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A Multi-Case Study

# Systems Engineering in Construction

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# Content

- Background
- Research method
- Case projects
- Results
- Indications
- Recommendations
- Limitations and generalization

# Background

## Pain Points

- 10% productivity decrease between 2000 and 2018*
- High conflict level
- Delays, cost overruns, quality issues

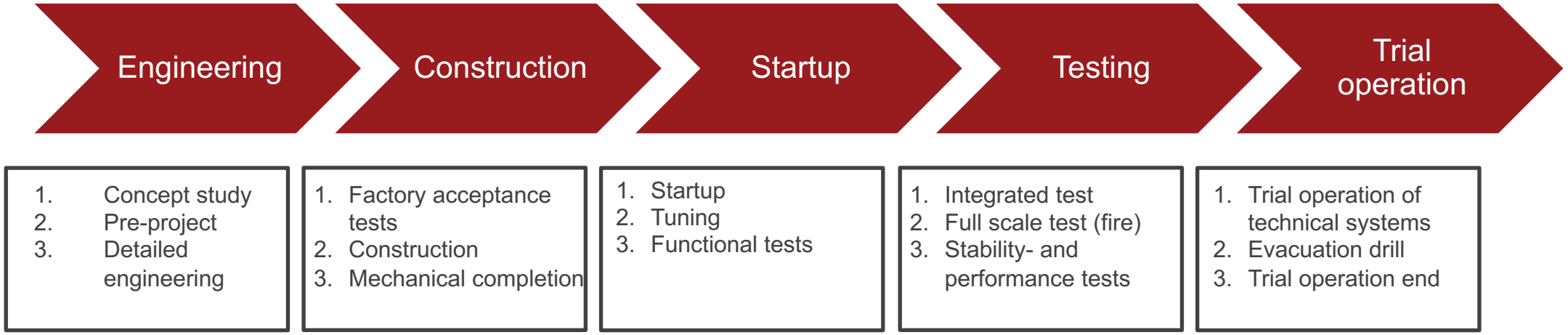
## Proposed Solutions

- Systematic Completion
- Integrated contractual approaches
- Lean Construction approaches

*(Statistics Norway, 2019)

# Background

NS 6450:2016*




*Authors translation

# Background [Problem]

The effect of Systems Engineering in the Norwegian construction industry is not well documented (Beste, 2020). It is uncertain whether the approach delivers the promised results or not, and there seems to be a lack of a shared understanding of the concept

# Background

## Goal

- Determine how successful implementation of SE is
- Contribute to shared understanding
- Recommendations for future efforts and research

