Systems Engineering in the B&U

Research into what lessons can be learned from the Systems Engineering method in the GWW-sector in order to improve the tendering phase of the B&U-sector and how can SE then be applied in a B&U tender.

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BESIX

Systems Engineering in the B&U

By

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Preface

"My passion and great enjoyment for architecture and the reason the older I get the more I enjoy it, is because I believe we – architects – can affect the quality of life of the people" Richard Rogers.

This belief has resonated with me through my undergraduate experiences in Built Environment where my fascination with buildings and the intricate relationship with their inhabitants nurtured. The construction design process especially what went on 'behind-the-scenes' sparked an insatiable curiosity because I could not truly appreciate the end result without understanding how it was achieved. I pursued a Master in Construction Management and Engineering, furthering my drive to know the unknown and there it was for the first time that I was introduced to Systems Engineering. This method put all the pieces of my architectural puzzle in perspective and served as the solution for systematic, and efficiently managing the design, construction and maintenance of construction projects. As SE has a multitude of applications within infrastructural design and development I wanted to explore and push the scope of its abilities to include building projects. As such I chose to investigate this topic for my final thesis at the Technical University of Delft.

After 10 months of research I am very pleased with the results and can reflect on this journey with a sense of pride. I leaned on many shoulders throughout this time, people who deserve to be named as they have been invaluable to the research process, my personal well-being and professional growth. Firstly, I would like to thank my graduation committee at TU Delft for bringing this thesis to a successful conclusion through their dedicated review of my progress. My heartfelt appreciation must go out to Hans for keeping me on my toes with his critical feedback; Sander for honing my focus and ensuring I persevere on the right course; Jos for taking so much of his time to help me acquire and retain in-depth knowledge of Systems Engineering.

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I would also like to thank the interviewees and all those who were involved with my thesis directly and indirectly. In particular, the BESIX's Systems Engineering team for ensuring I have memorable experiences during my graduate internship.

Last but not the least, I will acknowledge my true support system made up of family and friends as without them I would not be where I am today. Especially, for my parents and Sehrish's dedication and patience.

Usman Ishfaq,
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Summary

Introduction
In the Dutch residential and non-residential (B&U) industry, building projects are getting massive in size, increasingly complex and intelligent by integrating technologies such as safety, communications, comfort and entertainment. Moreover, the influence of the stakeholders on the requirements of buildings is continuing to grow too. With the rising complexity and stakeholder requirements in construction projects, the cost and time performance is below standard and at the same time, buildings are expected to adapt to the changing functional needs and user's requirements over the lifetime. Thus, construction projects in the Netherlands are getting complex and dynamic. The fast changing developments in the building industry demands a different approach towards construction projects.
Therefore, governments and building regulations across the world are shifting towards performance-based approach that encompasses the entire life cycle of a building. Hence, integrated contracts were introduced for the B&U-sector. The traditional process of construction projects was very much fragmented; each construction phase had different contracts with a different party. In the integrated approach a consortium is created, which is responsible for designing, constructing and maintaining the building for a given time period.
The introduction of integrated contracts has changed the internal organizational role of actors, especially for the architect. Instead of hierarchical architect-led decisions, decision-making in an integrated approach has flattened. As a consequence, every actor has to contribute and communicate his knowledge to the design process. The performance requirements from the client and the fulfilment of those requirements by the executing party are lacking a proper framework to accommodate the above-mentioned complexities.

In other industries, such as the GWW-sector (infrastructure), where also performance-based projects with high complexity and multidisciplinary teams are conducted, Systems Engineering (SE) is successfully practised. Since many building companies also work in the domain of infrastructure and have experience in using SE in infrastructure (GWW), an analogy can be made for building projects. Consequently, it can be explored if a Systems Engineering (SE) approach can be an opportunity for the building construction.
Therefore, the problem definition of this thesis is as follows: *It is unclear for construction companies in The Netherlands on how Systems Engineering can be applied and translated from the GWW-sector to their projects in the B&U-sector.*

Consequently, this thesis is prepared in collaboration with BESIX, a construction company in The Netherlands. Due to the scope decisions with BESIX it was chosen to investigate the applicability of Systems Engineering to the tender phase of building projects. This resulted in the following research question: *What lessons can be learned from the Systems Engineering method in the GWW-sector in order to improve the tendering phase of the B&U-sector and how can SE then be applied in a B&U tender?*

To answer the research question three sub-question were formulated:
1. Why are building projects getting complex?
2. What can Systems Engineering contribute to B&U?
3. What are the findings from the practices of SE in the construction industry?

By answering these research questions the main objective of this research can be met, which is: *to explore the Systems Engineering method in the tendering phase of the B&U-sector by comparing with the current practices of SE in GWW-sector of BESIX Nederland to ultimately give recommendations to the tender manager.*

Sub-question 1 and 2 will be answered through theory-oriented studies. The literature study is conducted to understand the problem statement in-depth and get a wider knowledge of the research objects, such as buildings, Systems Engineering, the role of architect, and integrated approach. From the literature study an analytical framework was developed in which propositions were defined. These propositions were constructed out of the information accumulated from the literature study which could not be validated. The propositions are tested with practical studies, which will answer sub-question 3.
The practical study consists of case studies in GWW and B&U and interviews with experts of SE. The interviews and case studies are then analysed and interpreted. As a result, the three sub-queries can answer the main research question and give recommendations so that the research objective can be achieved.

Literature study
In the literature study the first two sub-questions are answered. The answers are summarized hereunder.

In the first sub-question the characteristics are investigated for buildings and building design. With integrated contracts, the architect and constructor gets the opportunity to collaborate together from the design phase. Therefore, the architect forms a consortium with the contractor and other relevant parties. It ensures the architect that input from the builder (engineer, specialist and maintenance) is received during the design phase for the whole life cycle. Constructor's expertise and specialized knowledge of various disciplines can then be incorporated during building design. Consequently, an accurate design can be made with fewer failures in the later stages. It will create value and strive for more innovative solutions as both the disciplines can create synergy. Since, changes made in design phase are less costly than changes made during realisation, it will also reduce the failure cost. Therefore, a well-thought design that includes the life cycle of the building is important hence the role of an architect who leads the design is even more significant than before.
It is observed that due to the integrated approach, the complexity of building projects lies in the following characteristics:

- Changes in the design process of buildings. (Bektaş, 2013; B. Lawson, 2005; Pektas & Pultar, 2006; Sebastian, 2011; Zager, 2002)
- Increasing numbers of actors that are involved during project. (Chiocchio, Forgues, Paradis, & Iordanova, 2011; Flapper & Witten, 2004)
- Incorporating technical developments and innovations during the life cycle of buildings. (Sinopoli, 2010)
- Human aspects in buildings such as psychological, social, cultural and aesthetic aspects. (B. Lawson, 2005; Preiser & Vischer, 2005; Preiser, 1983)

The above-mentioned complexity challenges are imperative to overcome when designing successful buildings. Therefore, in the second sub-question, it was explored what Systems Engineering can contribute to the building projects to overcome the above-mentioned complexity.

Systems Engineering is defined as a systematic and interdisciplinary approach for designing, constructing and maintaining complex systems in order to provide quality products that meet the user needs. In a construction project, it aims at delivering a sound and successful project that meets the client's needs and stakeholders requirements. SE tools can create added value in the form of better project control through explicit communication and comprehensive documentation, cost reduction, time efficiency, risk management and decreasing the loss of resources. The contribution of SE tools to the building complexity is listed in the table hereunder.

Challenges in B&U due to integrated contracts	Contribution of Systems Engineering tools
Changes the contractual relationship of actors. Subsequently changing their roles.	Better control of projects and risks.
More stakeholders, due to life cycle approach, each with their own set of requirements.	Tools for transforming client's requirements into design solution.
Increasing numbers of internal organisation actors within the design process.	Clear, explicit, and structured way of documenting project information. Thus, better communicating.
Rapid technological innovations make the future unpredictable.	- Better control of projects and risks. - In line with integrated contracts because of the life cycle approach.
Different mode of reasoning by the actors involved in the design phase.	Structuring the problem space by - Tools for transforming client's requirements into a design solution. - Clear, explicit, and structured way of documenting project information. Thus, better communication.

Practical study
It is not clear how Systems Engineering can be applied in the tender phase. Neither can the research objective be entirely validated from the literature study. Therefore, three propositions are drawn from the literature study that will be analysed by means of a case study and interviews.

I. Systems Engineering can contribute positively to B&U projects in the tender phase.
II. The Systems Engineering process in B&U project will be different from the SE process in GWW projects.
III. An architect, due to the nature of his work can't use Systems Engineering.

To test the propositions six interviews where held with representatives in three case projects. Moreover, the documents of the case projects were also examined. In addition, 5 interviews were held with experts in the field of Systems Engineering. In total: eleven interviews and documents examination of three projects led to an analysis of the propositions.

Analysis of the proposition
It turned out that proposition I holds true. In practise: the project personnel perceived better control of the projects by applying Systems Engineering. Proposition II however is not entirely true. From the analysis it is observed that the process of B&U is not different than the process of GWW. The tools used and the steps taken are the same in the B&U and GWW. On the other hand, a distinction is made on the importance and dominance of the tools and the starting point of SE. Proposition III is also not completely true. The Design Thinking of an architect is in contrast with the Systems Thinking of SE. In Design Thinking, the architect focus on the solution space, while Systems Thinking emphasises the problem space. In that sense, Systems Engineering can help the architect in understanding, unravelling and structuring the problems to provide adequate solutions to the project.

The practical study led to formulating the findings from the practises of SE in the case projects, these are;
- SE is indirectly used in the tender phase
- SE is perceived as V&V and Relatics
- Lack of SE standardization is observed in the tender phase
- The starting point of SE in B&U is from the activities needed and of GWW the functions performed
- In B&U the emphasis is placed upon different tools compared to the tools in GWW.
- In a B&U-tender a balance is needed in Systems Thinking and Design Thinking.

Conclusions and recommendations
The conclusion to the main research question can be given in two parts:
(A) What lessons can be learned and implemented from the case projects?
(B) How can Systems Engineering be applied in a B&U tender?

(A) What lessons can be learned and implemented from the case projects?
- Project personnel do not view SE from a comprehensive view and believe it encompasses verification & validation and Relatics.
- If there is a larger degree of standardization of SE for the tender phase understanding and usage of SE tooling will be easier for project personnel.
- In B&U, a balanced approach of Systems Thinking and Design Thinking is required
- B&U gives significance to GBS (Geographical Breakdown Structure) and in GWW the importance is towards SBS (Systems Breakdown Structure).

(B) How can Systems Engineering applied in a B&U tender?
To apply Systems Engineering in the tender, following aspects have to be considered
- Mode of thinking: Start with Systems Thinking and gradually shift to Design Thinking
- Steering: Risk driven SE should be applied, where risk is prioritized
- Tooling: Start with the activity process and GBS.

To apply SE in the B&U tender six recommendations are given for the tender manager

- Gain knowledge of SE tools and current practises
- Understand the perspectives of various thinking methods
- The architect must have a leading role in the tender
- In B&U: more interactions are needed than in GWW
- Optimize standardization of SE for the tender
- Use SE from the beginning of the tender process

Samenvatting

Introductie
In de Nederlandse Burgelijke- en Utiliteitsbouw (B&U) worden bouwprojecten steeds groter in omvang, complexer en intelligenter door het integreren van technologieën zoals veiligheid, communicatie, comfort en entertainment. Daarnaast blijft de constante invloed van stakeholders en de vraag naar flexibiliteit in gebouwen groeien. Met de stijgende complexiteit en toenemende eisen in de bouwprojecten, komen de kosten en de tijd prestaties onder druk te staan. Tegelijkertijd wordt er verwacht dat gebouwen zich aan kunnen passen aan de veranderende behoeften en doelstellingen van de gebruikers over de levensduur. Zodoende worden bouwprojecten in Nederland steeds complexer en dynamischer. De snel veranderende ontwikkelingen in de bouw vraagt dan ook om een andere benadering richting projecten.
Momenteel verschuiven overheden en bouwvoorschriften in de richting van prestatie gericht bouwen. In deze vorm van bouwen wordt de gehele levenscyclus van een gebouw opgenomen. Hiervoor zijn geïntegreerde contracten geïntroduceerd voor de B&U-sector. In geïntegreerde contracten wordt een consortium gecreëerd die verantwoordelijk is voor het ontwerpen, bouwen en onderhouden van het gebouw voor een bepaalde periode. In tegenstelling tot het traditionele proces van bouwprojecten waar ieder bouwfase verschillende contracten heeft met verschillende partijen.
Als gevolg heeft de introductie van geïntegreerde contracten de interne organisatorische rollen van de actoren veranderd, vooral de rol van de architect is veranderd. Eerst werden op een hiërarchische methode beslissingen genomen door de architect, maar nu in een geïntegreerde benadering is hierarchie wegevallen en worden beslissingen genomen door samenwerking. Als gevolg daarvan, behoort iedere actor zijn kennis bij te dragen en te communiceren in het ontwerpproces. De prestatie-eisen van de klant en de bijbehorende vervulling van de bouwbedrijf ontbreken de juiste kader om de bovengenoemde complexiteit tegemoet te komen.

In vergelijkbare sectoren, zoals de GWW-sector (infrastructuur) waar ook geïntegreerde contracten zijn geïntroduceerd, wordt de Systems Engineering (SE) methode met succes uitgevoerd. Aangezien veel bouwbedrijven ook werken op het gebied van infrastructuur en daarnaast ervaring hebben in het gebruik van SE in de infrastructuur (GWW), kan een vergelijking gemaakt worden voor bouwprojecten. Hierdoor kan onderzocht worden of de Systems Engineering (SE) methode ook een mogelijkheid biedt voor de B&U sector.

De probleemstelling in dit proefschrift kan als volgt gedefinieerd worden:
Het is onduidelijk voor bouwbedrijven in Nederland hoe Systems Engineering kan worden vertaald en toegepast vanuit de GWW-sector voor hun projecten in de B&U-sector.

Daarom wordt dit proefschrift opgesteld in samenwerking met BESIX, een bouwbedrijf in Nederland. Vanwege de scope beslissingen met BESIX werd er gekozen om de toepasbaarheid van Systems Engineering gedurende de aanbestedingsfase van bouwprojecten te onderzoeken. Dit heeft geleid tot de volgende onderzoeksvraag:
Welke lessen kunnen getrokken worden uit de Systems Engineering methode in de GWW-sector om de aanbestedingsfase van de B&U-sector te beoordelen en hoe kan SE dan worden verwerkt in een B&U aanbesteding?

Om de onderzoeksvraag te beantwoorden zijn drie sub-vragen geformuleerd:
1. Waarom worden bouwprojecten steeds complexer?
2. Wat kan Systems Engineering bijdragen aan de B&U-sector?
3. Wat zijn de bevindingen van SE vanuit de infrastructuur industrie?

Door het beantwoorden van deze onderzoeksvragen kan de hoofdvraag van dit onderzoek worden voldaan, het doel van het onderzoek is: *Verkennen van de Systems Engineering methode in de aanbestedingsfase van de B&U-sector door te vergelijken met de huidige praktijken van de SE in de GWW-sector van BESIX Nederland om uiteindelijk aanbevelingen te verstrekken aan de tender manager.*

Om de hoofdvraag en de sub-vragen te beantwoorden zijn er twee studies uitgevoerd.
Deelvraag 1 en 2 zijn beantwoord door middel van een theoretisch georiënteerde studie. In deze studie wordt een literatuuronderzoek uitgevoerd om de probleemstelling met diepgang te begrijpen en een breder beeld te verkrijgen van het onderzoek objecten, zoals gebouwen, Systems Engineering, architect, en geïntegreerde

aanpak. Uit de literatuurstudie is vervolgens een analytisch kader ontwikkeld waarin stellingen zijn gedefinieerd. Deze stellingen konden niet volledig gevalideerd worden door de literatuurstudie alleen, daarom worden de stellingen getest met praktische studies. De praktische onderzoek bestaat uit case studies in de GWW en B&U, die sub-vraag 3 beantwoorden. Er zijn interviews met experts en beoefenaars van SE gehouden om de stellingen te valideren. De interviews en case studies worden vervolgens geanalyseerd en geïnterpreteerd.

Literatuuronderzoek
In de literatuurstudie worden de eerste twee sub-vragen beantwoord.
In de eerste deelvraag worden de karakteristieke kenmerken onderzocht voor gebouwen. Met geïntegreerde contracten krijgen de architect en de aannemer de kans om samen te werken vanaf de ontwerpfase. Daarom vormt de architect samen met de aannemer en andere relevante partijen een consortium. Dit zorgt ervoor dat de architect input krijgt van de bouwer (ingenieur, specialist en onderhoud) tijdens de ontwerpfase voor de gehele levenscyclus. De bouwers expertise en gespecialiseerde kennis kan dan tijdens het ontwerpen van gebouwen worden meegenomen. Derhalve kan een nauwkeurige ontwerp worden gemaakt met minder fouten in de latere stadia. Aangezien wijzigingen in de ontwerpfase minder kostbaar zijn dan veranderingen tijdens de uitvoering, zal het ook de kosten voor falen verminderen. Daarom is het belangrijk om een goed doordacht ontwerp te maken die de hele levenscyclus van het gebouw omvat.
Het is opgemerkt dat door de geïntegreerde benadering, de complexiteit van bouwprojecten in de volgende eigenschappen ligt;

- Veranderingen in het ontwerpproces van gebouwen. (Bektaş, 2013; B. Lawson, 2005; Pektas & Pultar, 2006; Sebastian, 2011; Zager, 2002)
- Toenemen van de aantal actoren die betrokken zijn bij het project. (Chiocchio, Forgues, Paradis, en Iordanova, 2011; Flapper & Witten, 2004)
- Integratie van technische ontwikkelingen en innovaties tijdens de levenscyclus van gebouwen. (Sinopoli, 2010)
- Menselijke aspecten in gebouwen zoals psychologische, sociale, culturele en esthetische aspecten. (B. Lawson, 2005; Preiser & Vischer, 2005; Preiser, 1983)

De bovengenoemde complexe uitdagingen zijn noodzakelijk te overwinnen bij het ontwerpen van succesvolle gebouwen.
Daarom is bij de tweede sub-vraag onderzocht wat Systems Engineering kan bijdragen aan de bouwprojecten om de bovengenoemde complexiteit te overwinnen.

Systems Engineering is gedefinieerd als een systematische en interdisciplinaire benadering voor het ontwerpen, aanleggen en onderhouden van complexe systemen om de kwaliteit van producten die voldoen aan de behoeften van de gebruiker te bieden. In bouwprojecten, betekent dit het leveren van een goed en succesvol project dat voldoet aan de behoeften van de klant en stakeholders. De SE gereedschappen kunnen een toegevoegde waarde bieden in de vorm van een betere projectbeheersing door middel van expliciete communicatie en uitgebreide documentatie, kostenreductie, tijd efficiëntie en effectief risicomanagement. Bijdrage van SE instrumenten aan de complexiteit van het gebouw kan gezien worden in de onderstaande tabel.

Uitdagingen in B&U door geintegreerde contracten	Bijdrage van SE gereedschappen
De contractuele relaties van actoren veranderen. Waardoor hun rol veranderd.	Beter controle van projecten en risico's.
Toenemen van stakeholders, door het levenscyclus aanpak, elk met zijn eigen vereisten.	Gereedschappen om cliënt eisen om te zetten in een ontwerp oplossing.
Toenemen van de interne organisatie actoren binnen het onwerp proces.	Heldere,expliciete en een gestructureerde manier van documenteren. Hierdoor ontstaat er een betere vorm van communicatie.
Technische innovaties maken de toekomst onvoorspelbaar.	Beter controle van projecten en risico's. De plannen komen overeen met geïntegreerde contracten door het levenscyclus benadering.
Verschillende beredeneringen van actoren worden al behandeld in het ontwerpfase.	Structureren van het probleem met - Gereedschappen voor het transformeren van klanten eisen naar de ontwikkelings oplossing. - Heldere, expliciete en een gestructureerde manier van documenteren. Hierdoor onstaat er een beter vorm van communicatie.

Praktijkonderzoek
Om de derde centrale vraag (Wat zijn de bevindingen uit de praktijken van SE in de bouw?) te beantwoorden is het niet duidelijk hoe Systems Engineering in de aanbestedings fase kan worden toegepast. Evenmin kan de doelstelling van het onderzoek niet volledig gevalideerd worden uit de literatuurstudie. Daarom zijn drie stellingen vanuit de literatuur ontleend die worden geanalyseerd met behulp multiple casus en interviews.

