity), some systems like the building automation system are not able to fulfill any purpose without integrating with the other systems. Moreover, all building systems are integrated into the building's structure, and recent technological advancement pushes in the direction of even more integration between the systems. In the increasing interrelatedness of systems, the electrical system and building automation systems play a crucial role. However, considering designing the construction process rather than the system itself, with projects divided into many separate contracts awarded to a wide range of suppliers, the construction effort should definitively be considered a system-of-systems effort.

Nevertheless, the interrelated characteristics of construction systems have implications for the constituent system's architecture and the architecture of the construction process. The constituent systems must be designed and architected to integrate properly with each other. So must also the enabling construction process. A tailored version of Systems Engineering [17 p.165] may provide the necessary tools for success.

A. Systematic Completion

Johansen & Hoel, and Beste describe and visualize Systematic Completion through the V-model [2], [3], well recognized in System Engineering. The approach moves through requirements analysis, functional analysis, and design synthesis. In iterations, the process facilitates the development of complete system architecture and design, similar to the Systems Engineering process as described by the Department of Defense [20]. Subsequently, the system is constructed and verified in a stepwise series of integration and test activities, similar to the system build approach described by Gleckler and O'Neil [9]. While moving through these processes, Systematic Completion aims to consider all aspects, similar to the list stated in the INCOSE definition of Systems Engineering. Based on these identical traits, we conclude that Systematic Completion is a tailored version of Systems Engineering and hereafter treat Systematic Completion as Systems Engineering.

V. Discussion

The literature review reveals a wide range of challenges, opportunities, and positive effects of Systems Engineering in the construction domain. Yet, three interrelated topics stand out. In the following subsections, we discuss knowledge aspects, verification and validation (V&V), and the contractual boundaries that result from the design and construction taking place in inter-organizational collaboration. We discuss the findings in the literature in the context of our industry experience.

A. Knowledge

Using a structured framework, de Graaf, Voordijk, and van den Heuvel reveal that three factors are essential for the successful implementation of Systems Engineering in a construction firm [12]. First, the firm must clarify procedures and responsibilities before project initiation. Second, the firm must educate its employees, and employees must practice using Systems Engineering methods. Third, an explicit demand for Systems Engineering from the client will positively affect the implementation [12]. Extending these perspectives, we argue that a firm must first have the competence to succeed with the clarification of procedures and responsibilities. To achieve the third, the client must also have the necessary competence. In addition to these three factors, "all layers of the organization should be involved in implementing Systems Engineering practices" [15]. Specifying this, de Graaf, Vromen, and Boes found that management support, in particular, contributed positively to Systems Engineering implementation [13].

Furthermore, White argues that *"leadership (as opposed to management) is the more appropriate focus in creating* *conditions for effective action in dealing with very complex situations"* [21]. Nevertheless, management support can materialize as leadership and vice versa. See [22] for further discussion on management versus leadership.

Exploring the knowledge aspect further, we find that besides knowledge about the Systems Engineering processes, technical domain knowledge and knowledge management are critical to achieving effective Systems Engineering teams in construction projects [14]. We assume that the construction industry has the necessary domain knowledge in its highly specialized and discipline-oriented organizations. Systems Engineering is relatively new for the sector, and there is little literature on Systematic Completion [2]. Therefore, we assume more variation related to the Systems Engineering competence level. However, this paper shows that there is a rich literature on Systems Engineering in construction available. We find academic papers, guidebooks, and several academic books on Systems Engineering in general.

We assume the construction industry can benefit from tapping into this well of knowledge. Comparing the guidebook on Systematic Completion with guidebooks written for the construction sector abroad [23]–[25], we find that the Norwegian guidebook is far less detailed and explicit on how to perform the various processes successfully. To some extent, the templates available [26] and Statsbygg's planning instruction for systematic completion [27] elaborate more together with the standards NS3935 [28] and NS6450 [29]. All material, however, heavily focuses on integration and test. Focus on integration is in line with statements that *"the greatest benefit of applying Systems Engineering principles is gained in the systems integration and construction stage"* [1, p. 168] when addressing tailoring to infrastructure construction. Relying on guidebooks that only address prior enabling processes (such as requirements elicitation) on a superficial level may prevent the industry from maximizing the integration and test phase benefits.