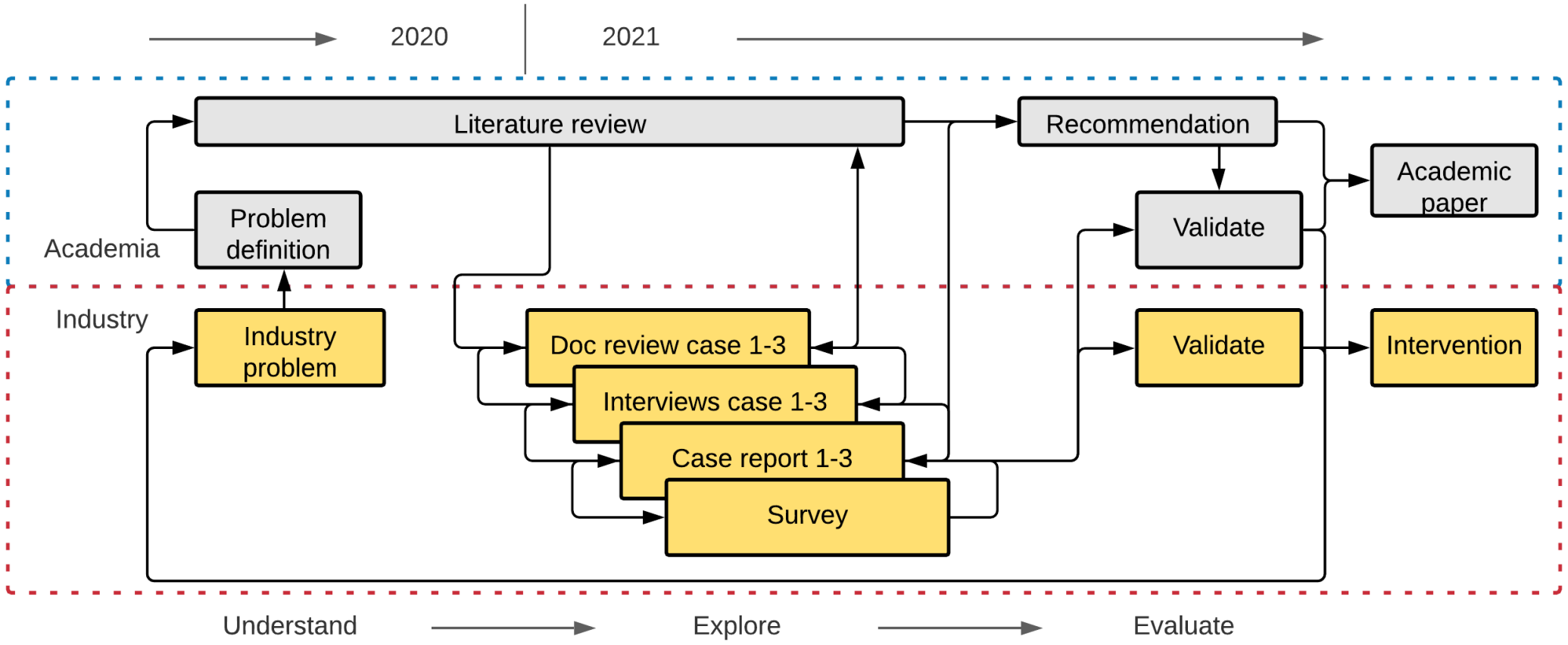
## Research Questions

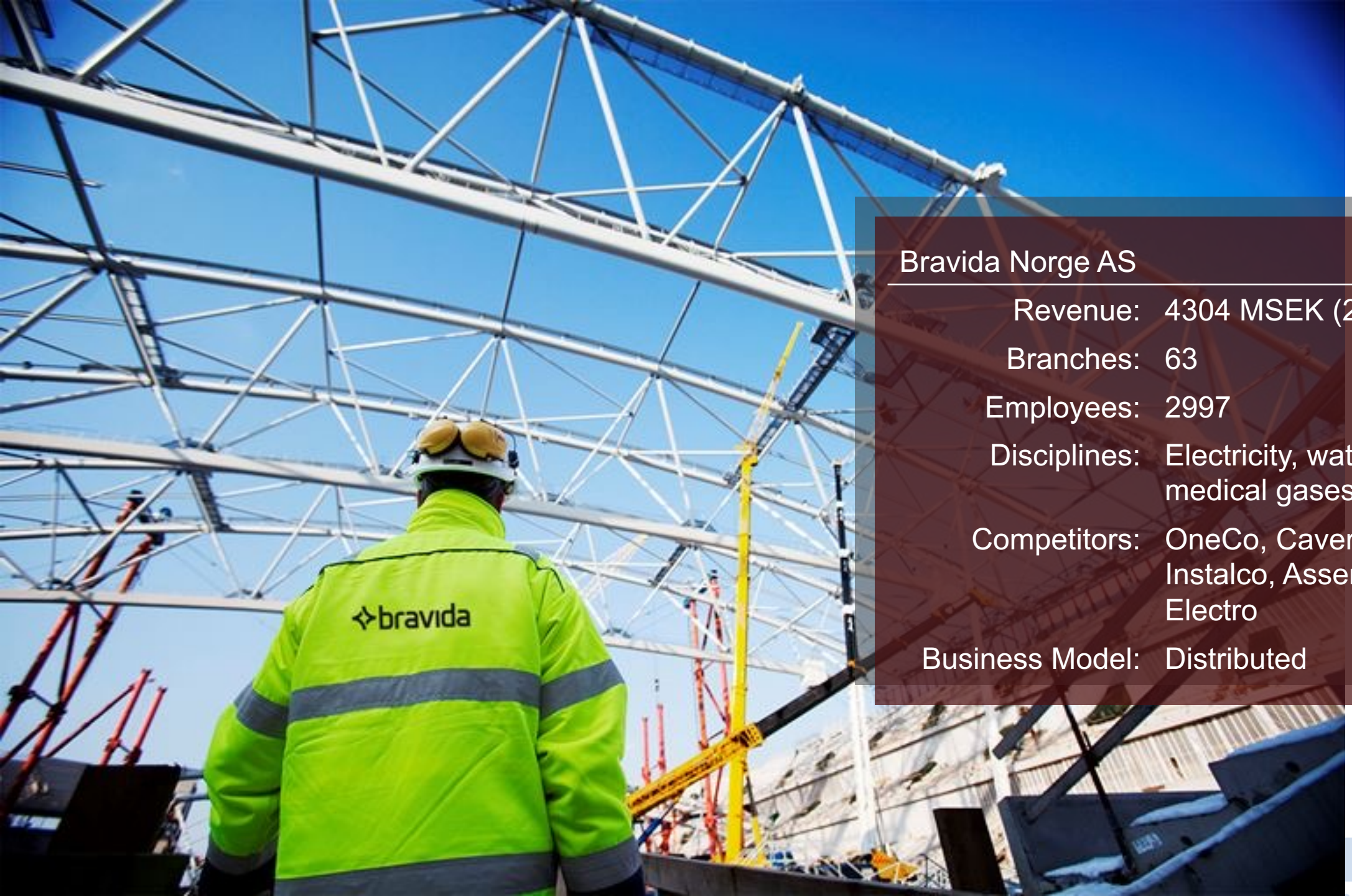
**RQ1:** How does Systems Engineering affect the technical subcontractor's project management performance in public healthcare building construction projects?