I. Systems Engineering kan een positieve bijdrage leveren aan B&U-projecten in de aanbestedingsfase.
II. Systems Engineering proces in de B&U-project is anders dan de SE-proces in de GWW-projecten.
III. Architecten kunnen door de aard van hun werkzaamheden geen gebruik maken van SE.

Om de stellingen te testen zijn zes interviews gehouden met de vertegenwoordigers in drie casus projecten. Bovendien zijn de documenten van de casus projecten ook onderzocht. Daarnaast zijn er vijf interviews gehouden met experts op het gebied van Systems Engineering. In totaal zijn elf interviews gehouden en documenten geanalyseerd, wat heeft geleid tot een analyse van de stellingen.

Stellingen
Uit de case studie en interviews komt naar boven dat de eerste stelling waar is. In de praktijk is het gebleken dat de projectpersoneel een betere controle op het project heeft ervaren door het toepassen van Systems Engineering. Stelling II is niet helemaal waar. Enerzijds wordt er van de analyse opgemerkt dat het proces van B&U niet anders is dan het proces van GWW. De gebruikte instrumenten en de genomen stappen zijn hetzelfde in de B&U als de GWW. Anderzijds, wordt er een onderscheid gemaakt op het belang en de dominantie van de instrumenten en het startpunt van SE. Propositie III is ook niet helemaal waar. De creativiteit "ontwerp denken" van een architect is in samenhang met het systeem denken van SE. In het ontwerp denken, focussen de architecten zich op de oplossingsruimte, terwijl in systeem denken de nadruk ligt op het probleemsruimte. In die zin kan Systems Engineering de architect helpen in het begrijpen, ontrafelen en het structureren van de problemen om adequate oplossingen voor het project te voorzien.

De praktische studie heeft geleid tot het formuleren van de bevindingen uit de praktijk van SE, dit zijn:

- SE is indirect gebruikt in de aanbestedingsfase
- SE wordt gezien als V & V en Relatics
- Gebrek aan SE standaardisatie is waargenomen in de aanbestedingsfase
- Het startpunt van SE in de B&U is vanuit de activiteiten die nodig zijn en GWW de functies die uitgevoerd gaan worden.
- Het belang van instrumenten is anders in B&U en GWW.
- In de B&U aanbesteding is een evenwicht nodig in systeem denken en ontwerp denken.

Conclusies en Aanbevelingen
Het antwoord op de hoofdvraag kan in twee delen worden gegeven, (A) Welke lessen kunnen worden getrokken en uitgevoerd worden uit de onderzochte projecten? en (B) Hoe kan Systems Engineering toegepast worden in een B & U tender?

(A) Welke lessen kunnen worden getrokken en uitgevoerd worden uit de projecten?

- Project personeel beschouwen SE als verificatie en validatie en Relatics alleen;
- Als er een grotere mate van standaardisatie voor de aanbestedingsfase is en het gebruiken van SE tooling zal dit resulteren tot het makkelijker maken voor projectmedewerkers;
- In de B&U is een evenwichtige benadering van Systems Thinking en Design Thinking vereist;
- Voor B&U is een activiteiten- en ruimteboom belangrijk en voor GWW ligt het nadruk op de SBS (Systems Breakdown Structure).

(B) Hoe kan Systems Engineering toegepast worden in een B&U aanbesteding?
Om Systems Engineering toe te passen in de aanbesteding, zal er met de volgende aspecten rekening worden gehouden:

- Manier van denken: Begin met Systems Thinking en verander geleidelijk naar Design Thinking;
- Sturing: Het is aangeraden om risico gedreven SE toe te passen, waarbij het grootste risico prioriteit heeft;
- Gereedschappen: Begin met de activiteit proces en ruimteboom voor gebouwen;

Om SE toe te passen in de B&U tender zijn er zes aanbevelingen gegeven voor de aanbestedingsmanager

- Vergroot de kennis van SE instrumenten en de huidige praktijken;
- Verkrijg inzicht in de perspectieven van de verschillende denk methoden;
- Geef de architect een leidende rol in de aanbesteding;
- De B&U vereist meer interactie dan in de GWW;
- Optimaliseren van standaardisatie van SE voor de aanbesteding;
- Gebruik SE vanaf het begin van het aanbestedingsproces.

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1 Research

1.1 Introduction

Construction projects in the Netherlands are getting complex and dynamic. The fast changing environment asks for a different approach towards construction projects (Ridder, 2013). Clients now demand that the market should think about the whole lifecycle of the project. Moreover, the client wants to utilize the knowledge of the contractor in full extent. Therefore, the client is shifting from solution-based approach to problem-based approach, where the contractor is free to implement his experience in the project (Werkgroep 1 Leidraad SE, 2007). In order to achieve that, different procurement methods and variety of contracts were introduced in the market. The life cycle approach or in other words the integrated approach meant that variety of engineering fields have to interlace with each other in order to achieve a solution for the problem of the client. This integrated approach asks for a new method for working together.

Hence, due to integrated approach Systems Engineering (SE) was adopted in the construction industry. Systems engineering is a methodical and interdisciplinary approach for designing, constructing and maintaining complex systems in order to provide quality products that meet the user's needs (INCOSE, 2015). The systems engineering method create an added value in the form of an integrated and efficient optimization of the life cycle approach (Wasson, 2006). And according to a study by Systems Engineering Body of Knowledge (SEBoK) shortfalls in SE results in cost overruns and higher total cost of ownership. Conversely, investments in SE method produces highly cost-effective systems (BKCASE Editorial Board, 2015). Moreover, the execution parties can work explicitly towards the customer's needs (Werkgroep 3 Leidraad SE, 2013). The increasing use of integrated approach (contracts) and the rising complexity in the building sector can be supported by the systems engineering method to explicitly work towards the client's needs and control the total cost of ownership.

According to Spekkink & Savanović research "Kennispapier: Vooronderzoek in Systems Engineering in B&U[1]", Systems Engineering method can contribute substantially to the renewal and innovation in the building sector. Likewise, Stichting Pioneering concluded that SE is lagging behind in the building sector compared to the infrastructure sector (Stichting Pioneering, 2013). Moreover, Plegt and Leicher concluded in their reports that SE creates an added value in cost, planning and innovation compared to the traditional project management (Leicher, 2010; Plegt, 2009). While SE is comprehensively being used in the infrastructure sector, the building sector is still lagging behind (Spekkink & Savanović, 2010).

Therefore, a study in order to look for possibilities to use SE efficiently in the residential and non-residential buildings will be conducted. This report will focus on the challenges and problems in the Dutch building sector, regarding to Systems Engineering. The research will be conducted at and for BESIX Nederland, a Belgian construction company based in The Netherlands. BESIX Nederland already uses SE in its infrastructure projects and now wants to explore if there is a possibility to use SE also in the building sector. Therefore, a comparison study with the SE in the infrastructure sector and SE in the building sector will be presented. Now we need to further explore what lessons can be learned from the infrastructure sector in order to implement SE efficiently in the building sector.

[1] B&U is Burgelijke & Utiliteitsbouw which stands for the residential and non-residential buildings in the Dutch construction sector.

1.2 Problem definition

1.2.1 What is the problem?

Buildings are complex structures, which are getting increasingly massive in size and technology. The increasing requirements, the influence of stakeholders, the response to the changing functional needs of the users, the amendments in laws and regulations, the owners, the environment over the buildings lifetime and the rapid change of the technical innovations, all of this ensures that buildings need to be robust, dynamic, adaptable and flexible. Consequently, the traditional approach to building construction is not sufficient anymore (Augenbroe, 2011; Baudains e.a., 2014; Bluyssen, Oostra, & Böhms, 2010; Emes, Smith, & Marjanovic-Halburd, 2012; Ma, Le, He, & Zhang, 2013).

Moreover, the recently published[2] *"Marktvisie"* of Bouwend Nederland (Bouwend Nederland, 2016) acknowledges the above mentioned developments in the construction industry. The Marktvisie is a joint-document of Rijkswaterstaat[3], Rijksvastgoedbedrijf[4] and Bouwend Nederland. Martkvisie recognizes the following trends; Projects are getting complex and dynamic, new developments are rapidly evolving and the importance of information sharing is also increasing and there is a growing need for integrated specialized knowledge and appreciation of technical/content workmanship. These trends are parallel with what researchers above have concluded. In this context there is a necessity for a different approach in the construction industry.

1.2.2 Why is it a problem?

Many governmental agencies (and clients) are moving away from the traditionally prescriptive driven design solution to performance based domain (Augenbroe, 2011). In addition, the construction of a building requires a team of specialist from different disciplines to work together to deliver a successful project. A team consist of an architect, structural engineer, planner, and maintenance engineers to name a few, who need to collaborate in order to come with a sound solution. The performance-based approach changes the internal and external relations between different disciplines within the construction sector, hence a more integral collaboration and method for projects is required.

1.2.3 What do we know about the problem? A short preliminary literature study

In other industries, such as space and infrastructure, where performance-based projects with high complexity and multidisciplinary teams are also conducted, Systems Engineering method is successfully used. From that analogy, buildings are also complex systems and it can be explored if the Systems Engineering approach can be an opportunity for the building construction. Consequently, this research will explore if the Systems Engineering method can be used to tackle the above-mentioned problems.

A short preliminary literature study is conducted for exploration of Systems Engineering in B&U from the analogy of GWW-sector. There are several reasons stated in the literature why Systems Engineering is hardly being used in the B&U-sector even though it can have added value. One of the reasons is that the clients do not prescribe SE in their contracts and construction companies do not recognize any value for using SE. On the other hand, in the GWW-sector,[5] Systems Engineering is used because it is enforced by the RWS (Rijkswaterstaat) and Prorail[6]. For that reason in the infrastructure departments of the construction companies many people with SE background or training operate. But these are hardly working in the building departments. That is why SE is not optimally developed and implemented for the B&U-sector (Spekkink & Savanović, 2010). Additionally, Hoed mentions in his report, that the RVB (Rijksvastgoedbedrijf) believes that the limitations in the integrated contracts can be overcome with use of the SE framework. RVB want to integrate SE in their project management but the development of SE is lagging behind (Hoed, 2014).

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[2] www.marktvisie.nu (accessed feb 2016)

[3] Rijkswaterstaat is a government agency that is responsible for the road and water infrastructure.

[4] Rijksvastgoedbedrijf formerly Rijksgebouwendienst is a government agency that is responsible for the government real estate.

[5] Prorail is a government agency that is responsible for the rail infrastructure.

[6] GWW is Grond, Weg en Waterbouw and stands for the infrastructure sector. Rijkswaterstaat and Prorail are the largest clients in the GWW-sector.

While RVB acknowledges the many interfaces of integrated contracts and SE but does not prescribe the method in their projects yet. Furthermore, the B&U sector encompasses private and public clients whereas the GWW-sector has almost always public clients. These different clienteles have different contracting policies, the public clients wants to solve a problem or provide service to the public while the primary goal of the private clients is to maximize their profit by selling and/or renting the asset. The public clients get the policies steered by the lawmakers, while private clients are free to use their own contracting policies. These variations in clients and policies in the B&U sector make integrated contracts a sluggish and cautious job to implement. Likewise, the detail level in the B&U sector compared to the GWW-sector is much higher. In the B&U the architect or end user defines in details what and how they want specific details or things (Weiden, 2011).Consequently, Hamid conclude in his research report that SE in the building sector is less matured then in the infrastructure sector. The building sector looks into the development of the infrastructure sector which is far ahead. More time and experience is required to establish SE in the building sector (Hamid, 2013).A case study conducted by Britt van Son on the National Military Museum and Ministry of Finance where SE method is used concludes that SE, due to uncertainty within the employers, is not optimally implemented in the projects. Since Systems Engineering is not widely accepted it is not proved to be trust winning in some cases. A mental shift and full backing by the employers is required (Son, 2013; Werkgroep 2 Leidraad SE, 2009).

1.2.4 Problem statement: What do we not know about the problem?

With respect to previous researchers, all their research is prepared for using Systems Engineering in the GWW-sector. No research has been done to investigate the possibility of the Systems Engineering methods in the building sector. The master thesis of Hoed (2014) is one of the first to look into the B&U sector. But his thesis is done from the viewpoint of Rijksvastgoedbedrijf and applications of SE in real estate. There is no research done from the perspective of a construction company. That is why the problem statement in this research is as follows:

It is unclear for construction companies in The Netherlands on how Systems Engineering can be applied and translated from the GWW-sector to their projects in the B&U-sector.

1.2.5 For whom is it a problem?

The problem is of great concern for the whole B&U-sector, including the clients and members of the consortiums. Particularly the problem is for the construction companies in the building sector who needs to understand SE in B&U in order to use it properly.

1.2.6 BESIX Objective

This research is prepared in collaboration with BESIX Nederland. BESIX Nederland is a subsidiary of BESIX GROUP, a Belgium based construction company with headquarters in Brussels. As the largest construction company in Belgium, BESIX Group is active in over than 22 countries with 18.000 employees and operate in construction of buildings, roads, environmental projects and infrastructure. As for 2014 the Group's revenue was 2 billion euros[7]. Some of the notable projects done by BESIX are the Burj Khalifa in Dubai (U.A.E) the highest building in the world, the Grand Egyptian museum in Cairo (Egypt) and in the Netherlands the Maastoren in Rotterdam, the highest office building in the Benelux (Figure 1).

Figure 1 De Maastoren
(source: www.vandorpbv.nl)

The contracts applied by the Dutch government requisite BESIX to use Systems Engineering for their projects. Hence, BESIX Nederland started applying SE in their infrastructure projects and along the way they recognize the benefits of reduction in failure cost in their construction projects. Subsequently, BESIX Nederland wants to apply SE in all their complex construction projects. Furthermore, even BESIX GROUP in Brussels is impressed by the use of SE in The Netherlands and is raising the question why BESIX isn't using Systems Engineering in other countries too. Systems Engineering in BESIX GROUP is only applied in The Netherlands and one project in Belgium where the Dutch SE team contributes. The SE team in The Netherlands is starting

[7] www.besix.com (accessed Sept 2015)

to be reckoned as SE knowledge centre for BESIX GROUP, with even queries coming from Australia for applying SE in projects[8].

BESIX Nederland (from now on BESIX) wants to explore if they can use SE in their residential and non-residential projects (Burgelijke & Utiliteitsbouw, B&U) in the Netherlands. As mentioned before, BESIX recognizes the benefits of SE in infrastructure (GWW) projects but the question lies if SE can also be applied in the B&U projects? In the last couple of years not many B&U projects were tendered by BESIX. Now that the financial crisis is coming to a halt BESIX wants to procure B&U projects in The Netherlands again. BESIX will participate in several tenders of RVB in the coming five years[9]. Since RVB mostly follows the trends of Rijkswaterstaat, BESIX expects that SE will also play a prominent role in the future tenders of RVB. For that reason to strengthen their market position BESIX is already looking for SE knowledge in B&U.
In particular, BESIX acknowledges the advantageous of Systems Engineering in construction projects and wants to use SE as an intern process even if it is not a requisite from the client.

Since GWW and B&U are different on many fronts one-on-one copy of SE from GWW to B&U will not be feasible. For that reason BESIX wants to explore what differences are there with SE in GWW and B&U? What lessons can be learned from the GWW-sector. More prominently what should a (tender) manager do with regards to SE when he or she receives a B&U tender? For that reason it is interesting to limit this research to the early phases of a project.

1.3 Research objective

From the problem description and BESIX objectives it can be concluded that Systems Engineering is an opportunity that is not optimally utilized in the B&U sector. Besides, a lot of construction companies already use Systems Engineering process in their GWW projects.

From that perspective, **the research objective of this thesis is to explore the Systems Engineering method in the tendering phase of the B&U-sector by comparing to the current practices of SE in GWW-sector of BESIX Nederland to ultimately give recommendation to the tender manager.**

The research objective can be divided into two parts, the first being theoretical: where the general knowledge and know-how of SE will be investigated together with the characteristics of the B&U-sector. The second part is practical that includes an assessment of SE in GWW. The Systems Engineering method in GWW sector will be examined alongside the SE in B&U.

1.3.1 Assumptions

The method lags behind compared to the infrastructure sector, yet there are enough reasons to be found in the literature to explore the SE method in the B&U sector. The assumption is that the SE method will aid the architect, the tender, process and project management teams in the B&U sector. From preliminary study and informal interviews with practisers of SE, following assumptions are made:

I. The SE framework can positively contribute to the increasing complexity and shift towards integrated contracts in the B&U (Baudains e.a., 2014; Emes, Smith, & Marjanovic-Halburd, 2012). The added value of SE will be a successful project in the form of an efficient and transparent working towards the customer's need. It will ensure to build the right thing in the precise and transparent way with the set budget and subsequently with minimum disappointment for the client afterwards.
II. A different Systems Engineering process is needed in the B&U compared to GWW. In B&U more details and interfaces occur, so a one-on-one copy of the process is not possible.
III. The architect has a greater role/power in B&U projects and due to the integrated contracts, architect has to work differently. Consequently, Systems Engineering is not meant for architect due to their nature of work (Design thinking vs. System thinking).

These assumptions give the first insight on how SE is perceived for the B&U and defines the course of this research. The highlighted texts are the research objects that will be investigated in this report (see §1.5 Research Design).

[88] source: Intern conversation with Alexander Heeren (Commercial director (INFRA) BESIX Nederland)
[9] source: Intern conversation with Stijn van de Sande (Commercial manager (B&U) BESIX Nederland)

1.3.2 *Why the comparison with the GWW-sector?*

Because successful Systems Engineering techniques from other domains as infrastructure can help identify the differences (Emes e.a., 2012; Geyer, 2012) and enable the understanding of complex system-elements in system-wide performance (Baudains e.a., 2014). Since BESIX already uses Systems Engineering in its infrastructure projects they do not need to start from scratch for implementing SE in B&U. The lessons learnt from the GWW-sector can help modify or adjust Systems Engineering to the requirements of the B&U-sector. By drawing analogies from both the sectors it will ensure that the process of implementing SE in B&U can be done efficiently and smoothly.

1.3.3 *Intended end result*

The end result of this report will be deliverables in the form of recommendations that will support the tender manual of BESIX Nederland. The conclusion and recommendations will support the tender manager during the tendering of a B&U project with regard to Systems Engineering. The tender manger will know which steps to take during the tender phase and how to use the SE process during a tender.

1.3.4 *Scope*

A full implementation of SE in B&U is very extensive to explore in the given time period. For that reason this research will contribute knowledge towards the implementation process of SE in <u>the tender phase</u> of the B&U project by comparing it with the GWW-sector.
To be noted, solely from this research one cannot implement SE entirely in the B&U-sector.
For the complete integration of SE in B&U more in-depth study will be needed across all the life cycle phases of a project. The purpose of this research is to fill a small part of the bigger picture on implementing SE in B&U. The largest clients in the GWW-sector are government agencies RWS and ProRail, respectively for road & water and rail infrastructure. After consultation with BESIX this thesis limit itself to the practises of RWS in SE. This is done due to the time constrain and manageability of this report. Since RWS works with a V-model that represents top-down integration and bottom-up realization, the scope in the V-model is illustrated in Figure 2. The V-model is further elaborated in paragraph 3.3.2 Systems Engineering at Rijkswaterstaat.

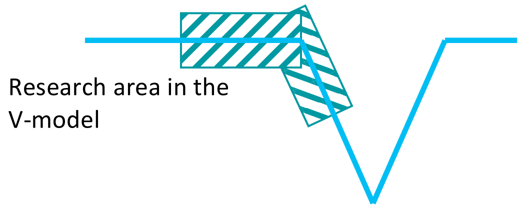


Figure 2 Research scope

1.3.5 *Perspective of Systems Engineering*

Systems Engineering is a broad term that can be associated with a lot of different engineering disciplines. Even within the construction industry, Systems Engineering can have various viewpoints. Someone from the ICT department will have a different view on SE then someone from the planning. The ICT department will associate SE with a software tool or an internal company software, while the planning department see SE as a tool to identify and manage their project risks and keep track of the planning.
During conversations with project managers and engineers in BESIX it came forward that SE gets a lot related with BIM (Building Information Model). This thesis will not research the relation between SE and BIM. This research in SE is done from the viewpoint of a construction company. The thesis will give insight in the B&U sector for the tender manager, SE team and project management's team of the contractor's side.

1.4 Research questions

In order to achieve the research objective, sets of research questions were formulated, where useful and necessary information will be identified. The **main research question** to be answered is:

What lessons can be learned from the Systems Engineering method in the GWW-sector in order to assess the tendering phase of the B&U-sector and how can SE then be processed in a B&U tender?