Except for Beste [2], who barely touches into the V-model being "inspired" by Systems Engineering, none of the Norwegian material links Systematic Completion to Systems Engineering. In light of this missing link, in terms of potential competence development, we find it necessary to ask, "how can you find what you need if you do not know what you are looking for?" Given the discipline specialized silo division of the construction industry [16] and that some contract regimes have several phase transitions (where also responsibility transfers between actors), a deeper shared understanding of processes in all lifecycle phases across all actors in a project should boost the effects of applying Systems Engineering.

B. Verification and Validation

The Dutch construction sector's failure cost increased from 6% to 11% of the project cost between 2001 and 2010 [30]. Among the major reasons for this is little focus on V&V incorporated [30]. Less V&V focus is somewhat in contrast to the Norwegian construction sector's current situation, emphasizing verification (testing). However, at this time, we have only anecdotal evidence of this being successful. To improve, Elich, Schreinemakers, and Vullings propose explicit V&V of all stakeholder requirements [30]. However, enabling verification and validation of stakeholder requirements is depending on well-defined requirements.

Elich, Schreinemakers, and Vullings' review of more than 50 specifications in the Dutch principal and contractor domain revealed ill-defined requirements open to multiple interpretations, derived requirements without any design decision, and requirements unnecessarily prescribing solutions as the top 3 issues with requirements [30]. Similarly, studying construction projects of the New York City Transit reveals problems with ill-defined requirements leading to schedule delays, which prevented verification for an integrated system and resulted in inadequate training of facilities management personnel [9]. In sum, poor quality requirements are drivers of poor project management performance (time, cost, quality). Assessing requirements quality from a Systems Engineering perspective may provide benefits to the Norwegian construction industry as well.

Elich, Schreinemakers, and Vullings [30] also propose a dedicated organization to perform V&V at the project's initial stages. Moreover, "formal requirement reviews reveal early improvement opportunities and increase awareness of requirements quality". However, a challenge related to early V&V is the limited time and budget to perform V&V activities before releasing projects to tender due to external time pressure [30]. Moreover, the lack of V&V activities in the early phase results in incomplete specifications of tenders. The discipline-oriented division of work in the construction domain plays a crucial role in this. Whether the client chooses a principal contractor setup or chooses to coordinate all disciplines directly, the result is pretty much the same: the contract serves as a basis for the contractor of each discipline after the tender is completed [7], [9], [16], [30]. This increases the importance of a good partnering phase with enough time for proper stakeholder interaction and analysis.

Changes then result in claims and contract variations [7]. This is consistent with the Norwegian construction industry situation today. Norwegian standard contracts strictly regulate claims and contract variations, making changes or even clarifying ill-defined requirements an economic and legal matter. As Beste [2] reports, some projects do not start the Systematic Completion processes before beginning the construction phase. The late start of Systematic Completion processes does not mean that no other processes perform an initial review of requirements. However, examining the guidebook for the early phase from BA2015 [31] and the instructions for the early stages in hospital projects [32], we find that these only superficially address requirements development.

C. Discipline Orientation and Architecting of the Work

A distinct difference between sectors traditionally associated with Systems Engineering and the construction industry is that an often-long list of separate entities, responsible for a small part of the system, perform the system development and construction. The discipline-oriented structure and contractual boundaries have implications for system development. The flow-down of requirements happens across contractual boundaries [17]. The Systems Engineering effort becomes more about designing the work than the system [7]. The contract structure becomes the system architecture, which sometimes creates sub-optimal interfaces [30]. In addition to the discipline-oriented division, the design process is often isolated from the contractor's concerns [17], increasing barriers and decreasing commitment to the whole not only between disciplines but also between phases of a project.

Elich, Schreinemakers, and Vullings [30] found that when the principal had selected a small number of main contractors, those subcontracted work to other contractors in many cases due to specialization. This is consistent with the situation in Norway, although we see the contours of consolidation toward interdisciplinary contractors in the technical fields (such as Bravida, Caverion, and GK). Furthermore, there are often restrictions related to how many levels of subcontractors are accepted.

That Systems Engineering design in the construction domain is more about designing how to perform the work, is in part in keeping with what we see when working with tenders in the Norwegian construction industry. E.g., interface matrices in the tender specification to some extent address system interfaces. However, the emphasis lies on contractual interfaces and the definition of who shall coordinate with whom. Furthermore, following the traditional design process in construction, Aslaksen, Brouwer, and Schreinemakers argue that requirements serve only to develop the first design level. After that, the industry builds the next level of design on the previous level of design. The missing link to requirements makes verification and validation difficult [7], [17].