**RQ2:** What are the prerequisites to make Systems Engineering work for the technical subcontractor?

**RQ3:** What are the elements that contribute to effective Systems Engineering in construction?

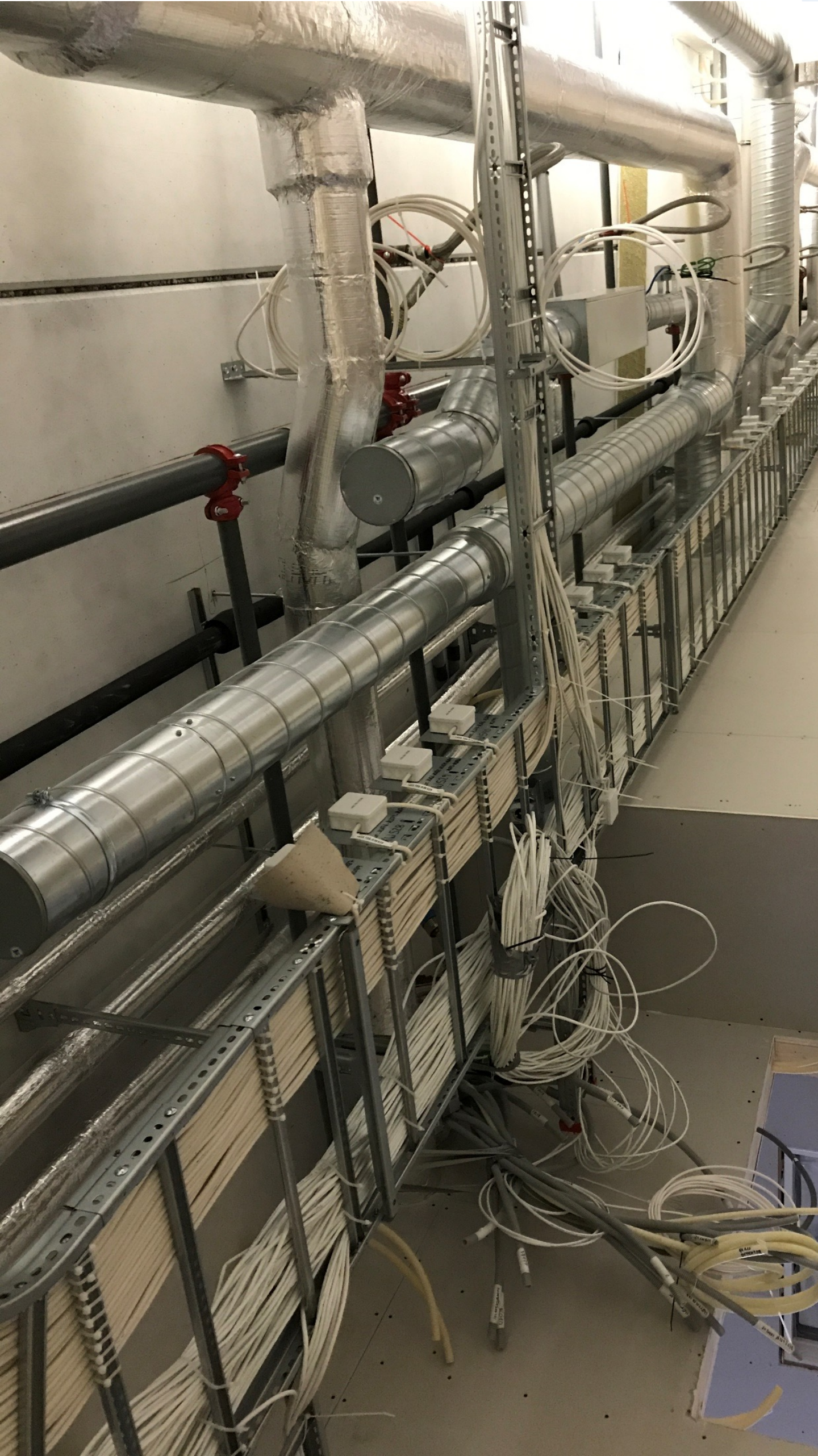
# Research Method





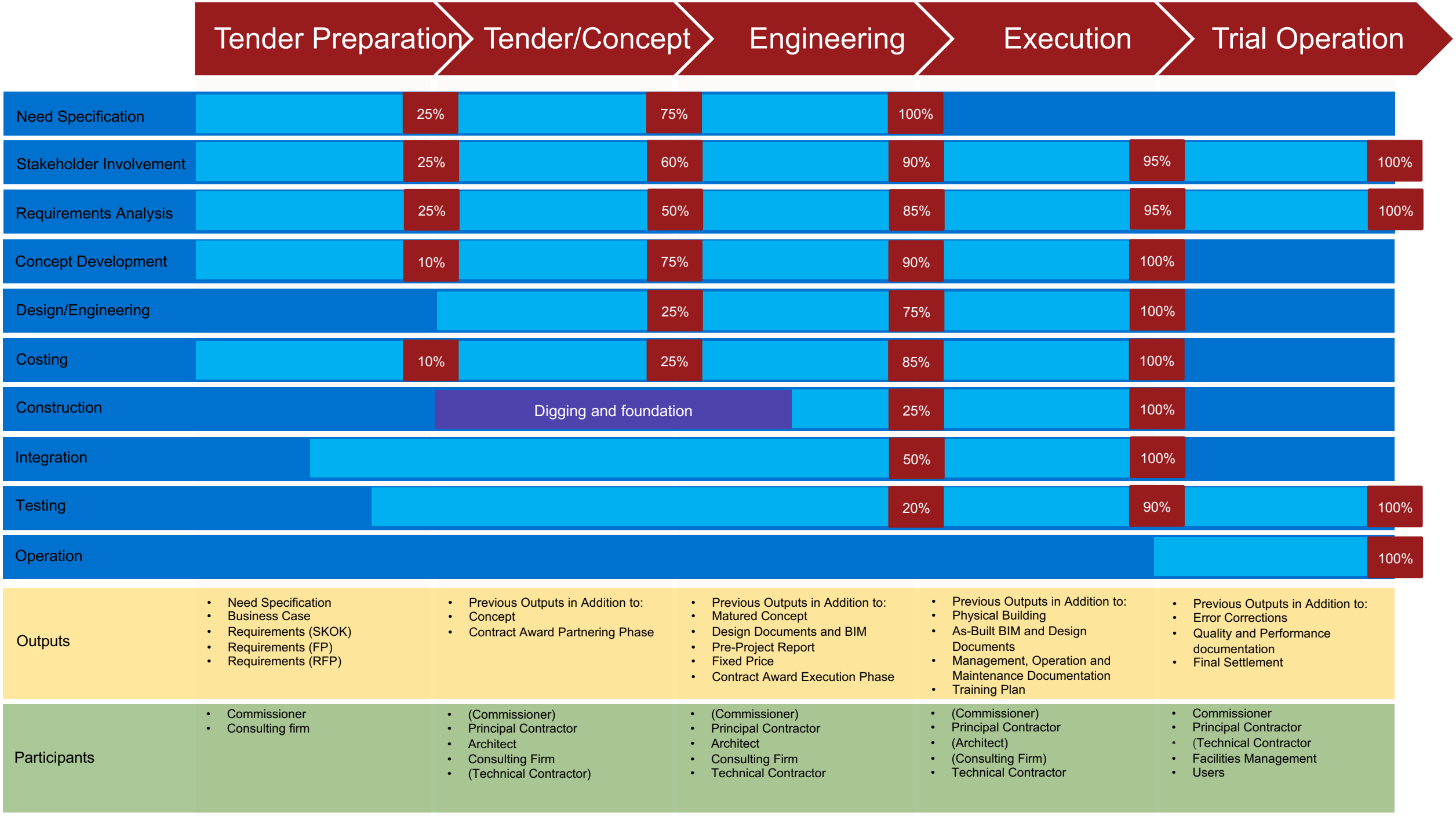

## Bravida Norge AS

| | |
|---|---|
| Revenue: | 4304 MSEK (2021) |
| Branches: | 63 |
| Employees: | 2997 |
| Disciplines: | Electricity, water, ventilation, medical gases, automation |
| Competitors: | OneCo, Caverion, GK, Instalco, Assemblin, Midroc Electro |
| Business Model: | Distributed |