To answer the main research question, three additional central questions and subsequently their sub-questions are formulated. The sum of these 3 central questions will answer the main research question.

1. Why building projects are getting complex?
   - 1.1. What are the characteristics of buildings?
   - 1.2. What is the role of an architect in an integrated contract?

2. What can Systems Engineering contribute to B&U?
   - 2.1. What is Systems Engineering?
   - 2.2. How is the Systems Engineering process implemented in GWW?
   - 2.3. What are the current applications of SE?

3. What are the findings from the practices of SE in construction industry?
   - 3.1. How is SE currently applied in the tender phase?
   - 3.2. What are the differences between the GWW and B&U, with respect to SE?

1.5 Research design

From the assumptions, research objects are identified. Since the main goal of this research is to explore the lessons learned from GWW, different strategies are used to get an extensive understanding of the research objects in this study. The research can be divide into three parts, therefore this thesis follows Verschuren and Doorewaard strategies (Verschuren & Doorewaard, 2010). See Figure 3 for the research framework.

The different strategies (theory and practical) are further explained in appendix A

1.5.1 Part one: Theoritical study

In part one the central question 1 and 2 will be answered through theory oriented studies. Therefore, a literature study will be conducted to understand the problem statement in depth and get a wide knowledge of the research objects. Subsequently, a conceptual model (propositions) is formulated from the literature study.

1.5.2 Part two: Practical study

The propositions will then be tested in part two with a practical study. The practical study is a case study where GWW and B&U projects will be observed with respect to SE. Additionally, the practical study also contains interviews with experts and practitioners of SE. The interviews and case study will be analysed and interpreted. As a result the central question 3 will be answered through the practical study.

1.5.3 Part three: Conclusion and recommendation

Finally, from the input of the previous two parts, part three will provide an answer to the main research question in the form of a conclusion. The research will then be finalized with recommendations. The conclusion and recommendation will be validated by BESIX.

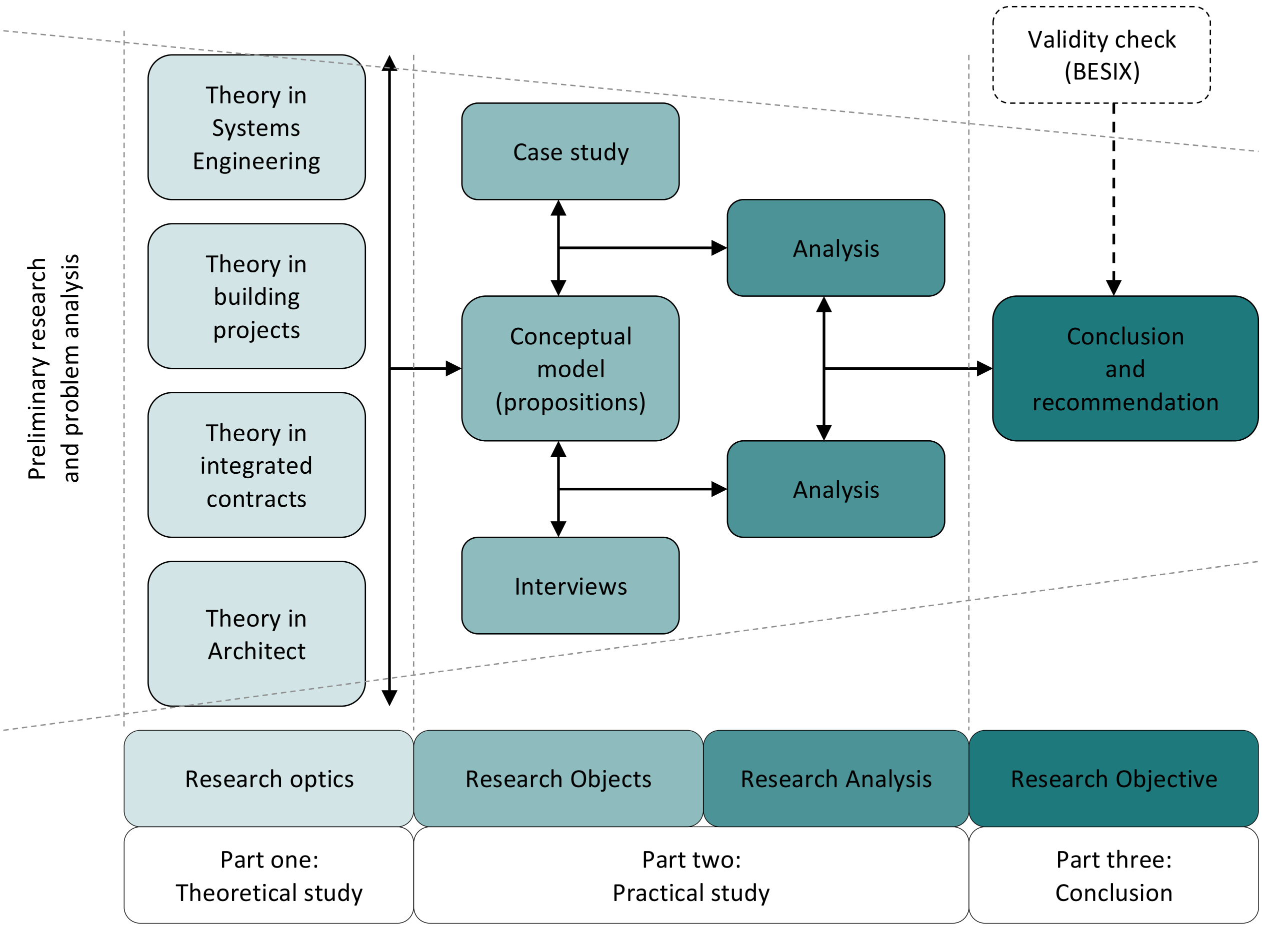


Figure 3 research framework

1.6 Overview of the report

The report can be split into three parts as seen in Figure 4. Part one: the Theoretical study consisting of chapter 2 and 3. In Part one the theoretical background is also described. Chapter 2 and 3 forms the literature study and respectively give answer to the central question 1 and 2.
Subsequently, Part two provides the practical knowledge. Chapter 5 explains methodology on how the case study and interviews will be performed. In chapter 6, the results of the case study and interviews will be presented. Next, chapter 7 will contain the results will be interpreted and analysed. An answer to the central question 3 will be given here and consequently to the propositions too.
Finally, in Part three the conclusion and recommendation will be presented, respectively in chapter 8 and chapter 9. In the conclusion the main research question will be answered.

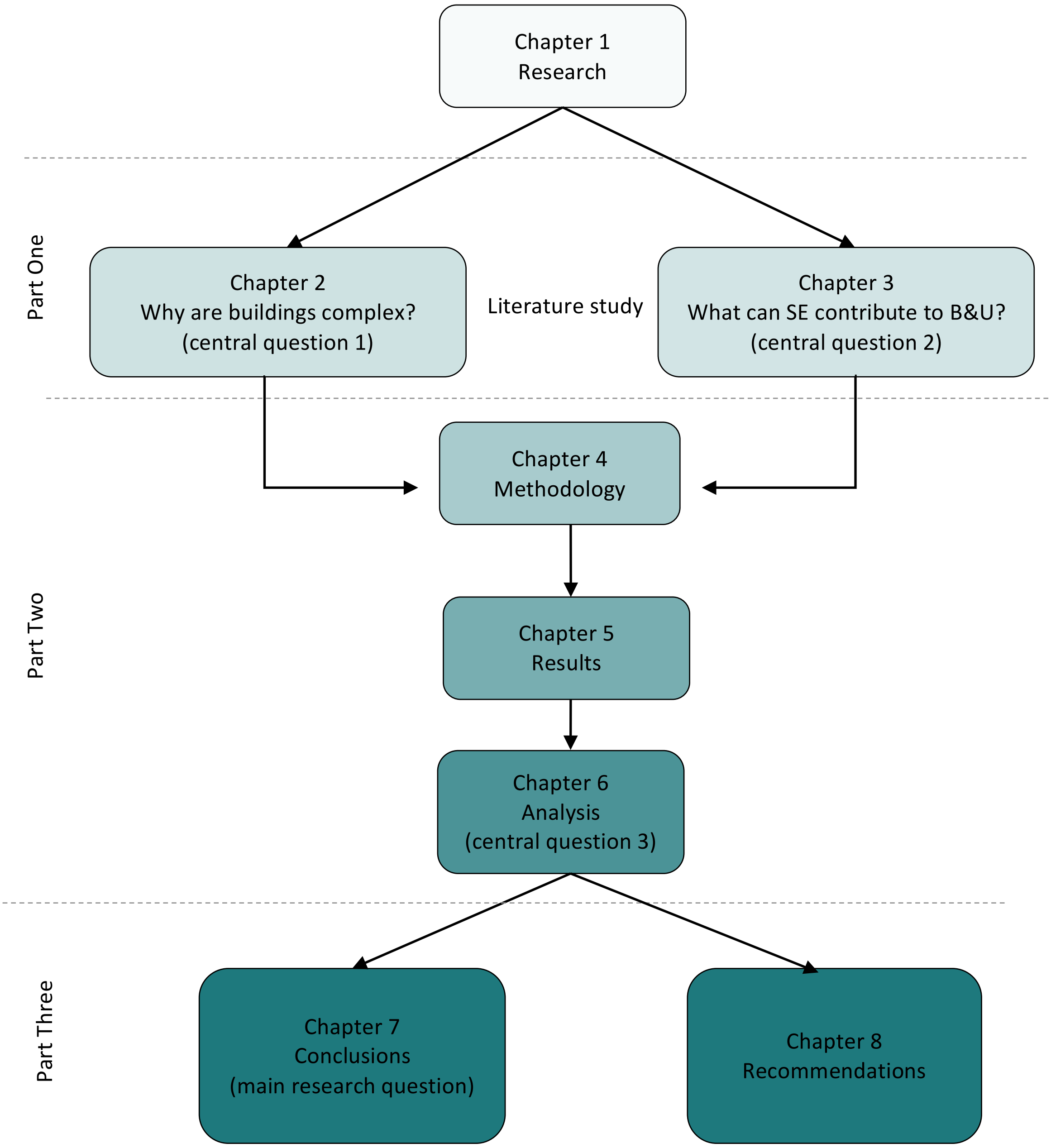
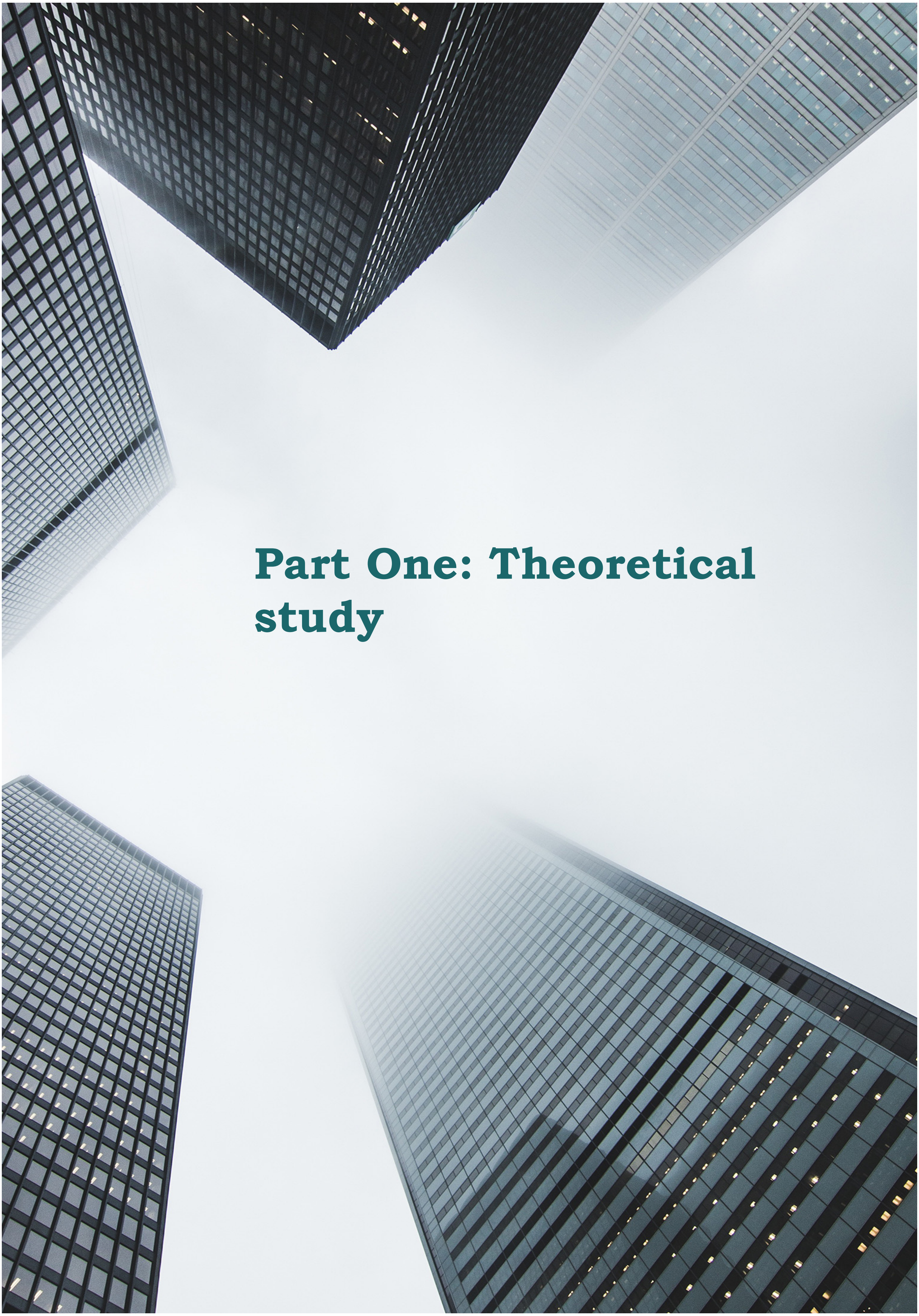


Figure 4 Report overview



Part One: Theoretical study

2 Why are building projects getting complex?

The problem definition stated that clients and governments are moving away from traditional approach towards performance-based approach. At the same time, building projects are getting complex and dynamic. Therefore, traditional approach towards building construction is not sufficient anymore.
This chapter will investigate the problem definition in-depth. In particular, in §2.1 the background of why the shift occurred and the consequences of the shift are described. Then in §2.2 characteristic of buildings are explored in order to understand buildings. Next, to validate the assumptions made in the research objective, in §2.3 the role of architect is examined in performance-based approach. The thinking process of the architect is then further elaborated in §2.4. As result, the last paragraph §2.5 will provide a conclusion together with an answer for the sub-question one.

2.1 Background of performance-based approach

2.1.1 The Dutch policy

In the last decade, the construction industry in The Netherlands rapidly evolved. Partly due to the changing policy of The Netherlands largest client, the government and partly due to the major fraud *"de bouwfraude"* in the Dutch construction market. The policy change of the government is due to the circular economy principles. This paragraph will study the background of why and how this *change* occurred.

People, Planet and Profit
John Elkington came up with the idea of Triple Bottom Line (TBL), which is more famously known as People, Planet and Profit (3P) (Slaper & Hall, 2011). John argued that to create sustainability and to keep greater company value the 3P's framework should be followed. In the 3P framework a company should strive for a balance in people, planet and profit. The concept of sustainable development gain momentum when the United Nations took up the notion of sustainability development in their report, stating *"meets the needs of the present without compromising the ability of future generations to meet their own needs"* as a consequence many countries followed (Brundtland, 1987).

In extension for the 3P's the Dutch government had introduced Maatschappelijk Verantwoord Ondernemen (MVO) and heavily promoted it throughout the Netherlands (Rijksoverheid.nl, 2008). Fast-forward to 2016, the Dutch government has now introduced for the construction industry the "Martkvisie". In the Marktvisie the government gives their vision about the future on the construction industry and how they see it. The first point they make, is to be sustainable, as quoted "*Duurzaam — We nemen verantwoordelijkheid voor de leefbaarheid en de beperkte draagkracht van onze planeet in onze keuzes"* (Bouwend Nederland, 2016).

This is in line with the 3P's framework. The policy steering from the government have pushed, sometime by promoting and sometimes by obligation through law, the companies towards sustainability. Of course sustainable working has a positive effect on the 3P's, but at the same time it has also put a burden on companies, which they have to cope with.
The construction industry faces challenges in integrating work practices conducive to sustainability development (Larsson, 2002). The combination of current practices and sustainability makes the work even more complex than it already was (Chiocchio e.a., 2011).

Circular Economy
The overall political vision in the Netherlands is heavily concentrated on sustainability development. Not only in the Netherlands but also on the global level, the political climate of governments are leaning towards sustainable future, a recent example is the climate conference in Paris in November 2015. At the heart of the conference was circular economy and one of the outcomes of the climate conference was to limit the

temperature rise to 2 degree Celsius[10]. Subsequently, these agreements and commitments lead to stricter regulations of law on the national level to achieve the goal.

In the past many conferences and climate tops are conducted and agreed on. All these conferences were based on the circular economy principles. In a circular economy, the resources are used as long as possible until the maximum values from the resources are extracted. At the end of the products' life cycle, the materials are recovered and regenerated. The core of circular economy lies on, using fewer resources per unit of economic output for more people and consequently reducing the environmental impact of resources that are used or economic activities that are undertaken (Fischer-Kowalski, 2002).
The CO_2-ladder is one of the prime examples of the circular economy principles in the construction industry. The CO_2-ladder is an initiative to reduce the carbon emission of companies. The governments actively stimulate this with fictionist reductions on construction procurements. Another developments are for example the energy labels for housing, which tells how energy efficient a house is. Or the BREEAM certificate, BREEAM is a sustainability assessment method for buildings and infrastructure.

Circular economy investigates and affects the whole life cycle of the product as it approaches the projects in a holistic manner. All these factors put pressure on the overall production industry and especially the construction industry. Indeed it is meant to be sustainable but to take all these matters in consideration, it also increases the complexity of projects. Therefore, performance-based contract were introduced in the construction industry to get maximum value and resource efficiency. More about performance-based contracts will be elaborated in the next paragraph.

Shift to managerial-based role
The governing bodies of the government Rijkswaterstaat (RWS), ProRail and Rijksvastgoedbedrijf (RVB), respectively responsible for the civil infrastructure sector, rail-network and the real-estate sector, have withdrawn from the execution-based role to a managerial-based role in the construction industry.
In the execution-based role, every aspect of the project was worked out in details and handed over to the contracting party to execute the work. With the changing policy the government limits itself to specify the requirements only and the contractor is free to execute the work as long as the requirements are met (Werkgroep 2 Leidraad SE, 2009).

The notion behind the managerial role is that the government wants to utilize the knowledge and experience of the construction industry. First, this is done by distributing the risk efficiently. Risk will be managed by the party which can handle the risk best (Kenniscentrum PPS, 2014). Second, the managerial role will lead to more freedom and early phase interventions for the execution parties, which will be good for the innovation of the construction market (Ministerie van Financiën, 2015; Werkgroep 3 Leidraad SE, 2013). Third, the price-quality ratio will be positively affected. The lifecycle approach will push the execution parties to think in advance about the maintenance and sustainability of the project. That means that the quality can be kept constant in the whole lifecycle of the project. Therefore, projects will meet the quality standards for the same price or even for a lower price during their lifespan (Ernst & Young, 2006).

The policy change meant that the governing bodies and the execution parties had to work together in a different way. For an optimal distribution of responsibilities and risks between the market and government, procurement in the form of a Public Private Partnership (PPP) provided a solution (Expertisecentrum Aanbesteden Rijksgebouwendienst, 2009). In a Public Private Partnership, public parties legally work together with private parties to realize and exploit the project. PPP is understood as a "container concept" which comprehends many forms of legal (integrated) contracts (Bruggeman, Chao-Duivis, & Koning, 2013).
Thus in recent years a shift from traditional contracts towards integrated contracts has taken place. In the traditional contract the client is responsible for a detailed design, the specifications and conditions of the construction project. Through a tender process, the work is awarded to the contractor who, based on the drawings and specifications given by the client, executes the work. By nature construction projects are dynamic and complex where different phases, expertise, information comes together (Williams, 1999). And in the traditional procurement there is for each phase a different contract e.g. a design contract with the architect and a separate construction contract with the builder. This led in some cases to disappointing end results and moreover, not promoting innovation and sustainability which the construction industry was in

[10] http://www.cop21.gouv.fr/en/ (accessed on feb 2016)

need of. Hence, traditional contracts were no longer sufficient to accommodate the industries need and instead clients preferred integrated contracts (Mooiman-Salvini, Kuypers, & Cremers, 2006). More about the integrated contracts will be explained in the next paragraph.