Explicitly assessing verification of subcontracted work, Makkinga, de Graaf, and Voordijk find similar problems [16]. They propose heavy coordination of further requirements development, verification, and interfaces by the principal to ensure the ability to verify at the top-level and reduce contradictions between decomposed requirements. Heavy coordination assumes requirements decomposition is happening.

Makkinga, de Graaf, and Voordijk [16] see verification and validation challenges rising due to new contract types, transferring responsibility from the client to a principal contractor. Principals then subcontract and more or less transfers responsibility to subcontractors for parts of the project. Examining tender specifications in our work over the last year, we find clauses making the individual subcontractor responsible for coordinating with other actors to ensure the successful solving of interfaces and enable the system's intended functionality. In keeping with Elich, Schreinemakers, and Vullings, what is defined in the contract gets done, at least from a theoretical perspective [30].

In addition, in the Norwegian construction domain, we see a shift towards increased use of more integrated contracts in the construction domain. First, the design-build contracts to a certain level integrate the design firms and the contractors. It alters their contractual relations in a way where the design firm works for the contractor instead of having a direct relationship with the client. Second, the partnering contracts and integrated project delivery contracts facilitate even more integrated project teams, creating more consortium-like relations across firm boundaries. Third, design, build, finance, maintain, and operate contract types also integrate the various lifecycle stages of a project. The use of such contracts is, however, rare in building construction. Although not yet studied in a Systems Engineering context and being aware of the various extent to which partnering is implemented [33], we assume partnering will positively influence contractual barriers that challenge verification and validation in construction projects.

VI. Conclusion

We find that the Norwegian construction industry has a fundamental problem of negative productivity growth, is plagued by delays, cost overruns, and quality problems. The sector is currently implementing Systems Engineering, under the name Systematic Completion, to address the challenges. We conclude that Systematic Completion is, in fact, a tailored version of Systems Engineering, and that Systems Engineering in construction must be considered a system-of-systems effort. This paper presents the context and design of an upcoming research project and explores the literature on Systems Engineering in the construction domain.

In the literature review, we find that knowledge is a crucial enabler of successful Systems Engineering implementation. Comparing the guidebooks and other material on Systematic Completion with guidebooks on Systems Engineering abroad, we find that the Norwegian guide is far less detailed. We also see a missing link to Systems Engineering, which may prevent the development of Systems Engineering competence in the Norwegian construction domain. We assume that the industry will benefit from tapping into the available literature and developing more detailed Norwegian guidebooks.

The literature reports about lack of focus on verification and validation. We also find issues with V&V related to ill-defined requirements. Ill-defined requirements are in part blamed on the lack of budget and time for V&V activities in the early phase. Subsequently, ill-defined requirements result in ambiguous contract specifications, schedule delays, and verification failure. In the Norwegian construction industry, we find an emphasis on verification. Requirements elicitation and quality of requirements are, however, less emphasized. As the Norwegian construction sector repeatedly fails to meet the time, cost, and quality requirements, the upcoming research project will focus on V&V effort in the early phase, including requirements.

In the manufacturing domain, system development is often carried out by one organization and the resulting product is produced in large volumes. In the construction domain, the development and construction efforts are spread across an often-long list of entities and the projects are mostly one-off efforts. While, in manufacturing, the design effort focuses on the system, the construction sector is more concerned with designing the work. Furthermore, contractual barriers result in suboptimal interfaces and verification and validation challenges. We assume that contractors' early involvement and partnering contracts can mitigate the contractual barriers the literature describes.

VII. LIMITATIONS

The present literature survey is far from exhaustive. It represents only a starting point for the Norwegian construction industry to familiarize itself with Systems Engineering in construction from an international perspective. Furthermore, the analysis considers only a limited number of aspects. However, we consider elements of fundamental and enabling character, hence serving as a good starting point.