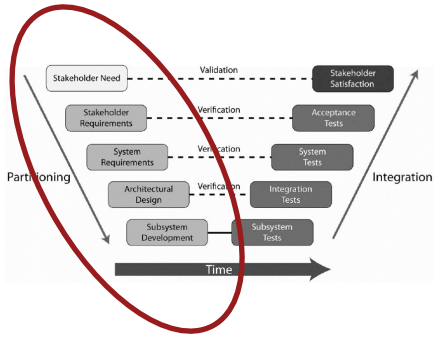


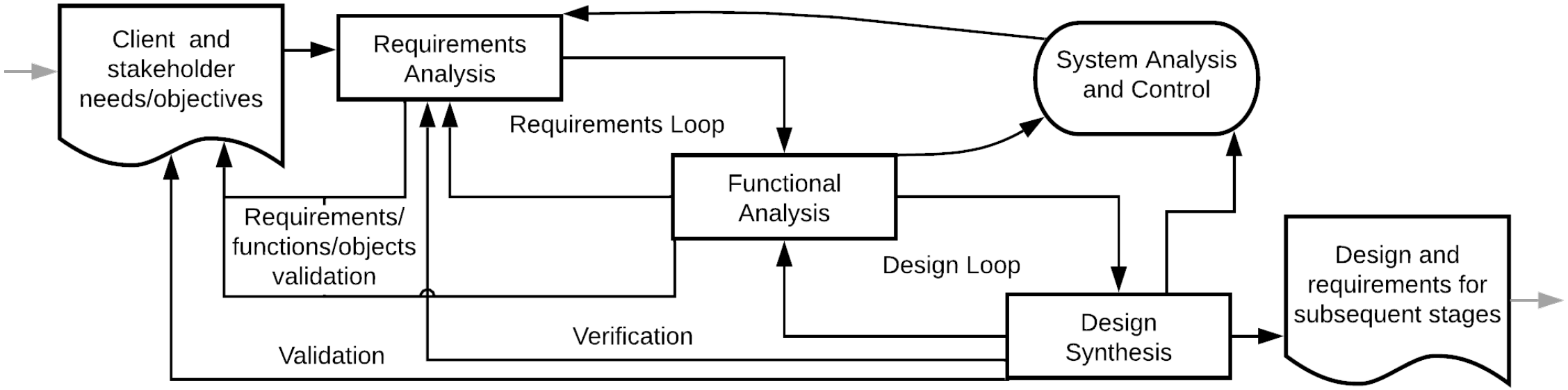
# Case Projects

| | Project 1 | Project 2 | Project 3 |
|---|---|---|---|
| **Description** | Project 1 builds a new healthcare facility in Norway. The facility includes hundreds of rooms of various sizes and complexity. | Project 2 builds a new healthcare facility in Norway. The facility includes hundreds of rooms of various sizes and complexity. | Project 3 builds a new healthcare facility in Norway. The facility includes thousands of rooms of various sizes and complexity. |
| **Contractual approach** | Partnering contract with a consecutive design-build contract. | Partnering contract with a consecutive design-build contract. | Design-bid-build approach with partnering/optimization before construction starts. |
| **Size / Budget** | >=30 000 sqm | <=30 000 sqm | >=100 000 sqm |
| **Bravida scope** | Single discipline contract | Interdisciplinary contract | Single discipline contract |
| **Bravida contract worth** | >=100 MNOK | >=100 MNOK | >=100 MNOK |


Tender Preparation
Tender/Concept
Engineering
Execution
Trial Operation
Need Specification
25%
75%
100%
Stakeholder Involvement
25%
60%
90%
95%
100%
Requirements Analysis
25%
50%
85%
95%
100%
Concept Development
10%
75%
90%
100%
Design/Engineering
25%
75%
100%
Costing
10%
25%
85%
100%
Construction
Digging and foundation
25%
100%
Integration
50%
100%
Testing
20%
90%
100%
Operation
100%
Outputs
• Need Specification
• Business Case
• Requirements (SKOK)
• Requirements (FP)
• Requirements (RFP)
• Previous Outputs in Addition to:
• Concept
• Contract Award Partnering Phase
• Previous Outputs in Addition to:
• Matured Concept
• Design Documents and BIM
• Pre-Project Report
• Fixed Price
• Contract Award Execution Phase
• Previous Outputs in Addition to:
• Physical Building
• As-Built BIM and Design Documents
• Management, Operation and Maintenance Documentation
• Training Plan
• Previous Outputs in Addition to:
• Error Corrections
• Quality and Performance documentation
• Final Settlement
Participants
• Commissioner
• Consulting firm
• (Commissioner)
• Principal Contractor
• Architect
• Consulting Firm
• (Technical Contractor)
• (Commissioner)
• Principal Contractor
• Architect
• Consulting Firm
• Technical Contractor
• (Commissioner)
• Principal Contractor
• (Architect)
• (Consulting Firm)
• Technical Contractor
• Commissioner
• Principal Contractor
• (Technical Contractor
• Facilities Management
• Users