The construction fraud

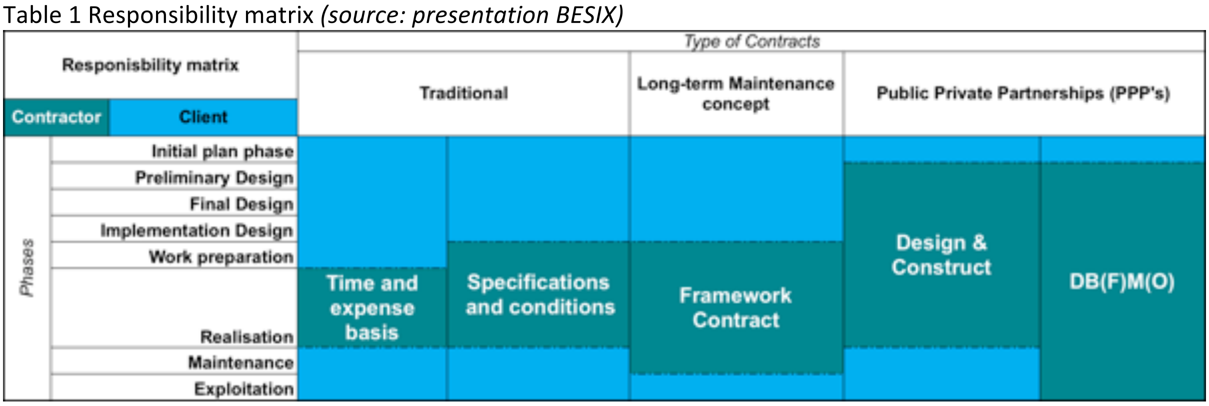
Additionally as mentioned before, a major fraud in the construction industry also led to the policy-makers thinking of changing the construction process in the Netherlands. In 2002 the government investigated a major fraud in the Dutch construction industry, *"de bouwfraude".* Construction companies made price-fixing agreements and major companies formed a cartel-like formation, which resulted on average 8.8% higher prices for government project. The research committee, who investigated the fraud, recommended that the Dutch construction industry is in need of transparency and a better control of process should be implemented. This urged the policy-makers to rethink their approach towards the construction process and accelerated the implementation of it. (Parlementaire Enquêtecommissie Bouwnijverheid, 2003).

The call for transparency, better control of process, changing policy of the government and different way of working asked for a different method. A method, where parties can work in a structured way and where the risk is distributed to one who is best capable of handling the risk. For that reason performance based contract were introduced, the next paragraph will explain what performance based contracts are.

2.1.2 Performance-based contract

In the '90s the idea of Public Private Partnership (PPP) first emerged (Hessels & Deuten, 2013; Werkgroep 1 Leidraad SE, 2007). As mentioned before Public Private Partnership is a venture between a government agency and a private party. PPP led to different types of contracts between government and private parties for example, alliance contract or integrated contracts such as Design & Build. In The Netherlands PPP is understood as DBFM(O) which stands for Design, Build, Finance, Maintain and occasionally Operate. The Ministry of Finance is responsible for the general policy of DBFM(O) in The Netherlands (Ministerie van Financiën, 2015). The governing bodies of the government Rijksvastgoedbedrijf (RVB) en Rijkswaterstaat (RWS), respectively responsible for real-estate and road and water infrastructure, apply DBFM(O) contracts in their project. The procurement in the form of Public Private Partnership, mainly the DBFM(O), started a shift from traditional procurement towards integrated tendering (See Table 1).

Table 1 Responsibility matrix *(source: presentation BESIX)*



Integrated Contracts, DBFMO

Before procurement the government examines which contract is most efficient and have an added value for the project. A PPC (Publiek Private Comparator) is deployed at an early stage in order to determine the type of contract for the particular project is most suitable. If concluded on this basis to prepare a DBFM(O) -tender than a PSC (*publieke sector comparator*) is made. This is compared to the actual bids from the DBFM(O)-tender to see if a choice for DBFM(O) is actually beneficial. A threshold of €25mln and €60mln, respectively for building and infrastructure is set to test PPC (Government.nl, z.d.; Ministerie van Financiën, 2015). Anything lower than that will not be beneficial for a DBFM(O) contract because of the high cost between the several construction phases (Wijsman, Prins, Gorgels-Timmermans, Gulpen, & Blanken, 2011). That means that usually larger projects thus also relatively complex projects are tendered as DBFM(O) project.

In an integrated contract various phases of the construction project (
Table 2) are placed into one contract, hence the name integrated contract and it is outsourced to one party (mostly a consortium of several companies). The most common type of integrated contract in The Netherlands for government is the DBFM(O). All other contract forms (DB, DBM etc.) are however a variant of DBFMO and have to deal with the limited division of responsibilities and risks to the parties (Bruggeman e.a., 2013). Applying DBFMO-contract therefore urges the executing party to consider and plan in advance about the entire lifecycle of the project including the finance. Because the project is awarded to one party that manages all the phases, an integrated contract creates an added value to the project in the form of chain integration, balanced risk distribution, financial benefits, efficient project quality and encouraging an innovative solution for the project.

Table 2 Integrated contracts and responsibilities *(source: Kennisportal Europese aanbestedingen, 2014)*

		Program	Design	Construct	Finance	Maintenance	Operate
	Traditional	**Client**	**A**	**B**	**C**	**D**	**E**
Integrated Contracts	D&B	**Client**	**A**		**C**	**D**	**E**
Integrated Contracts	DBF	**Client**	**A**			**D**	**E**
Integrated Contracts	DBFM	**Client**	**A**				**E**
Integrated Contracts	DBFMO	**Client**	**A**				

The successful use of DBFM(O) has led to 10-15% added value in projects and a total saving of all DBFM(O) projects in the Dutch construction industry till now is €1.3 billion (Kamerstukken, 2015; Ministerie van Financiën, 2015). This imply that integrate contract can reduce the cost of the projects. And since the contractor also takes care of the maintenance of the projects, a life cycle approach is needed and project sustainability will increase for example, due to well thought choices of resources (circular economy). Consequently, Rijkswaterstaat only works with DBFM(O) contracts. (Expertisecentrum Aanbesteden Rijksgebouwendienst, 2009; Kamerstukken, 2015; Mooiman-Salvini e.a., 2006).

Integrated contracts are based on *"Uniforme Administratieve Voorwaarden voor geïntegreerde contractvormen 2005"* (UAVgc). The UAVgc define the contractual relationship between the employer (client) and the employee (contractor). It provides standard provisions for the combination of design with execution activities and/or maintenance in a set of general terms and conditions (Bruggeman e.a., 2013). In these provisions the roles and responsibilities are also explained. The employer is responsible for the demand specification, preconditions and providing a solution space wherein the contractor can work.
On the contrary, the contractor is responsible for the design, execution and maintenance work. The contractor works within the given solution space and translate the customer needs into customer requirement, recorded in the Customers requirement specification (CRS). Although the contractor is responsible for the design and execution process that does not mean that the employer can sit back. The employer can avail the opportunity given in the UAVgc to monitor the contractors activities and where needed (under certain circumstances) order modification and variations in the project. This way the employer can control the quality assurance of the project (Bruggeman e.a., 2013). For complex work the contractor uses the System Engineering method to translate customers need into CSR (Projectburo B.V., 2015; Werkgroep 3 Leidraad SE, 2013).

2.2 Characteristics of buildings

As stated in the problem definition, buildings are complex systems that are getting increasingly ambitious in scope and technology. In exploring the opportunity of applying Systems Engineering, it is good to understand the characteristics of buildings. This paragraph will provide an answer to the question ***1.1. What are the characteristic of buildings?***

In this paragraph building characteristic will be explored, what makes a building projects complex? How is the design approach in traditional versus the integrated approach?
As it becomes clearer that the architect plays an important role in the building sector, it will need more elaboration which is done in the next paragraph.

2.2.1 Aesthetics of building

In the B&U the building is characterized by the relatively large degree of influence from the architecture. This allows the architect to take a central role in building projects. In a study on the application of integrated contracts in the B&U conducted by the PSIBouw (Mooiman-Salvini e.a., 2006) it is cited, that the degree of influence of the architecture, the role of the architect and his design liability are the reasons for the hesitancy for using integrated contracts, unlike in the GWW-sector where this is not the case. Architects are reluctant to use integrated contracts because they think that the architectonic value will be undermined and due the contractual relationship there will be less contact between the client and architect. Since the architect plays a major role in the building projects, this will be further elaborated in paragraph 2.3. But before investigating the role of the architect, it is important to know the design process, the contractual relationships and other characteristics that make constructing buildings a complex project to undertake.

2.2.2 Traditional versus integrated design process

In the traditional process for building design the work is very much (external) fragmented (Zager, 2002). For every process, different contracts are used (see also Table 2) and there is no real communication between the parties. The communication is in a formal way because of the contractual relationship see Figure 5.Unlike in other design industries such as industrial or product designers, in the building design the designers are not the builders. Thus the architect does not make the building itself but instead other parties such as building contractors construct the building. Which mean that the communication is very vital between the architect and builder.

On the other hand, in an integrated approach the architect collaborates with the contractor and they form a consortium which in case of an DBFM(O) also include investors, maintenance (and operations) companies. They work together in order to deliver a successful project. Since the contractor carries the major part of risk, the contractor is mostly the leading party in these collaborations (Wamelink, Koolwijk, & van Doorn, 2012). There are some thoughts about the architect leading the design and build contract, called design-led design-build (DLDB) (see Wamelink e.a., 2012) but that is not in the scope of this research.
Associations within the consortium are thus important for achieving successful project. Moreover, it is also significant how the consortium that consists of several parties communicate towards the client. These points are also acknowledged by Esra Bektas' (2013) research in Knowledge sharing strategies in large complex building projects.
Bektas highlighted in her research that knowledge sharing between organizational (referred in this report as consortium-client relation) and inter-organizational (relationship within consortium) is highly important. Since complex building involve many actors, with specialized knowledge in their domain of field, they produce artefacts such as drawings, calculations, reports etc. that in turn is integrated by other individuals in to the project. Thus in large complex building projects, knowledge sharing is crucial among design team actors (Bektaş, 2013).
Consequently she argued for the necessity of a holistic approach in building projects. Project approach can be divided into two types of approaches namely, tool-oriented approach, such BIM and CAD systems etc. and people-oriented approaches such as work processes and social aspects of team collaboration.
In line with Bektas' research this thesis studies the relationship within the consortium between architect and contractor looking at Systems Engineering as tool-oriented approach.

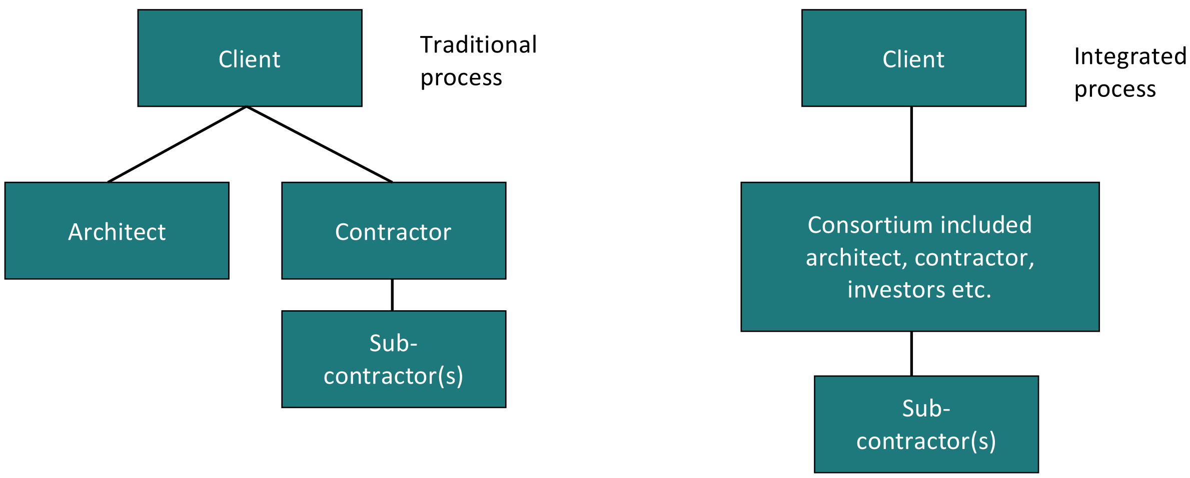


Figure 5 Traditional vs. integrated process. *Source: (Bruggeman e.a., 2013)*

2.2.3 Many stakeholders and actors invloved

With the integrated approach, DBFM(O) contracts, construction companies have to consider the whole life cycle of the building. This means they have to think in advance about all the aspects of the building and still be competitive. For example, what material would be efficient to use? Should a relatively expense material be used with minimum maintenance required or should a cheap material be considered with high maintenance. These are one of the questions consortium has to deal with.

Since the life cycle of the buildings are longer than the projects time, more stakeholders are also involved. All those stakeholders have their own requirements. As stakeholders you can think of users, environmentalist, neighbours, local authorities such as welfare committee, fire authorities, water board etc. but also future users and the future availability of resources has to be considered too.
The unpredictability of future requirements makes designing for a building difficult, which is why design is often a matter of decisions made on the basis of inadequate information. All the above-mentioned stakeholders in project have their own requirements. Some stakeholders are influential and powerful e.g. fire authorities have legislative power while other are just there to be informed. With a stakeholder analysis, the stakeholders can be mapped out with their corresponding powers and interests. Important for a consortium is to take account of all the stakeholders and keep the key stakeholders satisfied.

The building industry is also characterized by internal fragmentation. Not only is building itself a unique product but also for each new project there is a unique process, technical requirements in structural and installations and organization. The increasing complexity of buildings and building processes have led to the participation of more specialists and reinforcement of this fragmentation. For example, for building an energy neutral building, there is a need for specialist in energy technology or the need of an environmental manger to map out and manage the environmental aspects. Because of the specialization in construction projects, the amount of the actors/parties is enormously increased. Potential participants, containing or being involved in the design process are: the architect, the engineer, the installation advisor, building physicist, the project manager, the housing counsellor, the counsellor and the building costs Quality Manager (Flapper & Witten, 2004).

If the actors (internal organisation and external stakeholders) involved in project increase, the management becomes tougher. The increase leads to more communication between project members. Therefore, information sharing and clear and easy communication between actors is important for realising a successful project.

2.2.4 *Innovations in the building sector, smart buildings*

Buildings today no longer provide only the shelter and accommodation. Rather nowadays they consist of complex connection between structure, systems and technology as seen in Figure 6. In addition, the technological requirements of building-owners are increasing day by day. A modern-day building involves the installation and use of advanced and integrated building technology systems. These systems include building automation, life safety, telecommunications, user systems, and facility management systems (Sinopoli, 2010).Another example of technological systems can be of data requirements such as Wi-Fi or internet connections throughout the building. Or climate control for efficient use of energy and automation in the building such as mobile control for the temperature, for instance. These systems on their turn are optimized and improved independently.
As Yao and Zheng describe in their paper, there is an increasing trend towards the application of digital technology to support control systems in order to achieve energy efficiency in buildings (Yao & Zheng, 2010). Moreover, the building-owners are also looking outside their building and considering the impact of their buildings on the electricity grid[11].

The rapid developments and innovations in the building sector and technology in general are in a steep increase. The engineers and designers of today can no longer follow a set of procedures since the rate of continual change and a need of innovation in the world where they must work would soon leave them behind. Rather they must learn to appreciate and exploit new technologies as it develops. Variations in both the materials and technologies available is becoming too rapid for the designers and engineers evolutionary process to cope with (B. Lawson, 2005).

During the design of a building the future technological changes have to be incorporated, that makes the design a difficult and complex job. It also requires a specialist who can help the designers and engineers to incorporate innovative technical systems and provide a brief in the technical knowledge.
Just like the stakeholder's requirements can change in the future, the unpredictability about the technical innovations is equally apparent. This uncertainty makes the designing and engineering of a building a challenging and difficult process.

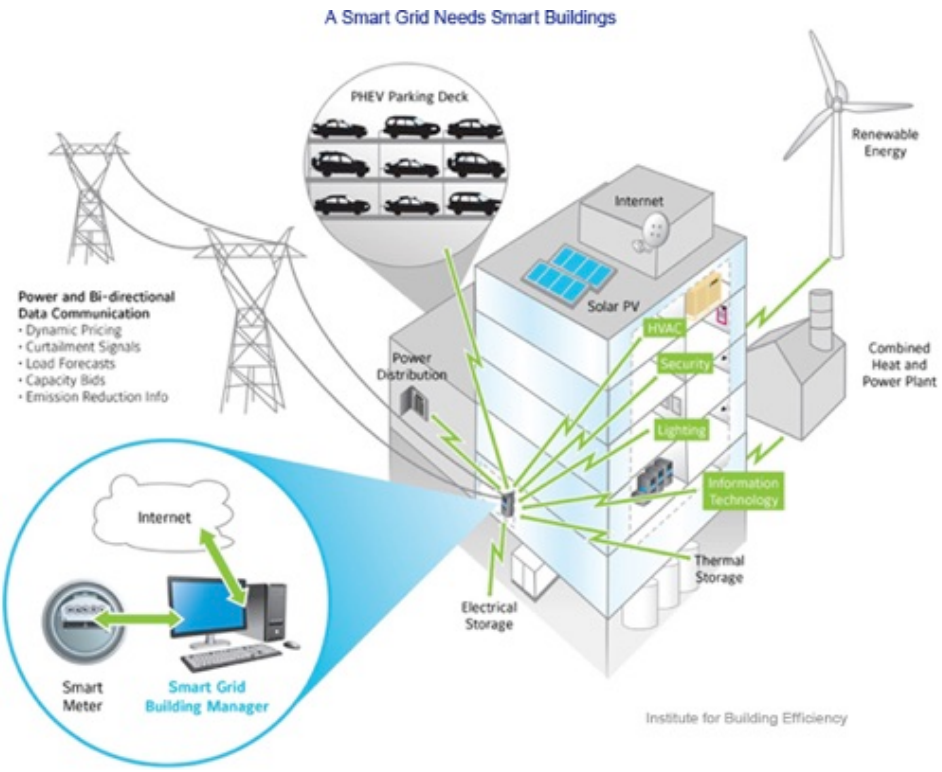


Figure 6 Smart Buildings. *Source: http://www.buildingefficiencyinitiative.org/ (accessed Feb 2016)*

[11] http://www.institutebe.com/smart-grid-smart-building/What-is-a-Smart-Building.aspx (accessed feb 2016)

2.2.5 Habitability framework

Around the 15th century BC, Vitruvius - considered as the first architect of the Roman empire – described in his work the *Ten Books on Architecture* that a good architecture should satisfy on three criteria of firmitas (firmness or durable) utilitas (usable or functional) and venustas (beautiful) (Vitruvius, 1914). Only when these criteria with their corresponding priorities are met, the architecture will be successful as seen in Figure 7. Firmness can be achieved through good knowledge of construction. The structure has to be solid for safety reasons and that is why it has the highest priority.

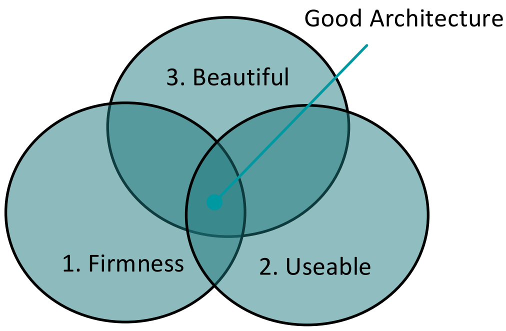


Figure 7 Vitruvius principles on good architect
Source: own illustration. Adapted from Vitruvius (1914)

Usability has the second priority and is achieved through a comprehensive understanding of the client and users needs. While beautiful is a relative term, it has the lowest priority. Only when the higher order of priority is achieved one can go further to the next criteria. These criteria with the their priorities are still an important aspect in the present-day architecture.