VIII. FUTURE RESEARCH

We see numerous directions that further studies in this area can take. Beste [2] pointed out, taking other actors' perspectives will contribute to improved insight into the effects of systematic completion. We also suggest future research to take a quantitative approach assessing Systems Engineering application in the Norwegian construction domain. Furthermore, a comparative analysis between Systems Engineering projects and non-Systems Engineering projects may contribute to build justification of money spent in Systems Engineering efforts. While the present study focuses on the Systems Engineering approach, researching the effects of emerging digital tools (not to be confused with Model-Based Systems Engineering) on the Systems Engineering processes might be beneficial as the industry gets more familiar with the approach. Finally, preliminary findings in this study indicate that the industry may benefit from developing a more comprehensive and detailed Norwegian guide on Systems Engineering for the construction industry.

REFERENCES

[1] INCOSE, *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, 4th Edition | Wiley*, 4th ed. Hoboken, NJ, USA: John Wiley & Sons, Incorporated, 2015.

[2] T. Beste, "Effect of systematic completion on public construction projects," *Facilities*, Jun. 2020, doi: 10.1108/F-11-2019-0127.

[3] P. R. Johansen and T. I. Hoel, *Systematisk Ferdigstillelse - Veileder*. BA 2015, 2016.

[4] "GDP per capita (current US$) | Data," *The World Bank*, 2021. https://data.worldbank.org/indicator/ny.gdp.pcap.cd?end=2019&most_recent_value_desc=true&start=1960&view=chart (accessed Apr. 21, 2021).

[5] R. K. Yin, *Case Study Research and Applications: Design and Methods*, 6th Edition. Los Angeles: SAGE Publications, Inc, 2018.

[6] T. Cooke-Davies, "The 'real' success factors on projects," *Int. J. Proj. Manag.*, vol. 20, no. 3, pp. 185–190, Apr. 2002, doi: 10.1016/S0263-7863(01)00067-9.

[7] E. W. Aslaksen, P. Brouwer, and P. J. P. Schreinemakers, "Designing the Construction Process," *INCOSE Int. Symp.*, vol. 18, no. 1, pp. 1–15, Jun. 2008, doi: 10.1002/j.2334-5837.2008.tb00787.x.

[8] M. R. Emes, A. Smith, and L. Marjanovic-Halburd, "Systems for construction: lessons for the construction industry from experiences in spacecraft systems engineering," *Intell. Build. Int.*, vol. 4, no. 2, pp. 67–88, Apr. 2012, doi: 10.1080/17508975.2012.680428.

[9] W. Gleckler and A. O'Neil, "Applying Systems Engineering to Transit Facilities: Advancing Beyond 'Building Commissioning,'" *INCOSE Int. Symp.*, vol. 23, no. 1, pp. 1400–1417, Jun. 2013, doi: 10.1002/j.2334-5837.2013.tb03095.x.

[10] I. S. Yoo and Y. W. Park, "Conceptual Design of Building Automation System by Applying Systems Engineering Approach," *INCOSE Int. Symp.*, vol. 11, no. 1, pp. 1042–1046, Jul. 2001, doi: 10.1002/j.2334-5837.2001.tb02407.x.

[11] D. Boyd and D. Bentley, "A critique of conceptions of design and management in construction projects," *Constr. Manag. Econ.*, vol. 30, no. 6, pp. 441–454, Jun. 2012, doi: 10.1080/01446193.2012.688136.

[12] R. de Graaf, H. Voordijk, and L. van den Heuvel, "Implementing Systems Engineering in Civil Engineering Consulting Firm: An Evaluation," *Syst. Eng.*, vol. 19, no. 1, pp. 44–58, Jan. 2016, doi: 10.1002/sys.21336.

[13] R. S. (Robin) de Graaf, R. M. (Rick) Vromen, and J. (Hans) Boes, "Applying systems engineering in the civil engineering industry: an analysis of systems engineering projects of a Dutch water board," *Civ. Eng. Environ. Syst.*, vol. 34, no. 2, pp. 144–161, Apr. 2017, doi: 10.1080/10286608.2017.1362399.

[14] R. S. de Graaf and M. L. A. Loonen, "Exploring Team Effectiveness in Systems Engineering Construction Projects: Explanations Why Some SE Teams Are More Effective than Others," *Syst. Res. Behav. Sci.*, vol. 35, no. 6, pp. 687–702, Nov. 2018, doi: 10.1002/sres.2512.