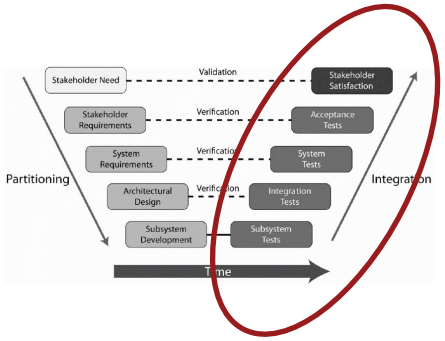
# SE Process

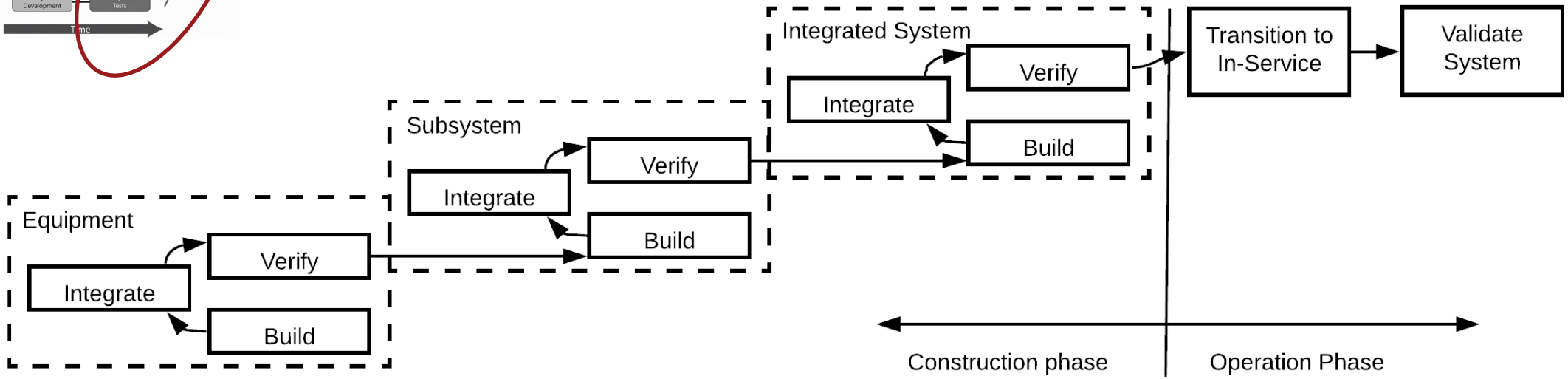



Adapted from Department of Defense (2001)

# SE Process




Adapted from Gleckler & O'Neil (2013)

# Results Document Review [Project 1-3]

- All three projects are required to follow the BA2015 guidebook, NS6450 and NS3935
- Systems Engineering is coordinated by either the principal contractor or the commissioner
- There is little traceable flow-down of requirements
- Requirements analysis is poorly documented in projects 1 and 2
- Functional descriptions are immature or not yet developed at all in projects 1 and 2

# Results Interviews

- Varying level of Systems Engineering Competence
- The lack of shared understanding of the approach is evident in the interviews
- Varying competence level combined with personnel replacement seem to contribute to poor continuity in Systems Engineering processes
- Perception of novelty varies between «we have always been doing this» and «this changes our projects in regard to XX and YY»
- Informants from all three projects have a positive perception of Systems Engineering's positive contribution to project management performance (time, cost, quality)
- Informants in project 3, in general, are more confident both in their competence and expected results

# Survey

1. Competence, knowledge and experience
2. Prerequisites to succeed with Systems Engineering
3. Process Importance for effective Systems Engineering
4. In my project we have […]
5. Systems Engineering contributes to [BA2015 statements]

# Competence and Knowledge

NPS = ∑(5) - ∑(1,2,3)

NPS > 0 is favorable

| | 1 | 2 | 3 | 4 | 5 | NPS | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|
| I have a clear understanding of how to perform Systems Engineering | 0 | 1 | 3 | 3 | 2 | -2/9 | -3/3 | -1/4 | 1/2 |
| I have a clear understanding of what Systems Engineering is | 0 | 0 | 1 | 4 | 4 | 3/9 | 1/3 | 1/4 | 1/2 |
| I am well acquainted with the BA2015 guidebook for Systematic Completion | 3 | 2 | 1 | 2 | 1 | -5/9 | -3/3 | -2/4 | 0/2 |
| I am well acquainted with NS6450 | 1 | 1 | 2 | 2 | 3 | -1/9 | -1/3 | 0/4 | 0/2 |
| I am well acquainted with NS3935 | 2 | 1 | 2 | 3 | 1 | -4/9 | -3/3 | 0/4 | -1/2 |
| I have participated in skills development initiatives related to Systems Engineering | 3 | 2 | 0 | 1 | 3 | -2/9 | 0/3 | -2/4 | 0/2 |

# Prerequisites to succeed with Systems Engineering

NPS = ∑(5) - ∑ (1,2,3)

NPS > 0 is favorable

| | 1 | 2 | 3 | 4 | 5 | NPS | Rank |
|---|---|---|---|---|---|---|---|
| Well defined interfaces | 0 | 0 | 0 | 0 | 8 | 8/8 | 1 |
| Enough and unambiguous documentation | 0 | 0 | 0 | 0 | 8 | 8/8 | 1 |
| Shared understanding of Systems Engineering and how we should perform it | 0 | 0 | 0 | 1 | 8 | 8/9 | 2 |
| A commissioner that is capable of making decisions continuously and timely | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Interdisciplinary perspective | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Traceability of requirements through various phases and decision-making processes | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Buildable design documents before construction startup | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Allocation of enough time and resources to perform Systems Engineering | 0 | 0 | 0 | 2 | 7 | 7/9 | 4 |
| Involvement of all actors in the project on an early stage | 0 | 0 | 1 | 0 | 7 | 6/8 | 5 |
| Investment of more effort (hours) in the early stage of a project | 0 | 0 | 0 | 3 | 6 | 6/9 | 6 |
| Limiting replacement of project personnel | 0 | 0 | 0 | 4 | 5 | 5/9 | 7 |
| Design/Engineering team involved in the project throughout to handover | 0 | 0 | 1 | 2 | 5 | 4/8 | 8 |