With the shift to performance-based approach, the emphasis on usability or in the other words functionality for the contracting party is increased. In order to achieve the functionality every building comes with performance requirements, each building has its own set of unique requirements e.g. a school should accommodate x numbers of students in a classroom, a retail outlet should be accessible for disabled people or a nuclear plant should have a minimum thickness of x mm of concrete wall for preventing radiation leak.
Off course all the three buildings should be safe and comply first with the higher priority (firmness). Nevertheless, all buildings have their own specific requirements that arise from the client and users needs. The unique set of requirements, the complexity and the increasing size as mentioned before of a project makes it difficult to manage and keep in track of changes that the building project undergoes during its lifecycle.
In order to systematically approach a building project Preiser proposed a habitability framework (Preiser & Vischer, 2005; Preiser, 1983). The elements of the habitability framework relate buildings, occupants, occupant needs against their environment (Figure 8). The framework shows the person-environment relation in hierarchies from smaller to larger scale, or higher to lower priority.

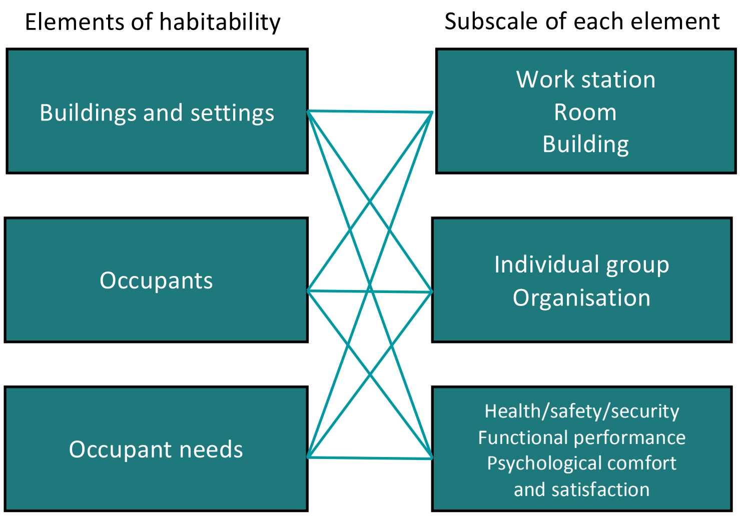


Figure 8 Habitability framework. *(source: Preiser, 1983 and 2005)*

The building and settings element is the physical environment that is expressed in settings and/or space such as workstations, room, building, and facilities and these spaces interact with the occupants that are using the space. For each setting/space sensory environment can be derived such as acoustic, luminous, visual, thermal, tactile etc. that correspond with occupant's needs.

The occupants are the people who will use the building, in some cases, the occupants are also the clients (like a corporations or company) in need of an office building. Sometimes, the client is not the user of the building, for example a real estate agency that rent space to third parties in a multifunctional building. It is important to recognize the needs of both the client and the occupants in order to come with sound solutions.

To systematically comply with the requirements Preiser has redefined and prioritize basic human needs into building performance levels in his habitability framework. According to Preiser, the user needs and requirements can be deduced back to standard performances of a building. For example, as mentioned above the wall thickness to prevent radiation leak of the nuclear plant can be deduced to a health performance and an easy accessible building for the disables is a matter of functionality of the building. Likewise, the number of students in a classroom can be deduced to efficiency and safety performances of the building.
The hierarchy of the performance levels and the performance levels itself are based on the Vitruvius principles and Maslow hierarchy of needs. Maslow's (extended 8 stage) hierarchy of basic human needs consist of physiological needs, safety, love, esteem, cognitive needs, aesthetic needs, self-actualization and transcendence needs (Maslow, 1970).
These needs are parallel to the build environment and can be extended to the user's needs on building requirements. Subsequently all buildings should be safe and secure firstly before they can be functional and then they can satisfy with the aesthetic and/or cultural performance. The three performance levels of the habitability framework are illustrated in Figure 9. They are:

1. Health, safety and security performance;
2. Functional, efficiency and work flow performance;
3. Psychological, social, cultural and aesthetic performance.

Each performance level consists of sub-goals. At the first level a sub-goal could be health, at the second level it can be functional and efficiency, depending on the requirement. For these sub-goals, performance levels interact or they can be conflicting, in that case a resolution is required between the sub-goals. The hierarchy of performance levels is also in line with the building standards, code and guidelines available to designers and professionals. The first performance level is in accordance with the safety standards and building codes that the project must comply with. The second performance level refers to the state-of-art knowledge about building types and systems. The third level concerns to research-based design guidelines, which are less codified, but nevertheless equally important for designers and building professionals (Preiser & Vischer, 2005).

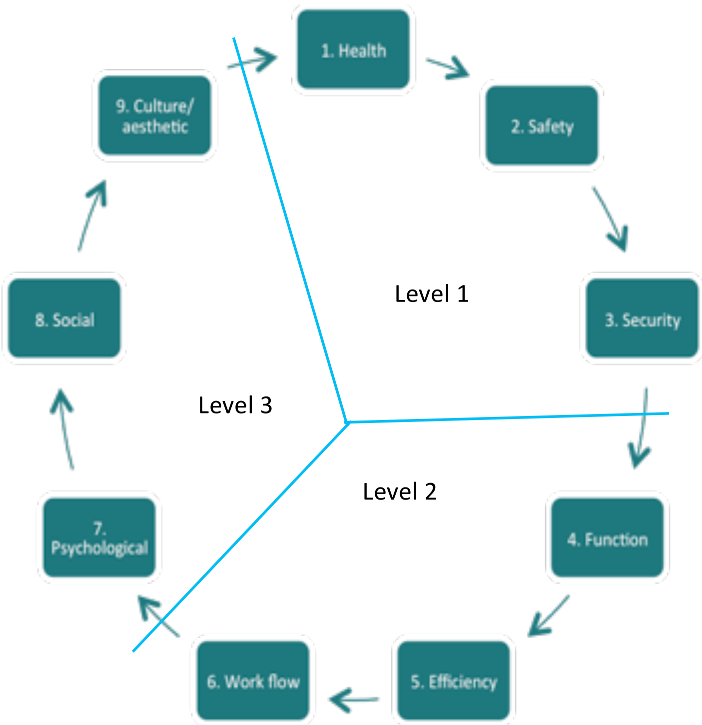


Figure 9 Levels of Evolving performance criteria. *(source: W. F. Preiser & Vischer, 2005)*

2.3 The role of the architect

From the preceding it became clear that the architect has a lot of influence in the design process of building, therefore this section will investigate the role of the architect. It provides an answer to the research question

1.2. What is the role of architect in an integrated contract?

What are the challenges and problems faced by an architect in an integrated team? Firstly, how the architect works in the traditional approach will be studied and afterwards the role of architect in an integrated process will be elaborated.

2.3.1 The traditional process

As mentioned earlier the architect plays an integral role in the process of building construction. It is the architect who lays down the foundation by the very first sketches and therefore determines the design and structure of the building. The process starts from a client who needs a building and formulates his needs. Then the architect defines the aesthetic and the space according to the requirements of the clients in the form of drawings. Subsequently, engineers will develop and incorporate the structural, mechanical, electrical and plumbing systems. This is done in the form of technical drawings and specifications. The deliverables of the design are prepared separately and assembled at the end in order to initiate the construction process. The traditional process of building project is very sequential and linear as seen in Figure 10.This makes the architect a dominant practice in the building process (Chiocchio e.a., 2011).

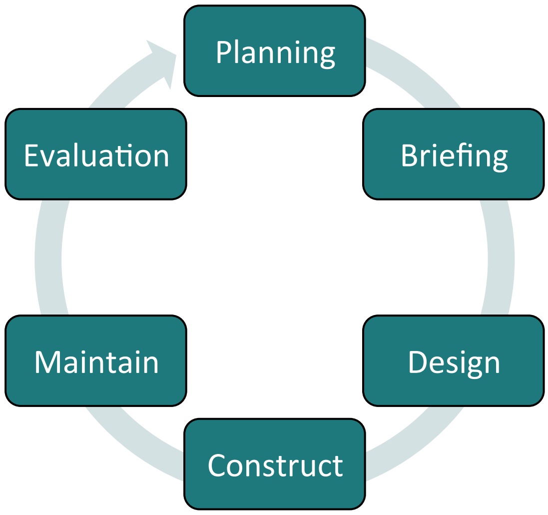


Figure 10 Phases of the building delivery process. *Adapted from Prieser*

Although it may seem logical to work in a sequential manner, but the standard is different. In practise the order of activities is different and unpredictable, it can go from briefing to design and then back several times. The activities to occur in a sequential manner are highly unlikely in the practise. Lawson, challenges in his book that these events cannot clearly distinguished from each other. Sometimes a solution has to be given in order to understand the problem. It seems more likely that in the design process the problem and solution emerge together, by going back and forth between the solution and problem (B. Lawson, 2005).
Furthermore, separating the designer from the manufacturing will need clear communications between the designer and the one who will build it. Now the central role for communication is drawings but the fragmentation in the building construction and at the same time continuing with the rapid changes in technology and innovation will lead to unpleasant end result. In that context, an integrated approach will be more successful where the architect can collaborate together with the builder. Clear communication between parties will still be needed. But by working together there will be less formal way of communicating and easy integrating of ideas.

In the past the architect could also be found on the construction site to help the construction of the building. Not only was he designing but also engineering and constructing, thus knowing exactly what and how to build. An architect is considered to be the person who knows how to design a building according to the client's needs. In the past, the architect had a one-on-one relation with his/her clients and in a certain sense, but nowadays, mostly in smaller projects, the architect still have that same association. The architect is able to know the sociocultural context in which the building is being built in order to respond to the client's needs. These needs, however, are not necessarily the requirements of the users.

The directness of the architect-client/user relationship is fading now, that larger organizations with more stakeholders and additional requirements are getting involved with the growing scale of building projects. As opposed to traditional organizational structure, power and roles within teams are based on ability, knowledge and mastery of appropriate rules defined by their professional bodies (Chiocchio e.a., 2011). The complexity of building requires input from specialist from the engineering field like structural and technical installation etc. In the traditional approach the architect has a contractual relationship with the client (see also Figure 5 on page 18) and the architect only prepare the design of the building. They express their work in very visual and graphical kind of way (B. Lawson, 2005). The communication between the architect and the builder/specialist is minimum or bound by contract (Bruggeman e.a., 2013). Subsequently, the architect does not have enough input from the specialist and the builder which leads to cost overruns or a failure in design. As an example, on average a building needs to be maintained for 25 years, the maintenance company have the best knowledge in how to maintain and if they can share their input on the design early on, the architect can incorporate their idea and knowledge. It can be assumed, that the construction company knows better how to build. In the traditional process, the input during design from other parties is missing and architect work mostly from his own experience and idea's. For simple and repetitive projects, the design can be done by architect only, but for large complex building project like hospitals or schools that demand sustainable design with maintenance for couple of years, the architect needs input from specialist and construction companies.

Likewise, decision-making is not done by individual clients anymore, but by committees, especially with government and corporation projects. Large teams with specialized people in certain field of buildings, as well from the client-side as from the architect-side, are leading the project. This results in a bureaucratic decision-making process with lots of information to digest over the building project. At the same time, the architects have to respond to the changing requirements and regulations during the life cycle of the building. It makes the work even more complex and a good communication between parties becomes even more important.

In order to overcome the challenges, the architect has to understand the clients needs better. In the building environment this role refers to the programming or briefing phase. Programming or briefing is to understand and express what the building project has to achieve, what is the goal and what is (are) the function(s) of the building. Briefing is an important part of the design process and tells the architect what to build. Since, in integrated contract the architect also works with requirements, which is similar to briefing, therefore it is good to understand the briefing. In the next paragraph briefing will be elaborated.

2.3.2 Briefing

The brief tells the construction professional what is expected from the building. In a brief the requirements, needs and wishes are stated clearly and explicitly for the designers. Ambiguous and vague information will lead to inadequate design and guesswork for designers and professionals (CABE, 2011). Therefore, the brief starts with a vision statement, which is prepared by the client (see Figure 11). But as the project develops further the brief get more and more specified. Knowledge and experience are then needed to state a detailed brief. Depending on the complexity and scale of the project a brief can be prepared by four different approaches, which are elaborated hereunder.

The terminology between different professions in the construction industry is not consistent; statement of goals, statement of needs, statement of requirement (SOR) is commonly used across the industry in the early stages of the project. As the project continue to progress throughout its life cycle, the briefing gets more specific. Terms as functional brief, output specification and operational brief are also used in the later phases of the project.

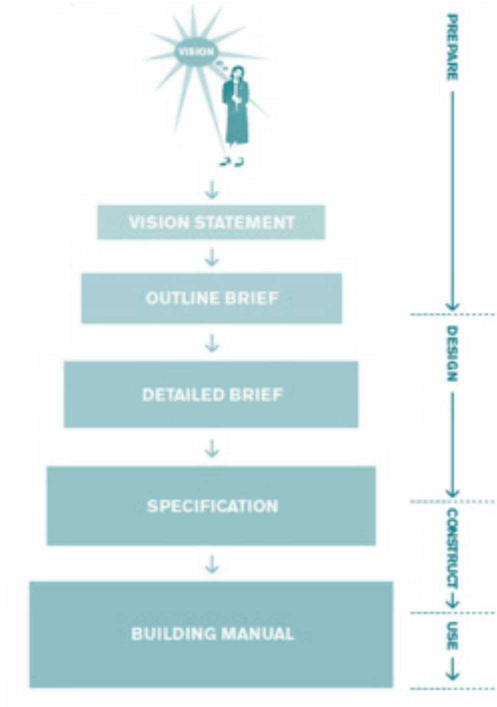


Figure 11 The stages of a brief. (*source: CABE Commission for Architecture and the Built Environment (2011). Creating Excellent Buildings: a Guide for Clients. London: CABE*

Brief prepared directly by the client	Small projects with straightforward functional requirements and limited group of users. Mostly individual clients. For example a private home, a small office or a small outlet store. Also possible for large projects with standardized work. Clients with an experienced internal team where the design and the set of requirements are agreed beforehand. For examples, an outlet stores of a retail chain, franchises of a fast-food chain or even repeated public projects such as small court buildings.
Brief prepared by the architect	Architect can prepare a brief as part of the design process. The architect asks the client and stakeholder what they need and forms an understanding to find a design solution that satisfies everyone. Usually on small projects the architect can prepare the brief himself by informally asking questions to the relevant stakeholders and users. This way the architect has more understanding and there will be more trust between the parties. On larger project and/or larger architecture firms more people than the architect are involved in the process. The architect doesn't know everything and there is less understanding between the parties. Formal ways of recording are then needed to understand the requirements.
Specialist brief writer	A specialist brief writer is needed on a large project or when the work is complex, there are extensive technical requirements and/or when the client has a large, complex internal organization. All of this requires someone with expertise in understanding the needs of the different stakeholders and keep in track the changes across the projects lifecycle. A specialist can be hired or it can be an extern consultancy firm.
Several parties in the DB(F)M(O) procurement	In DB(F)M(O) procurement the client make the outline brief and specify as much as he can. While the contractor make the detailed briefing with their own perspective and interpretation based on the specifications given by the client. The contractor may hire a specialist brief writer to do that.

In order to prepare the brief, it is important to understand the needs of the clients and that is not an easy task, especially when there are many requirements that are complex (Bluyssen e.a., 2010). After consulting with the contractor, the client thinks all of his needs are overheard and the contractor will build the right thing. But lots of the requirements are left out because they are too ambiguous and not explicitly stated. Moreover, if there is no specialist brief writer with the client experience then there is no one to oversee and correct the situation, which will as a consequence eventually lead to disappointing results.

2.3.3 Integrated process

In an integrated process the architect take part in a consortium. The consortium consists (depending on the type of contract) of a construction company, investors and maintenance company. These companies and their employees have to work together in order to deliver the project.
Pektas and Pultar state, “the architect, engineering and construction industry is one of the most multidisciplinary domains in which collaboration among related parties is of utmost importance” (Pektas & Pultar, 2006). This means architects have to collaborate with engineers, planners, financial, quality and safety managers etc. and the collaboration between these actors bring many challenges and problems. Collaboration is impeded because integrated design team members come from different organisations or practices and duplicate each other’s efforts, and many problems often fail to be resolved either quickly or to anyone’s satisfaction (Zager, 2002).
Architect deals with both precise and vague ideas that need systematic and chaotic thinking, both need imaginative thoughts and mechanical calculations. While engineers are different from architects, not just because they may use different design process but more importantly because they understanding about the different materials and requirements (B. Lawson, 2005). Moreover, Lawson argued that architecture is the dominant practise in a sequential design and delivery process, and the architect is the most powerful actor. The traditional management of design teams is based on command and control style. Where the architect have the authorities for directing activities, while in integrated approach the design teams strive to flatten the decision-making structure (Tyler, 2003). This is in contrast how the architect is used to work. Subsequently, lack of clarity in describing objectives or requirements, lack of coordination of roles and responsibilities at project inception, poor communication between designers and problems coordinating between disciplines later on are well-known issues (Rounce, 1998). In that case, both the architect as well as the engineer has to be organized and structured in their process and communication.

2.4 Design Thinking

Lawson described, the thinking process of an architect is different than that of the engineer's (B. Lawson, 2005). Consequently, Zager also argued in his report that collaboration between architects and engineers is impeded because they come from different fields with different practises (Zager, 2002).To understand the role of architect, this paragraph will capture the subject of Design Thinking as used by the architect.

Einstein quoted “a problem can never be solved from the context in which it arose”, meaning the situation that created the problem cannot be solved by the situation itself. The situation needs something ‘new’ to solve the problem. That something ‘new’ can be an action or a solution to the problem. In building design problems, the architect tries to find a solution by opposing something ‘new’ to the building. Since, buildings contain objective (level 1 and 2) and subjective (level 3) aspects, the architect has to deal with both precise and vague ideas for the solution. The thinking process to do this is conceptualized in Design Thinking.

Design Thinking as seen by Miemis (Miemis, 2010) is a set of principles from mind-set to process that can be used to solve a wide range of complex problems. Schön expressed Design Thinking is based on the human perception and takes into account the experiences of the designers (Schön, 1983). The supporters and practitioners of Design Thinking argue that designing cannot be fixed in a logical framework. Rather it is a process of trial and error to the problem emerged. To comprehensively understand Design Thinking, this research looks at the studies conducted by Kees Dorst (Dorst, 2003, 2004, 2010, 2011) and to the core design activities as described by Lawson and Dorst (B. Lawson & Dorst, 2009).

2.4.1 Abduction

Many authors have tried to describe and broaden the formal logic behind Design Thinking that is based on the work of Pierce. Pierce's work was about the scientific way of reasoning and has broadened the reasoning domain of Deduction and Induction with Abductive reasoning. Subsequently, Dorst has differentiated Abductive reasoning into Abduction-1 and Abduction-2. To understand Abductive reasoning, this thesis will follow Dorst's basic reasoning patterns through the setting of knowns and unknowns in the equation:

What	+	**How**	Leads to	**Result**
(thing)		(working principle)		(observed)

The 'What' is an object, service, system, or actor in a situation these are the 'players' in a situation we need to attend. The 'How' is the working principle, it tells us 'how' the players will operate together that will lead to 'Result'. With the equation we can predict results for example, if we know there is need for daylight (what) in a room, and we know the area of the room with the corresponding position and behaviour (how) of the sun, then we can create and position windows accordingly in the room

To have a better understanding of abduction, it is good to first grasp the deductive and inductive reasoning. The schematic expression of Deductive and Inductive reasoning is seen hereunder.

		Deduction		
What	+	**How**	Leads to	**???**
(thing)		(working principle)		

		Induction		
What	+	**???**	Leads to	**Result**
(thing)				(observed)

In Deductive reasoning the 'What' and 'How' are known and we can predict the results, just like designing windows according to daylight. In Inductive reasoning however, the 'What' and 'Result' are known but 'How' the result is achieved is unknown. For instance, the velocity of airflow (What) in building is too high which leads to an uncomfortable workplace (Result). But we don't know 'How' the airflow movement is displaced through the building. By proposing working principle we can observe (by testing hypotheses) the laws, which governs the air movement.

By Deductive and Inductive reasoning we can predict and explain phenomena in the real world. But what if we want to create something that does not exist in the real world yet, what if there is a need of something 'new' as quoted above by Einstein. That something 'new' will create value for others, therefore Pierce introduced abduction reasoning. In Abduction reasoning we try to create valuable things for others. The basic reasoning pattern is then Abduction:

		Abduction		
What	+	**How**	Leads to	**Value**
(thing)		(scenario)		(aspired)

Dorst has differentiated Abduction in Abduction-1 and Abduction-2. Both the reasoning aspires to achieve Value which is set beforehand. Abduction-1 is associated with closed problem solving and is often what designers and engineers do. In Abduction-1, as seen hereunder, the 'How' is known and the working principle will help to achieve the Value we aim for. What is unknown is 'What' (object, system, service) is needed to achieve the Value. Therefore, the challenge for designers is to search for solution.
For instance, the aim is to increase knowledge of physics, and the 'How' is the graduated students not having adequate knowledge (scenario). "What" can be in this case designing new advanced laboratories to assist the students, or to increase the 'education and teaching' knowledge of teachers. Putting a maximum acceptance of student can increase more one-on-one interaction with teachers, hence the quality. Reviewing and adjusting the curriculum can also be overlooked. Or a combination of the above can be made to increase the student's knowledge.