[15] B. Elliott, A. O'Neil, C. Roberts, F. Schmid, and I. Shannon, "Overcoming barriers to transferring systems engineering practices into the rail sector," *Syst. Eng.*, vol. 15, no. 2, pp. 203–212, Jun. 2012, doi: 10.1002/sys.20203.

[16] R. Makkinga, R. de Graaf, and H. Voordijk, "Successful verification of subcontracted work in the construction industry," *Syst. Eng.*, vol. 21, no. 2, pp. 131–140, Mar. 2018, doi: 10.1002/sys.21425.

[17] E. W. Aslaksen, "Systems Engineering and the Construction Industry - Unpublished position paper for the 15th INCOSE Symposium." Jan. 12, 2005.

[18] M. W. Maier, "Architecting principles for systems-of-systems," *Syst. Eng.*, vol. 1, no. 4, pp. 267–284, Jan. 1998, doi: 10.1002/(SICI)1520-6858(1998)1:4<267::AID-SYS3>3.0.CO;2-D.

[19] J. Axelsson, J. Fröberg, and P. Eriksson, "Architecting systems-of-systems and their constituents: A case study applying Industry 4.0 in the construction domain," *Syst. Eng.*, vol. 22, no. 6, pp. 455–470, Nov. 2019, doi: 10.1002/sys.21516.

[20] S. M. C. Department of Defense, *Systems Engineering Fundamentals*. Defense Acquisition University Press, 2001.

[21] B. E. White, "Leadership under conditions of complexity," in *2016 11th System of Systems Engineering Conference (SoSE)*, Kongsberg, Norway, Jun. 2016, pp. 1–6, doi: 10.1109/SYSOSE.2016.7542887.

[22] B. E. White, "On Leadership in the Complex Adaptive Systems Engineering of Enterprise Transformation," *J. Enterp. Transform.*, Sep. 2015, Accessed: Mar. 20, 2021. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/19488289.2015.1056450.

[23] E. W. Aslaksen *et al.*, *Guide for the application of systems engineering in large infrastructure projects*, Version 1. San Diego: INCOSE Infrastructure Working Group, 2012.

[24] ProRail, *Handboek Systems Engineering (SE) Overzicht in processen, informatie en technieken*. 2015.

[25] Rijkswaterstaat, ProRail, Bouwend Nederland, Vereniging van Waterbouwers, NLingenieurs, and Techniek Nederland, *Guideline for Systems Engineering within the civil engineering sector*, 3rd Edition. Leidraad voor Systems Engineering binnen de GWW-sector, 2015.

[26] Atkins Norge AS, "Systematisk Ferdigstillelse | Atkins Norge," 2015. http://atkinsglobal.no/gjor-ting-riktig-forste-gang/ (accessed Dec. 05, 2020).

[27] Statsbygg, "PA 0701 SYSTEMATISK FERDIGSTILLELSE." Dec. 05, 2018, [Online]. Available: https://dok.statsbygg.no/wp-content/uploads/2021/02/PA-0701-Systematisk-ferdigstillelse.pdf

[28] Standards Norway, "NS 3935:2019 | Integrated technical building installations (ITB) - Designing, implementation and commissioning." 2019, Accessed: Dec. 05, 2020. [Online]. Available: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=1029927.

[29] Standards Norway, "NS 6450:2016 | Commissioning and testing of technical building installations." 2016, Accessed: Dec. 05, 2020. [Online]. Available: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=805837.

[30] E. Elich, P. Schreinemakers, and M. Vullings, "Verification & Validation; An inconvenient truth," *INCOSE Int. Symp.*, vol. 22, no. 1, pp. 650–662, Jul. 2012, doi: 10.1002/j.2334-5837.2012.tb01362.x.

[31] M. Lilleland-Olsen, M. K. Woldseth, and L. C. Iversen, *Tidligfase i byggeprosjekter - Veileder*. BA 2015, 2016.

[32] Sykehusbygg, "Veileder for tidligfasen i sykehusbyggprosjekter." 2017, [Online]. Available: https://sykehusbygg.no/Documents/Veiledere/Veileder-for-tidligfasen-i-sykehusbyggprosjekter.pdf

[33] A. Hosseini *et al.*, "Project Partnering in Norwegian Construction Industry," *Energy Procedia*, vol. 96, pp. 241–252, Sep. 2016, doi: 10.1016/j.egypro.2016.09.132.