# Process Importance for Effective Systems Engineering

NPS = ∑(5) - ∑ (1,2,3)

NPS > 0 is favorable

| | 1 | 2 | 3 | 4 | 5 | NPS | Rank |
|---|---|---|---|---|---|---|---|
| Requirements analysis | 0 | 0 | 0 | 2 | 7 | 7/9 | 1 |
| Functional analysis | 0 | 0 | 0 | 3 | 6 | 6/9 | 2 |
| Design synthesis and development of design documents | 0 | 0 | 0 | 4 | 5 | 5/9 | 3 |
| Integration and test planning | 0 | 0 | 0 | 4 | 5 | 5/9 | 3 |
| User involvement and need specification | 0 | 0 | 0 | 5 | 4 | 4/9 | 4 |

| | 1 | 2 | 3 | 4 | 5 | I do not know | NPS |
|---|---|---|---|---|---|---|---|
| It is the iterative approach and combination of the various elements/processes that is the key to success, more than each element in isolation | 0 | 0 | 3 | 2 | 3 | 1 | 0/8 |

# In my project we have […]

NPS = ∑(5) - ∑ (1,2,3)

NPS > 0 is favorable

| | 1 | 2 | 3 | 4 | 5 | I do not know | NPS | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Performed a through requirements analysis | 1 | 0 | 2 | 1 | 5 | 0 | 2/9 | 1/3 | -1/4 | 2/2 |
| Unambiguous system requirements | 0 | 1 | 1 | 4 | 3 | 0 | 1/9 | 1/3 | -1/4 | 1/2 |
| Well organized requirements documentation | 1 | 1 | 1 | 3 | 3 | 0 | 0/9 | 0/3 | -1/4 | 1/2 |
| Traceability from requirements to design | 0 | 1 | 1 | 3 | 4 | 0 | 2/9 | 1/3 | -1/4 | 2/2 |
| Traceability from requirements to test plans and procedures | 0 | 1 | 1 | 6 | 1 | 0 | -1/9 | 0/3 | -2/4 | 1/2 |
| Experienced challenges related to ambiguous requirements or lack of documentation | 0 | 1 | 3 | 1 | 4 | 0 | 0/9 | 1/3 | 0/4 | -1/2 |
| Experienced challenges related to changing requirements | 0 | 1 | 1 | 3 | 4 | 0 | 2/9 | 2/3 | 0/4 | 0/2 |
| Developed unambiguous functional descriptions (or received these from the client) | 0 | 1 | 3 | 3 | 2 | 0 | -2/9 | -1/3 | -1/4 | 0/2 |
| Designed according to the requirements | 0 | 1 | 1 | 5 | 2 | 0 | 0/9 | 1/3 | 0/4 | -1/2 |
| Started test planning in the partnering phase | 0 | 0 | 2 | 4 | 3 | 0 | 1/9 | 2/3 | 0/4 | -1/2 |
| A client that delivers decisions continuously and timely | 1 | 2 | 3 | 3 | 0 | 0 | -6/9 | -1/3 | -4/4 | -1/2 |
| Allocated enough man-hours to perform a good systematic completion | 1 | 1 | 1 | 3 | 2 | 1 | -1/8 | 0/2 | -2/4 | 1/2 |

# Shared Understanding

NPS = ∑(5) - ∑ (1,2,3)

NPS > 0 is favorable

| | 1 | 2 | 3 | 4 | 5 | NPS | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|
| We have a shared understanding in Bravida's project organization of Systematic Completion and how we should perform it | 0 | 4 | 3 | 1 | 1 | -6/9 | 0/3 | -4/4 | -2/2 |
| We have a shared understanding in Bravida of Systematic Completion and how we should perform it | 0 | 3 | 3 | 3 | 0 | -6/9 | -1/3 | -3/4 | -2/2 |
| There is a shared understanding in the industry of Systematic Completion and how we should perform it | 1 | 3 | 4 | 1 | 0 | -8/9 | -3/3 | -3/4 | -2/2 |