As seen from the examples there are many solutions for 'What' to achieve the aspired Value.

		Abduction-1		
???	+	**How**	Leads to	**Value**
		(scenario)		(aspired)

Abduction-2 reflects to open complex problem. In Abduction-2, the value is known but the 'How' and 'What' is unknown. The challenge here is to figure out 'What' to create, while there is no known or chosen 'working principle'. The challenge in Abduction-2 is closely associated to with design problems for which organisation are seeking new approaches. Problems in Abduction-2 are mostly social problems that cover a large spectrum of the society.

		Abduction-2		
???	+	**???**	Leads to	**Value**
				(aspired)

The challenge to abduction reasoning is central to design. The question is then, how does the designer overcome the challenge? What is the creative act performed to reach the desired Value? It turns out that designer's response to the challenge is by development or adoption of a 'frame'.

2.4.2 Framing

A frame is the general implication that by applying certain working principle we will create a specific value. The 'applying certain working principle' is then the creative act performed by the designer.

		Abduction		
What	+	**How**	Leads to	**Value**
		Framing		

Schön introduced 'framing' (Schön, 1983), he conceptualized that a frame is creating a standpoint from where the problem can be tackled. In other words, designers adopt an idea or a vision. Consequently, they create a frame by looking at the problem from that viewpoint and adopt the working principles associated with that position. Then they will create the value that they have been striving for. So designers link 'How' and 'Value' (frame) by opting for a viewpoint that parallel design the 'What'. If the problem situation is familiar, and the designer has dealt with such matters before, a frame will be integral part of the way designer is interpreting the situation and will come to conclusions straight away. If the problem is new and therefore not familiar, the more experienced designers search for the core paradox. Core paradox is where viewpoints and requirements are in opposition views. Once the designers have established the nature of core paradox to their satisfaction, they work towards a solution. The solution is then searched in the broader problem context. New frames with which to tackle the central paradox then arise (or emerge) from this engagement with the broader problem context.

Although new frame creation is an important element in design practise, it often appears to be an informal activity. While it looks like that designers are implementing vague ideas and viewpoint with a trial and error process for creating new frames. They are actually looking for clues in the broader problem context that can lead to the development of frames, which in turn can oppose as a solution to the core paradox. However, empirical studies of designers within cognitive psychology have shown that designers focus their creativity and analytical skills on the creation of solutions, testing and improving them, and not on analysing the problem up front (B. R. Lawson, 1979).

2.5 Sub-conclusion and answering sub-question one

In this chapter it is explored why building projects are getting complex. This paragraph concludes this chapter and provides an answer to the research question **1. Why are building projects getting complex?**

2.5.1 Conclusion

Background

Because of the circular economy principles governments are shifting towards sustainable development. This made the government use the performance based approach. In a performance based approach the consortium is paid by their performances over the lifetime of the building. Therefore, contracts such as DBFM(O) were introduced towards construction project to encompass the whole life cycle. In an DBFM(O) contract the consortium is responsible for the designing, constructing, maintaining (and in some cases also operating) the building. Subsequently in integrated contracts, the client specifies what they need in functional requirements for the entire life cycle and the consortium is free in designing and engineering of the project. At the end, the project has to comply with the requirements of the client.

2.5.2 Q1.1 What are the characteristics of buildings?

The design process and actors

In the traditional process for building design, the work is very much fragmented (Zager, 2002). Architects focus only on building design, but contractors construct the building, through different segmented contracts.
In contrast, with integrated contracts, the architect and contractor are afforded the opportunity to collaborate together from the onset of design. Therefore, the architect forms a consortium with the contractor and other relevant parties. Construction worker expertise and specialized knowledge of various disciplines can then be incorporated during the design phase of a building.
The life cycle approach and use of integrated contracts in buildings however, increases, the amount of actors/parties in building projects enormously. Integrated contracts for buildings involve many actors, with specialized knowledge of their respective fields. It emphasizes that relationships and communications within the consortium are thus important for the success of a project.

Developments and innovations

Rapid development has taken place in the building sector with novelty and technology being at the forefront of the 21st century construction. There is an increasing trend towards the application of digital technology to support control systems in order to achieve energy efficiency in buildings. This technological innovation requires specialized knowledge, which in turn proliferates the actors and interconnectivity within and between projects.
The life cycle approach demands that building information is accessible and practically applicable for the complete development process of the building as there is a high turnover of project actors. Information flow must be well structured and unambiguous, to maintain consistency of vision and message across project members supplementing the decision-making process. More importantly, each team member assigned to the next phase is aware of crucial structures and design elements that can significantly impact the entire project if affected.

The human context "soft aspects"

Good architecture is characterized by balanced design of aesthetic appeal, solidity and real-time usability. In order to systematically achieve good architecture, Preiser (2005) proposed a habitability framework for building projects. The elements of this framework relate buildings and settings, occupants and their needs against their environment.

To systematically comply with building requirements Preiser has redefined and prioritized basic human needs within his framework into the following three building performance levels.:
1. Health, safety and security performance;
2. Functional, efficiency and workflow performance;
3. Psychological, social, cultural and aesthetic performance.

The levels and sublevels are distinct in perspective and ranked in transition from objective to subjective categories. This research highlights the first two levels as objective and quantifiable but the challenging aspects of building development however both levels are well codified and with adequate guidelines. The third level is less quantifiable and prone to subjective evaluation and is defined by this research as softer aspects.

Soft aspects are associated with human context within a building that addresses comfort, safety, health and ambience designed to holistically address and augment an occupants living and working atmosphere. The human context is what makes a building unique therefore inspiring architectural creativity to achieve a complimentary merger of hard and soft aspects within design.

Traditional design is limited in its ability to artfully combine these aspects as minimum input is taken from engineers and specialists while the architect develops on a singular vision, isolates an aspect, such as creating efficient workflow, and then progresses through iterations and adjustments. This process can be correlated to that of piecing a puzzle together to progressively achieve a cohesive design.

2.5.3 *Q1.2 What is the role of an architect in an integrated contract?*

In integrated approach different parties have to collaborate to deliver a successful project. This makes an efficient process in building design and building construction very important. Architect is seen as the most central actor in the design process of a building. Therefore, the role of architect is further investigated.
In traditional approach the architect have formal contact with the contractor, while in integrated approach both need to collaborate and function as one towards the client. This requires a different approach and attitude form the architect as well from the engineers of the construction company.
The thinking process of an architect is different than the thinking of an engineer. While the engineers are inclined to inductive and deductive reasoning, the architect uses abduction as governing mode of thinking. The architect purposes with help of 'framing', what is seen as the creative act, a solution to the problem. However, in actual the architect is looking for clues in a broader problem context (problem space) to solve the core paradox. Therefore, there is a deliberate strategy involved to Design Thinking of an architect. However, studies have also pointed out that architect don't tend to explore the problem space thoroughly. Rather they focus on the creation of solution in the solution space and therefore sometimes missing the clues for the central paradox.

To search for clues in the problem context, the architect must evolve from hierarchically inclined decision maker to a role of mediator and problem solver in an integrated process (Chiocchio e.a., 2011; B. Lawson, 2005). The engineers and specialist can provide the architect clues he is looking for. On the other hand, the engineers in a construction company also have to take account, that the architect thinks and works differently than their process. The architect works on solution-base rather than process-base and thinks in both a systematic and chaotic way. Hence, the engineers must not provide rigid solutions to architectural demands. Rather they must learn to inject their knowledge and skills in the design process.
However, in an integrated approach a clear communication between both the actors is one of the most important instruments. The architect also have to explain the engineers, what is playing in his head and how he sees the design and what he wants to achieve with it. Consequently, the engineers in their turn can tell which technical solution will be viable to the design and give their input to the design. Therefore, clear and explicit communication is essential to achieve a successful project.

2.5.4 *Answering sub-question one, Why are building projects getting complex?*

With the introduction of integrated contracts the complexity in building projects has changed. This led to the following challenges:

- Changes the contractual relationship of actors. Subsequently changing their roles.
- Increasing numbers of stakeholders, due to life cycle approach, each with their own set of requirements.
- Increasing numbers of internal organisation actors within the design process.
- Rapid technological innovations make the future unpredictable.
- Different mode of reasoning by the actors involved in the design phase.

From the above challenges there is need of a method to manage the complexity within the integrated approach. Similar complexity due to integrated contracts was also seen in the infrastructure sector. In response to overcoming those challenges, Systems Engineering was successfully applied in the infrastructure. Therefore, this research will look if Systems Engineering can be applied to the building sector.

3 What can Systems Engineering contribute to B&U?

From the previous chapter it is obvious that the present situation the building projects are complex and there is an opportunity or even a need for a different approach to tackle them. Before this research gets into how Systems Engineering can help the building projects it is good to know what Systems Engineers can contribute to the building projects. Let us first understand what Systems Engineering is, thus chapter will start in §3.1 with a study on what is SE? Definitions, System Thinking and the added value of SE will be explored. Consequently, in paragraph 3.2 SE tools, which can contribute to B&U projects, will be reviewed. In the last paragraph the current application of SE will be explored. This chapter is intended to help to understand and grasp the theory and background in Systems Engineering, evaluate the tools that can be used in the B&U projects and to explore SE in practise.

3.1 What is Systems Engineering?

This section will provide an answer to the research question **2.1 What is Systems Engineering?**

Systems engineering first emerged in the military usage for management for technological project during and after the WWII. But the foundations for today's SE where laid by NASA in the 60's for their space programs (BKCASE, 2015; Emes e.a., 2012). The need for different engineering disciplines for complex project stimulated the use of SE in military and space programs. Soon after, major aircraft companies recognized the benefits and started adopting SE in their work (INCOSE, 2015). In 1990 NCOSE[12] (National Council on Systems Engineering) was established with the aim to develop and practice SE methods and with the introduction of the international standard ISO/IEC 15288 in 2002 SE was formally recognized. Furthermore, INCOSE fully incorporated with ISO/IEC/IEEE 15288 standards in 2008 (INCOSE, 2015). Moreover, in 2012 SEBoK (Systems Engineering Body of Knowledge) was introduced with the aim to assist professional practice in SE (BKCASE, 2015).

3.1.1 Definition

As mentioned in the introduction, Systems Engineering is a systematic and interdisciplinary approach for designing, constructing and maintaining complex systems in order to provide quality products that meets the user's needs (INCOSE, 2015). This definition is modified from the International Council on Systems Engineering Handbook (INCOSE). There are many different definitions to systems engineering, as various engineering fields have their own description of Systems Engineering. In the following section several definitions are stated in order to get a general idea of what SE is.

Definition 1

"Systems engineering is an <u>interdisciplinary approach</u> and means to enable the realization of successful systems. It focuses on defining <u>customer needs</u> and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the <u>complete problem</u>:

Operations Cost and schedule Performance Training and support
Test Manufacturing 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." (INCOSE, 2015)

Cited from Systems engineering handbook: a guide for system life cycle processes and activities, 2015 prepared by International Council on Systems Engineering (INCOSE). The definition of INCOSE is the most used and recognized by other organizations, including Rijkswaterstaat which is the government agency in The Netherlands responsible for the infrastructure sector.

[12] In 1995 INCOSE emerged from NCOSE to incorporate international view.

Definition 2
The second definition is from ISO/IEC/IEEE 24765:2010 Systems and Software Engineering - System and Software Engineering Vocabulary.[13] And define SE as an *"Interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life."* (ISO/IEC/IEEE, 2010).

Definition 3
Another very important document is the SEBoK (Systems Engineering Body of Knowledge) which defines SE as*," Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal."* (BKCASE, 2015)(see also Figure 12)

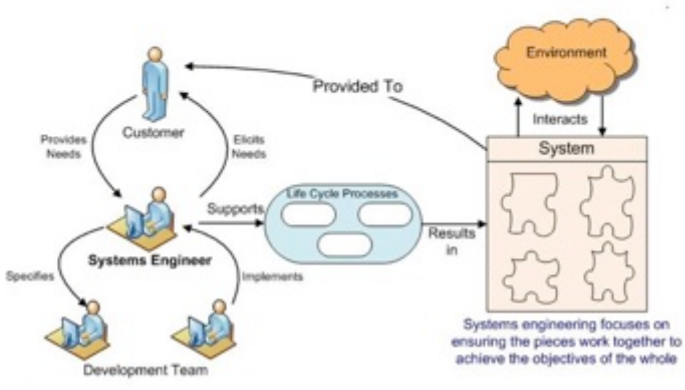


Figure 12 Systems Engineering *(source: BKCASE, 2015)*

Definition 4
Furthermore, Howard Eisner have studied several definitions in his book Systems Engineering, Building Successful Systems. His own definition adapted from his book Essentials of Project and Systems Engineering Management is, "*Systems Engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near-optimal manner, the full range of requirements for systems."* (Eisner, 2008, 2011)

Definition 5
A definition stated in the NASA Systems Engineering Handbook: *"Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system. (…) It is a way of looking at the "big picture" when making technical decisions. It is a way of achieving stakeholder functional, physical, and operational performance requirements in the intended use environment over the planned life of the systems. In other words, systems engineering is a logical way of thinking."* (Nasa, 2007)

Definition 6
The sixth and final definition comes from the book, System Analysis, Design, and Development by Charles S. Wasson. And state that Systems Engineering is *"The multidisciplinary application of analytical, mathematical, and scientific principles to formulating, selecting, and developing a solution that has acceptable risk, satisfies user operational need(s), and minimizes development and life cycle cost while balancing stakeholder interest."* (Wasson, 2006)

As seen from the definitions different engineering fields, organisations and individuals have different perspectives and expectations on SE. However, it can be emphasized that three concepts appears to come back in every description. These three underlined concepts in the definitions are the interdisciplinary approach, the life cycle processes and the stakeholder's requirements. Rijkswaterstaat also underpins the importance of these concepts as an integral part of the Systems Engineering (Werkgroep 3 Leidraad SE, 2013). Emes, Smith and Marjanovic-Halburd have given a well-defined and adequate summary of these key concepts regarding to SE. *"In essence, an SE approach to a project recognizes: the different phases in a project from conception to disposal (lifecycle); the need to strictly identify and track satisfaction of stakeholder needs (requirements); the way in which a delivered system can be partitioned into a hierarchy of subsystems and elements, with the functions required from a system mapped to subsystems, interfaces defined and*

[13]Not to confuse with ISO/IEC 15288:2008, which is about the System life cycle processes. The INCOSE Handbook is consisted with ISO/IEC 15288:2008**.**

responsibility for delivery of each subsystem allocated to a specific individual or enterprise (system); and that each subsystem will need a different blend of specialist skills to deliver it (interdisciplinary)." (Emes e.a., 2012).

3.1.2 System

Explicitly Systems Engineering is a multidisciplinary engineering of system (Wasson, 2006). In other words, SE is creating a system and a system engineer develops systems to solve problems in a holistic manner. *But what is a system?* A system itself is a set of interrelated parts that work together to accomplish a common purpose or mission (Cloutier, Baldwin, & Bone, 2015). Wasson gives a more comprehensive description; *"System is an integrated set of interoperable elements, each with explicitly specified and bounded capabilities, working synergistically to perform value-added processing to enable a User to satisfy mission-oriented operational needs in a prescribed operating environment with a specified outcome and probability of success"* (Wasson, 2006). So a system (Figure 13) is constructed out of elements, these elements interrelate and create synergy with each other to work for the same goal or mission. A system can again consist of subsystems and components.

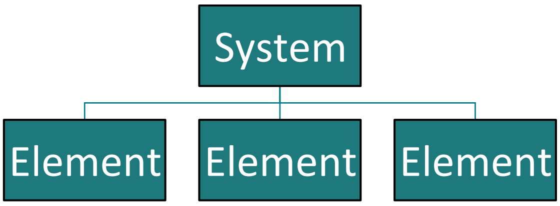


Figure 13 System and elements

In a broader context the hierarchy of system, subsystems, components and elements as mentioned above are shown in Figure 14, where the system in consideration is an aircraft system. The system itself is part of a greater system, which is called system of systems (SoS). For example in Figure 14 the transport system consists of air, ground and maritime transport. These three systems can be operated and managed independently, but all three strive for a common goal namely transportation of people and/or goods. Subsequently, the air transport system again consists of several other systems like ticketing system and aircraft system, which is the environment where the system is related. Expanding the aircraft system, which is the system of interest (SoI) in this example, shows that the aircraft system is decomposed of interacting subsystems. System of Interest is a system that is considered as independent system whose life cycle is under consideration and observed by the system engineer (BKCASE, 2015; ISO/IEC/IEEE, 2015). The system of interest is decomposed in subsystems, which are further decomposed in components and elements. Elements are the 'lowest level' in the system and cannot be further decomposed. The levels of the hierachy in the system model is depended on the complexity of the system in consideration and can be decomposed in more levels thn represented here. For example, the aircraft system (SoI) consistsof 4 levels, the Air transport system is level 0 which represent the evironment where the SoI is embedded. The other transport systems can be seen as higer order systems.

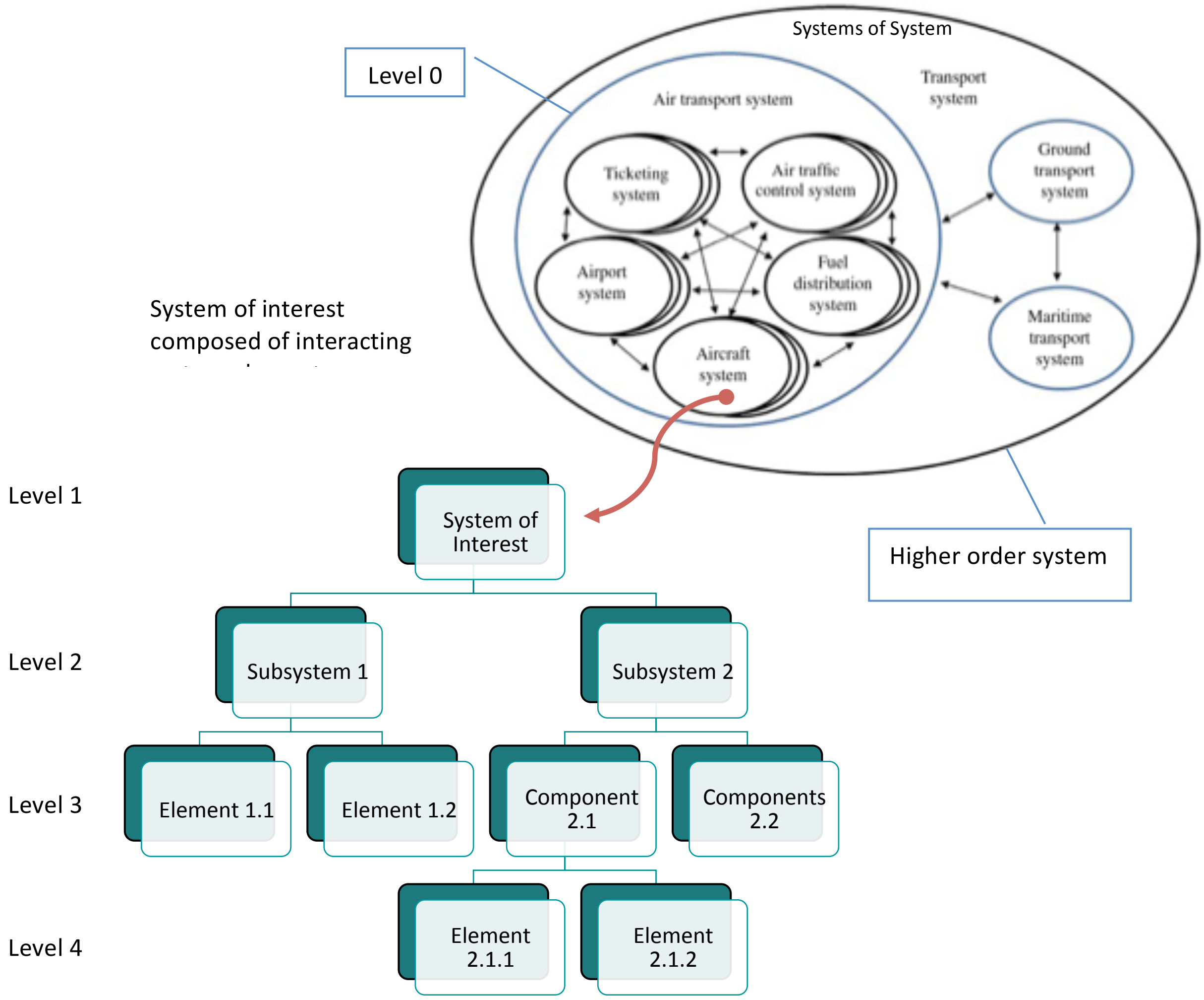


Figure 14 Systems of systems and System of Interest *(source: adapted from INCOSE, 2015 and Wasson, 2006)*

3.1.3 Systems thinking - the need of Systems Engineering

Beyond Ghor there was a city. All its inhabitants were blind. A king with his entourage arrived nearby; he brought his army and camped in the desert. He had a mighty elephant, which he used in attack and to increase the people's awe. From among this blind community messengers ran like fools to find it. As they did not even know the form or shape of the elephant they groped sightlessly, gathering information by touching some part of it. Each thought that he knew something, because he could feel a part. When they returned to their fellow citizens, eager groups clustered around them. Each of these was anxious, misguidedly, to learn the truth from those who were themselves astray. They asked about the form, the shape of the elephant, and listened to all that they were told. The man whose hand had reached an ear was asked about the elephant's nature.
He said: 'It is a large, rough thing, wide and broad, like a rug.' And the one who had felt the trunk said: 'I have the real facts about it. It is like a straight and hollow pipe, awful and destructive.' The one who had felt its feet and legs said: 'It is mighty and firm, like a pillar.'
Each had felt one part out of many. Each had perceived it wrongly. No mind knew all: knowledge is not the companion of the blind. All imagined something, something incorrect ……

---- Story by Idries Shah in the book, Tales of the Dervishes

This ancient Sufi story illustrates the lack of systems thinking in systems theory. Like the blinds have never seen an elephant and don't know what the shape or behaviour of an elephant is. A system itself cannot be known just by knowing the elements. Elements are an essential part of the system but that does not define the system alone. How the elements are connected, how they behave with each other and what goal or purpose does the elements serve is equally important as the elements itself. It is the sum of the parts that makes a system complete and Systems Thinking allows us to approach the system in a holistic manner, where the elements are interconnected with each other and work towards one goal.

To understand a system and its behaviour it is important to understand how the elements work together. A system is mostly seen only as (physical) elements such as in Figure 14 elements of an aircraft system can be a rotating blade, fuel pipe, tires, flaps etc. But as the aforementioned definitions, a system itself is a set of *interrelated parts that work together* to accomplish a common purpose or mission (Cloutier e.a., 2015). Therefore the relationship between the elements is also critically important. Put the elements of the aircraft system on a runway, but until they are not connected with each other and work as one, they cannot fly. It is easier to learn about a system's elements than about its interconnections. While elements are essential in systems' understanding, the interconnections of elements are an equally important part of systems thinking. Systems thinkers therefore also focus on the relationship between the elements to understand the systems behaviour. Because changing the relationship between the elements usually changes the system behaviour (Meadows & Wright, 2008). The relation within the system is mostly information based, where one element or subsystems sends information to the other element. For example, the pilot can use weather information to alter the route of the plane or the information of the wind flow during take-off and landing can help the pilot to take necessary steps in advance. Systems thinkers see the root causes and courses of action that control

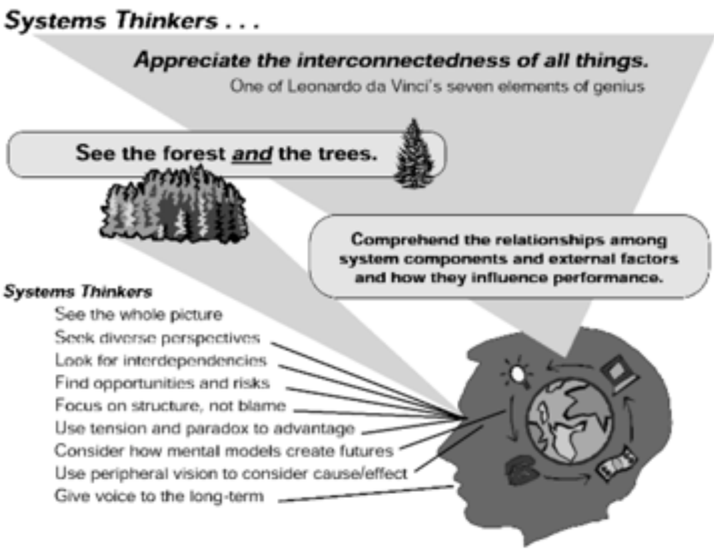


Figure 15 Systems Thinkers take a broader view of the world. *(source: Forsberg, Kevin; Harold Mooz, Howard Cotterman (2005),Visualizing Project Management)*

events (Forsberg, Mooz, & Cotterman, 2005). Systems thinking provide a framework for systems engineers in how to find and manage the information within the system. With Systems Thinking as seen in Figure 15 the Systems Engineers can approach a project in a holistic manner.

In the construction industry building project are getting larger in size, increasingly complex and intelligent by integrating technologies such as safety, communications, comfort and entertainment (Emes e.a., 2012). Moreover, stakeholder influences continues to grow too due to performance based approach. With the rising complexity and stakeholder requirements in the construction projects the cost and time performances in the constructions projects are below par (Meng, 2012). At the same time, buildings are expected to adapt to the changing functional needs and user objectives over the lifetime (Baudains e.a., 2014). Traditionally, construction processes were prescriptive processes driven on minimizing cost and time rather on the performance of the end product. While governments and building regulations across the world are shifting towards performance based processes (Augenbroe, 2011). The performance requirements from the client and the fulfilment of the requirements by the execution party managing the processes are lacking a proper framework (Emes e.a., 2012). Systems Thinking can provide that framework with methods used in Systems Engineering to enhance the overall design process, maintenance and reuse of the buildings (Baudains e.a., 2014; Emes e.a., 2012).

3.1.4 Added Value of Systems Engineering

Systems Engineering as portrayed in the definitions above is a method to work efficiently towards the customer needs. SE is an effective way to manage complexity and change while reducing risk of the projects (INCOSE, 2015). Studies shows that lack of SE can result in cost and schedule overruns, while investment in SE results in cost-efficient systems (BKCASE Editorial Board, 2015). Hereunder three studies will be discussed which highlights the added value of Systems Engineering in projects. Furthermore, an evaluation on a residential building project using Systems Engineering in The Netherlands will be elaborated. Overtime in projects decisions are made which determine the life cycle cost for the rest of the projects. As seen in Figure 16, the committed life cycle costs are drawn against the time of a project. The concept phase is 8% of the total life cycle cost. But the commitments made in the concept phase already determine 70% of the total life cycle cost of the project. Moreover, the diagonal arrow shows that changes made in decisions after the concept phase will likely to increase the cost with every phase. Thus, it is very important to make adequate and well-thought decisions early as possible in a project. The SE method supports in decision-making in the concept phase by an adequate and well-thought study. The life cycle approach of SE benefits the project to make suitable commitments early in the project.

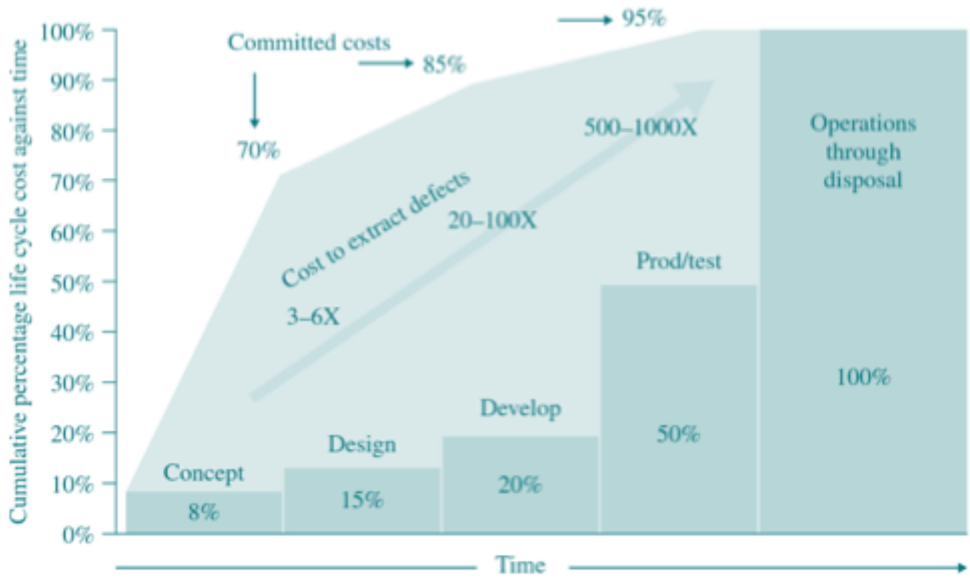
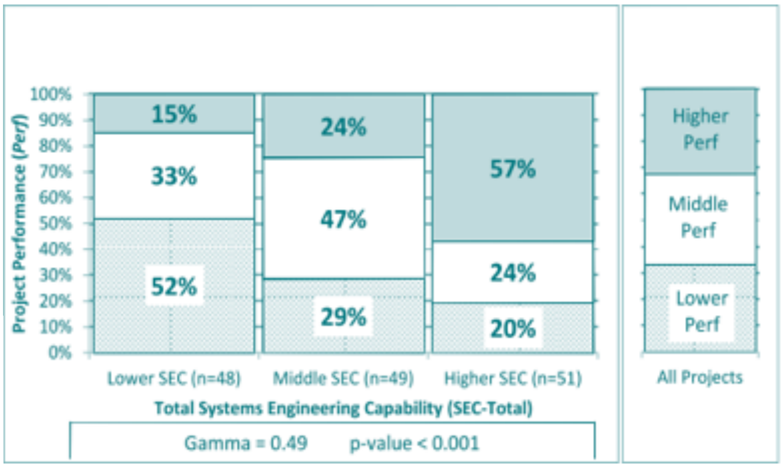


Figure 16 Committed life cycle cost against time
(source: INCOSE,2015. from Defense Acquisition University, 1993)

Moreover, Elm and Goldson studied the effectiveness of Systems Engineering on project performance in 148 projects. The conclusion of their report is; “Projects that properly apply systems engineering best practices perform better than projects that do not” (Elm & Goldenson, 2012). Their results are shown in Figure 17. The projects were assessed on budget, schedule and technical performance. The projects in the left column have used lower levels of Systems Engineering as measured by assessing the quantity and quality of specific SE work products. It shows that from the 48 projects, 52% have underperformed and only 15% were within the satisfactory budget, schedule and technical requirements. Subsequently, in the third column higher level of Systems Engineering is applied. It shows that from 51 projects 57% achieved higher level of performance than expected. Thus concluding that using Systems Engineering helps the project performance significantly better.

Figure 17 Project Performance VS Total Systems Engineering Capability
(source: Elm &Goldenson, 2012)



Furthermore, Eric Honour researched the relationship between SE and Return on Investment (ROI) with regards to project success. The project success is measured in cost, schedule and overall stakeholder success. The optimum of project success is found on 14,4% of the total cost, as seen in Figure 18. Meaning that if projects invest 14,4% in SE they have zero return. Investments in SE till 14,4% have an increased value of return and higher investments than 14,4% have a negative return. The maximum ROI is high as 7:1 on projects with little SE efforts. Meaning that for every 1 unit spend on SE, 7 units are saved on the total project costs. The average SE-ROI is on 3,5:1, see Figure 19 and the accompanying table. The results clearly state that using SE have a significantly added value in projects. (Honour, 2013)

In The Netherlands, a housing corporation completed a residential building project with the use of Systems Engineering as the primary management and design tool. Plegt and Leicher were involved with the SE process in project. The conclusions by both Plegt and Leicher in their reports are that SE creates an added value in cost, planning and innovation compared to the traditional project management (Leicher, 2010; Plegt, 2009). The evaluation of Leicher of SE against the traditional project management strategy has, as expected, a favourable role with SE (Leicher, 2010).
Leicher compared three traditional projects with a Systems Engineering project, all the four projects were conducted in the residential building and with the same housing corporation. The results were that Systems Engineering project had an additional worth compared to the conventional projects. The design phase was within the budget whereas the other three projects had cost overruns. Also the project was within the schedule in contrast to the traditional three, where the projects did not comply within the time limit. The recommendation of the report was to use SE method industry wide as the management and design tool in housing industry. Although this evaluation was done within one company and their projects, this made it difficult to apply for the whole industry. Nonetheless, it presented that SE had significant positive results compared to traditional methods.
From the studies above it is obvious that Systems Engineering creates an added value in the form of cost reduction, it restrains within the schedule and has a higher chance of increasing the overall project success.

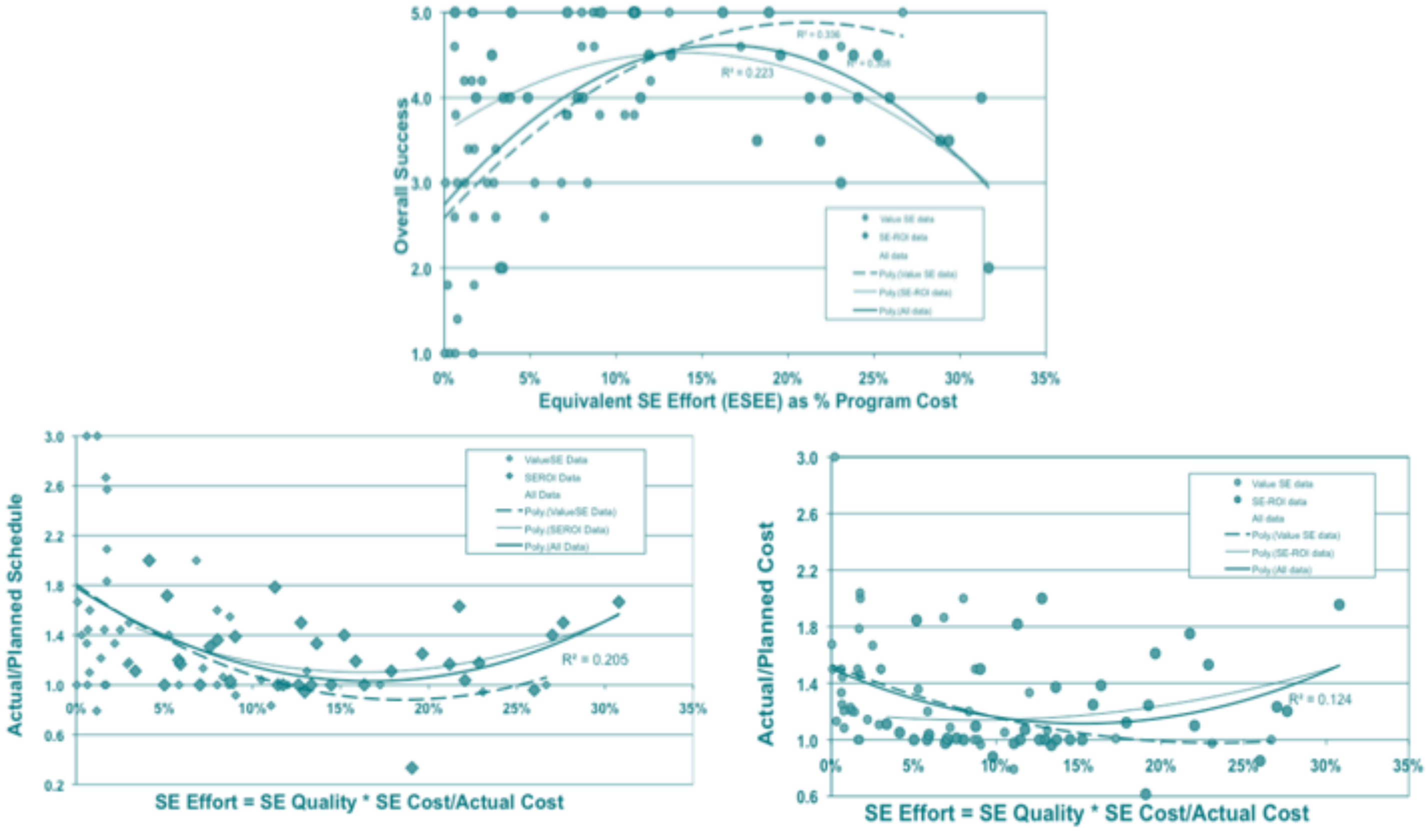
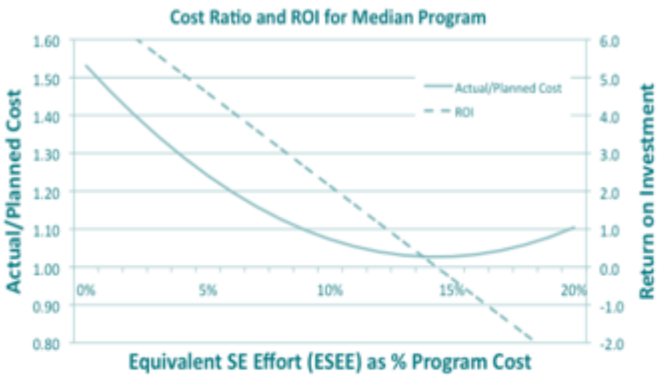


Figure 18 Overall Success against SE Effort (top)
Schedule against SE effort (left)
Cost against SE effort (right)
(source: Eric C. Honour, 2013)



Current SE Effort (% of Program Cost)	Average Cost Overrun	ROI for Additional SE Effort (Cost Reduction Per $$ Added)
0%	53%	7.0
5%	24%	4.6
7.2% (median of all programs)	15%	3.5
10%	7%	2.1
15%	3%	-0.3
20%	10%	-2.8

Figure 19 Cost ratio and ROI against SE effort
(source: Eric C. Honour, Systems Engineering Return on Investment, 2013)

3.2 Managing project complexity, Systems Enigneering toolkit

The previous paragraph defined what Systems Engineering is, in this paragraph the Systems Engineering process will be explored in GWW-sector and afterwards the tools that are needed for the process are analysed. This paragraph will provide an answer to the research question **2.2 How is Systems Engineering process implemented in GWW?**

3.2.1 The Systems Engineering process

The SE-process gives guidelines on how to approach complex project trough Systems Engineering. The elements of the Systems Engineering process are illustrated in Figure 20. Since in this research an analogy is made from the GWW-sector the SE process in Figure 20 is based on the civil engineering industry (Graaf, Voordijk, & Heuvel, 2016). The description of elements is based on the Systems Engineering fundamentals of the Department of Defence (US Department of Defense Systems Management College, 2001), guidelines available for the GWW-sector in the Dutch civil industry (Werkgroep 1 Leidraad SE, 2007; Werkgroep 2 Leidraad SE, 2009; Werkgroep 3 Leidraad SE, 2013) and Handbook Systems Engineering of ProRail (ProRail, 2015).

The core elements (1-9) of the SE-process consist of requirements analysis (1), functional analysis (2), synthesis (6) and the relations between them (3-5, 7-9). Furthermore, the process need input form the client (10) and as end result a design solution (11) will be deliverable from the consortium. System analysis & control (12) is the management of the process, evaluation, documenting data and decisions taken during the process and apply to all steps of the SE-process. The core elements will further described hereunder.