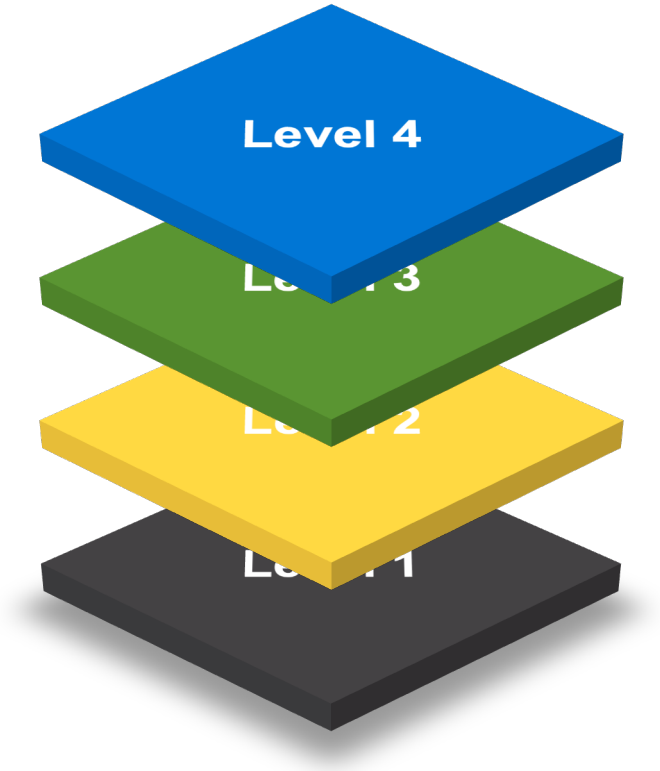
# Indications From Our Research

- Disconnect between what is considered important and what is done in practice
- Performance of Systems Engineering processes increases and challenges related to deficiencies decreases when competence level increases
- Poor process-quality leads to substantial risk
- Resource shortage in the early phases and frequent personnel replacement negatively affects process quality, documentation and continuity

# Recommendations

Formalize documentation

Improve Systems Engineering competence




Front-loading of workload and resource allocation

Formalize requirements analysis

# RQ1: How does Systems Engineering affect the technical subcontractor's project management performance in public healthcare building construction projects?

- Informants perceive that Systems Engineering contributes positively to project management performance
- Findings indicate that low Systems Engineering competence negatively affects process quality
- Findings indicate that poor process quality diminishes contribution to project management performance

# RQ2: What are the prerequisites to make Systems Engineering work for the technical subcontractor?

| | 1 | 2 | 3 | 4 | 5 | NPS | Rank |
|---|---|---|---|---|---|---|---|
| Well defined interfaces | 0 | 0 | 0 | 0 | 8 | 8/8 | 1 |
| Enough and unambiguous documentation | 0 | 0 | 0 | 0 | 8 | 8/8 | 1 |
| Shared understanding of Systems Engineering and how we should perform it | 0 | 0 | 0 | 1 | 8 | 8/9 | 2 |
| A commissioner that is capable of making decisions continuously and timely | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Interdisciplinary perspective | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Traceability of requirements through various phases and decision-making processes | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Buildable design documents before construction startup | 0 | 0 | 0 | 1 | 7 | 7/8 | 3 |
| Allocation of enough time and resources to perform Systems Engineering | 0 | 0 | 0 | 2 | 7 | 7/9 | 4 |
| Involvement of all actors in the project on an early stage | 0 | 0 | 1 | 0 | 7 | 6/8 | 5 |
| Investment of more effort (hours) in the early stage of a project | 0 | 0 | 0 | 3 | 6 | 6/9 | 6 |
| Limiting replacement of project personnel | 0 | 0 | 0 | 4 | 5 | 5/9 | 7 |
| Design/Engineering team involved in the project throughout to handover | 0 | 0 | 1 | 2 | 5 | 4/8 | 8 |

# RQ3: What are the elements that contribute to effective Systems Engineering in construction?

| | 1 | 2 | 3 | 4 | 5 | NPS | Rank |
|---|---|---|---|---|---|---|---|
| Requirements analysis | 0 | 0 | 0 | 2 | 7 | 7/9 | 1 |
| Functional analysis | 0 | 0 | 0 | 3 | 6 | 6/9 | 2 |
| Design synthesis and development of design documents | 0 | 0 | 0 | 4 | 5 | 5/9 | 3 |
| Integration and test planning | 0 | 0 | 0 | 4 | 5 | 5/9 | 3 |
| User involvement and need specification | 0 | 0 | 0 | 5 | 4 | 4/9 | 4 |

# Limitations and Generalization

- We only provide indications based on opinions
- None of the projects are finished
- Difficult to quantify in general – lack of high resolution performance data
- Inexperienced informants (5/9) raises a reliability issue and exposes results to confirmation bias
- Might not get the full picture of all processes in project 2 (frequent personnel replacement)
- External validation increases our confidence in the results and the generalizability
- Converging results with other research also increases our confidence in validity of the results

# Future Research

- More studies investigating Systems Engineering in Construction from various perspectives [client, general contractor, technical contractor, engineering consulting firm, etc.]
- Re-assessment of the three case projects throughout the life-cycle
- Extensive study using rigorous framework to assess degree of implementation, process quality, and results

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