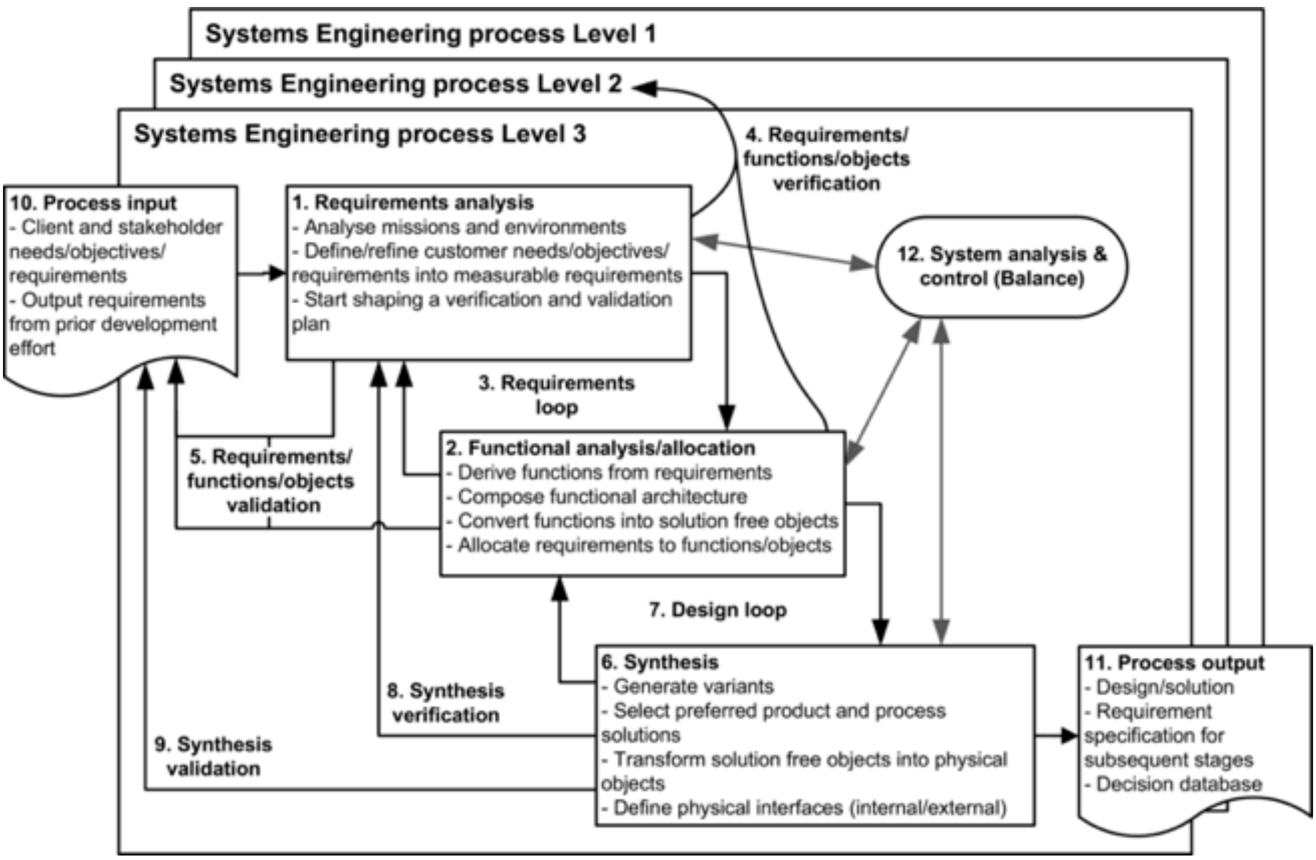


Figure 20 The Systems Engineering process in the civil engineering industry. Source:(Graaf e.a., 2016) based on U.S. Department of Defence.

1. **Requirements analysis (RA)**
   After the client and relevant stakeholders give their input (10) in needs, wishes, objectives and output requirements. The first step is to analyse the requirements. In this step the demands and needs of the clients and stakeholders are translated into a set of requirements. The set of requirements tell what a system must do and how well it must perform. Furthermore, a verification and validation (V&V) plan should be prepared. The V&V plan contains how, when, and by whom the requirements are verified and validated later in the project.

2. **Functional analysis and allocation (FA)**
   In the functional analysis and allocation step the functions of the system are identified, a functional architecture will be performed. It tells what the system should do and in what extend. The functions are derived from the requirement output in step 1. These functions are then decomposed in lower level functions and allocated with their performance requirements. Objects are then coupled to functions with their specifications. These objects are then the input for the design synthesis.

3. **Requirements loop**
   The requirement loop is the first iteration of the SE-process. Each function from FA should be traceable back to the requirements from the RA. Performing functional and performance analysis will lead to new insight into requirements. In result reassessing, the requirements in RA will give new perception to the system.

4. **Requirements/functions/objects (R/F/O) verification**
   Since the SE-process is an interactive process with top-down decomposition and bottom-up integration, the requirements, functions and objects needs verification with upper level processes. This means traceability will be kept in check and adjustment can be made before continuing the design.

5. **Requirements/functions/objects (R/F/O) validation**
   In this loop it is assed if the R/F/O meets the needs and expectations of the client and stakeholder.

6. **Synthesis**
   In the synthesis the objects and function from the FA are brought together into physical objects, also called the physical architecture. Various concepts or designs variants are developed on the basis of the functional analysis. Subsequently, the best design that meets the client and stakeholders needs is then chosen. Each object should be traceable back to the requirements in the RA step.

7. **Design loop**
   The design loop is a continuous process between the synthesis and the FA. During synthesis it can be assumed that other functions are needed or the functions can be decomposed further. Hence, new functions can arise and influence the design. In the case of new functions, a revision to RA process should be necessary because every function has to be allocated to a requirement.

8. **Synthesis verification**
   In the end verification should be made back to the FA to see if all requirements are achieved in the design. Any deviations will lead to adjustment in the solution and the process should follow again from the FA to synthesis for that specific requirement. The V&V plan made in the FA step can be used to verify the requirements in the synthesis.

9. **Synthesis validation**
   Likewise as the synthesis verification, the synthesis validation will assess if the design meets the expectation of the client and stakeholders.

3.2.2 SE toolkit

The SE-process outlines what steps have to be taken in order to build a system. But the vast information obtained on a construction project with many requirements can be a difficult task to tackle. This paragraph elaborates some methods and techniques that are used in the SE-process to manage the complexity during projects. Using the right tool in the right way makes the process understandable and easier to use, thus the complexity of the system is manageable by cutting the information in portions. These little portions contain information about physical objects, activities, risks, interfaces and specifications that are interrelated into one coherent system (Oostinga, 2014). The tools used for the core elements (1-9) of the SE-process, as seen in Figure 20, will be investigated. The question answered is, how the processes of the elements are conducted? Moreover, the process can be captured and managed by ICT-tool, which will be elaborated at the end.

1. **Requirements analysis (RA)**

   The requirement analysis is one the most important task in SE, because in the end the requirements will be transformed into a design. For that reason it is important to take time for this step and investigate the requirements. Good requirements are those, which are formulated SMART (Specific, Measurable, Acceptable, Realistic, Time bound) and are traceable with number/coding system.

   No exact tools exist for conducting an RA because the input is required from the client. Asking the right question is the key in formulating requirements. In that sense, doing a stakeholder analyses can help to understand the context and players in the project. Furthermore, involving people (integrated team) from the whole life cycle can ensure that all phases are investigated and expertise from all actors is used, this can be done in scrum-session and can help to formulate the right questions to ask to the client. Another tool that can be helpful is to make a requirement breakdown structure (RBS). With RBS, requirements can be decomposed into lower lever requirements and performances, which can help to get clear overview of the requirements. Having a clear and organised view of all the requirements will increase the efficiency of the project. Moreover, RBS can be used in later stages of SE to link the requirements to the objects and functions.

2. **Functional analysis and allocation (FA)**

   Requirements are transformed in functions, the functions tell what the systems have to do and in what extend to achieve the requirements. A function breakdown system (FBS) can be made where functions are decomposed in the underlining sub-functions. On the same time, objects in a System breakdown function (SBS) can be coupled on the functions and sub-functions. Objects "fulfil" the functions that they are coupled with (Oostinga, 2014). Thus making a SBS parallel with FSB will give clear view for all the objects needed for the design. Consequently, allocating the performance requirements with the objects will show in an organised and structured to what the object have to be met. By performing FA it is important to make throughout FSB this will ensure that all the functions are met and allocated with their objects. *"The objective is to identify the functional, performance, and interface design requirements; it is not to design a solution…yet!"* (US Department of Defense Systems Management College, 2001). A functional flow block diagram and Integration Definition for function for modelling (IDEF0) can help to make FSB and allocate the performance requirements.

6. **Synthesis**

   In the syntheses all the objects are brought together to form a physical architecture. This can be done with computer-based tools as CAD or other design software. The important thing in this step is to keep in check if all the requirements are met. This can be done with the V&V plan which is described next. The V&V-plan can be used throughout the whole SE-process. From the design synthesis Work breakdown structure (WBS) can be derived. A WBS consists of all the activities that have to be performed in order to get the system working. It is done by individuals or in teams. The WBS can then be linked to the SBS so that is also clear for each object what activities by whom and when have to be performed. The output of the design synthesis is the input for the next level of SE-process where the whole process is followed again in more details. This iterative process is done several times till all the requirements are met.

   Verification and Validation (V&V) plan for the iterative process (4,5,8,9)

   A verification and validation plan can be seen as quality management of the project. Verification is to fulfil the specification and requirements. Specifying in RA what, how and when the requirements have to comply with one can be verified later in the SE-process if the requirements are met. The V&V plan has to be developed in parallel with the RA, an example of a verification matrix is seen in Table 3.

Validation is to check if the end result fulfils its intended purpose. The traceability of requirements in a system and asking client if he agrees with what is achieved can validate the result.

Table 3 example of a Verification matrix. (Duvivier, 2007)

Verification Matrix				
Verification design matrix				
Specification				
Requirements number	**Requirement text**	**Verification method**	**Verification level**	**Verification result**
##		**Review** **Test** **Inspect** **Simulate** **Etc.**	**System (SO)** **Subsystem (VO)** **Component (DO)**	**Approved** **Deviation** **Rejected** **Etc.**

ICT tools
The role of ICT in construction project is to identify, manage, and share all of the information assets of an organization in an integral way (Bektaş, 2013). A digital technology as BIM (Building Information Modelling) is being widely practised in the construction industry. BIM is a computer-based virtual modelling tool to realize multi-dimensional visualization of the design and exchange of design data within the design team (Bektaş, 2013).
In practise, the SE-process is also done with support of ICT tools. The designs are made via computer programs such as CAD software for 2D and Revit for 3D modelling. The modelling of the SE-process can also be done by computers software (e.g. Excel and Visio etc.). Relatics is also a software programme where information can be shared and stored. Moreover companies can make FSB, SBS, WBS, and V&V plans and link them together to form a comprehensive and integrated management system. ICT-tools can make communication between actors clear and structured as consequence increase project control and reduce project risks.

3.3 Current applications of SE

This paragraph will provide an answer to the research question **2.3 What are the current applications of SE?**

3.3.1 Relevance SE in DBFM(O)

The Dutch construction industry can be split into two sectors, *Grond-, Weg en Waterbouw*(GWW) is the infrastructure sector and the *Burgelijke & Utiliteitsbouw* (B&U) is the building sector including residential and non-residential buildings. Systems engineering is widely used in the infrastructure sector mainly because RWS and ProRail respectively have imbedded SE method into their integrated contracts as a requirement. Therefore, a closer look at the relationship between integrated contract, particularly DBFM(O), and SE is required.

An important similarity between Systems Engineering and DBFM(O) contracts is that the 'questioning' (uitvraag) of the problem is done in the form of functional specifications. Where the contractor get the space to develop integrated solutions using their own expertise and their innovation capacity. In both the cases benefits are expected in terms of cost and quality. Common feature of both the methods is, therefore, that not the lowest price is decisive for the choice of the client, but the solution with the most favourable price-quality ratio (Spekkink & Savanović, 2010). Not only large and complex projects benefits from SE. The SE-pilot, as mentioned before, by the housing corporation in Almelo proves that optimizing the value for money is also applicable to smaller (housing) projects (Leicher, 2010). Another common feature is that a DBFM(O) contract and Systems Engineering both apply the lifecycle approach. In the DBFM(O) contract the maintenance and operating responsibilities are also included, in that sense the execution party have to think during the design phase, like in the SE, how to manage them both efficiently. A life cycle approach is then needed to allocate and manage the risks during the later parts of the project. Furthermore, as seen in the previous paragraph, Systems Engineering provide methods that can translate the functional specifications and requirements stated in the DBFM(O) contract efficiently into systems specification and systems requirements, which can be through verification and validation assessed to the specification in the DBFM(O) contract (Leicher, 2010; Plegt, 2009; Spekkink & Savanović, 2010; Stichting Pioneering, 2013).

3.3.2 *Systems Engineering at Rijkswaterstaat*

Integrating the project, quality assurance, transparency, and complexity makes sure that SE is a necessity in integrated contracts. SE is now a requirement for contractors to use in their projects, which are tendered by RWS (Werkgroep 1 Leidraad SE, 2007). This way RWS can check with the support of ISO norms as ISO15288, if the execution is going according to the plan and the quality is met to the needs of RWS. On the other hand, the execution party can work clearly and efficiently towards the RWS requirements. RWS itself explain SE in their "Leidraad SE binnen GWW-sector" version 1,2 and 3 which will be elaborated hereunder.

In general RWS use the V-model for Systems Engineering as seen in Figure 21. The key characteristics of SE in GWW-sector are customer needs, lifecycle optimisation, top-down specification and working explicitly. In line with this research only the concept and design/development phase (circled) will be elaborated in details.

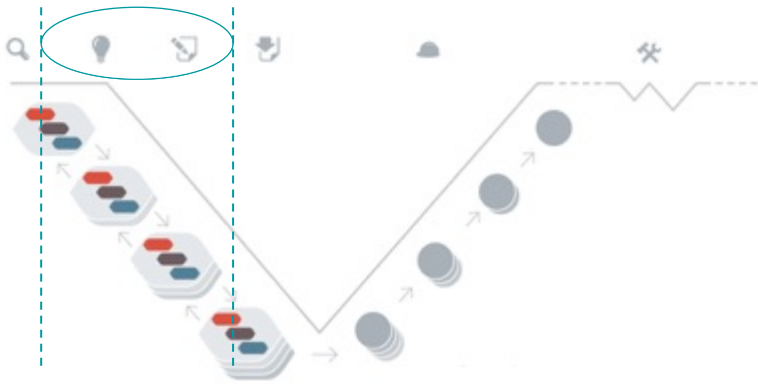


Figure 21 V-model RWS. (Source adapted from: Leidraad SE De samenhangcentraal, versie 3)

Customer need

The central purpose of using Systems Engineering is to accomplish customer need. As mentioned before, a system has to fulfil a purpose, goal or mission that is related to the customer need. To fulfil the mission of the system of interest the customer's problems and opportunities should be analysed. In the GWW-sector, the systems of interest can have various stakeholders for example, the RWS is the client of a highway but the municipality, province and the locals living nearby the highway as well as the non-governmental agencies can be stakeholders too within the system. A good starting point in the GWW-sector is to perform a stakeholder analysis and specify their need (Figure 22). Who are the stakeholders and what are their requirements? This will be recorded in the customer requirement specification (CRS – Klanteisenspecificatie). The CRS is then used as an input for the process of the system development. The customer need will be central for SE because in the end the customer decides what the problem is and what the limitations are for the system. And with SE the execution party can find an efficient solution within the systems limitations. Furthermore, the customer needs and limitations have to be managed throughout the system development, since those can be changed during the process due to design and law changes.

Figure 22 Stakeholder need to CRS
(source: Leidraad SE, versie 2)

Lifecycle optimisation

A system goes through several lifecycle phases in its lifetime, from exploration phase to concept, design, realisation, maintenance and eventually disposal phase. System Engineering focuses on optimizing the system throughout the whole lifecycle with again the notion that the customer need is central in the lifecycle process. That means that lifecycle optimization is not only done on cost and time but also on usability, maintainability and disposability. The technical processes used by RWS in the GWW-sector are based on the international standard of System Engineering ISO15288. These processes are positioned in relation to the phases in Figure 23 alongside the V-model of Figure 21. These processes are not performed once, but applied iteratively throughout the lifecycle. Some process goes through various phases but as mentioned before only the

Figure 23 technical processes in relation with lifecycle phases. *(source: adapted from leidraad SE versie 3)*

processes of the concept and design/development phase will be elaborated hereunder. Other process can be viewed in the ISO15288 and Leidraad SE versie 3.

The stakeholder requirements definition process

In this process the stakeholders are identified throughout the lifecycle and their wishes and needs are stipulated (customer requirement).

Requirements analysis process

The customer requirements are expressed in functions that the system has to fulfil during the lifecycle. During the requirements analysis process the customer needs and desires are translated and weighted into functions. Consequently, these functions are the set of requirements (System requirements).

Architectural design process

In this process various design alternatives are compared and weighted against each other to come up with a solution that meets the (system) requirements.

Verification process

The aim of the verification process is to determine if the system complies with the requirements. This process is done throughout the whole lifecycle.

Validation process

Just like the verification process, this process is also done throughout the whole lifecycle. And it emphasizes on if the customer requirements are specified correctly.

Top-down specification

The complexity of the projects in the GWW-sector is generally very high. Consequently, designing a system and the system elements in one go is not possible. Subsequently, working from abstract to a concrete solution, a top-down development and bottom-up realization of the system is necessary. Thereby, the iterative process repeats as seen in Figure 24 on several detail levels. The top-down development is based on the SE-process described earlier in the report.

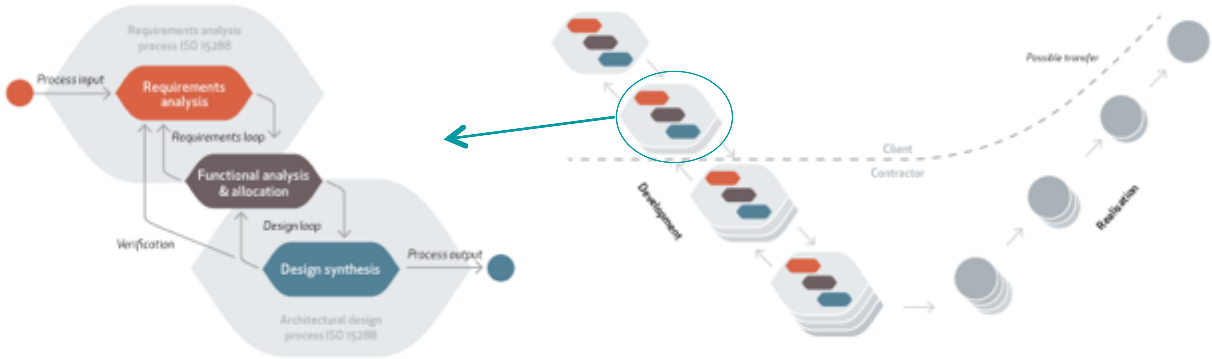


Figure 24 Top-down development with iterative specification *(source: Leidraadversie 3)*

In top-down specification, the system is decomposed in subsystems and systems element with each subsystem and element having their own requirements. The number of levels a system have depends on the complexity of the system. The iterative process keeps on repeating till the detail level is reached where the risks are acceptable. In general the following levels are used in the GWW-sector. Sketch design, preliminary design, final design, implementation design and functional design, spatial design and structural design. But these levels are not fixed and can vary depending on the complexity of the project.
The art in top-down specification is to work from abstract to concrete in respect to the interaction between functional, system requirements and alternative solutions. Every detail level has a specification of the solution space as input and specification of the solution as output. The output serves as input for the next detail level and draws the boundaries where in the solution will be found. The design solution has a certain margin what specifies the boundaries of the design. This margin should fit in the solution space that is specified by the output of the previous detail level (Figure 25).

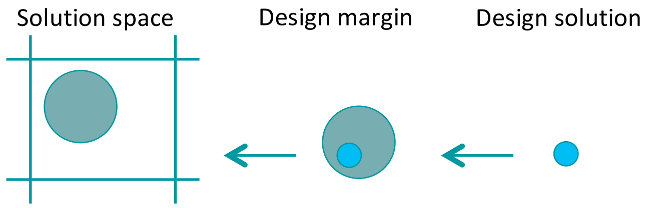


Figure 25 design VS solution space
(source: Leidraadversie 3)

Working explicitly

With various phases, subsystems and system elements, a lot of teams and individuals have to work together or transfer information to each other. That means that the various teams and individual have to clearly state the information in the right way, so that the other members can use the information adequately. By doing so, information can be communicated without getting misplaced in the process. The supporting processes for working explicitly are verification and validation (V&V). The V&V has to be done for every iterative process and detail level (Figure 26). As for example it can be seen above in Figure 24, the design synthesis goes through verification on the requirements analysis. The aim of V&V is to prove explicitly that the result (output) is in accordance to the solution space provided by the customer (input). By performing the V&V process the chance of errors are minimized and even prevented during the decision-making process. Since design deviations can be perceived early in the process and corrected in time due to V&V-process. Consequently, the correction can then alter the design or the perception of the customer needs.

Figure 26 iterative processes with
Verification and Validation
(source: Leidraadversie 2)

3.3.3 *Systems Engineering at BESIX*

BESIX Project Management
Before studying the cases this part will go into the methodology and background. BESIX uses for each project a standardized BESIX Project Management tool (BPM). Since the departure point for each project is from the BPM it is good to focus on the BPM master model before concentrating on specific projects.

BESIX started in 2012 with the development of the "BESIX Project Management" (BPM) methodology (BESIX, 2014). The goal of the BPM methodology is to help employees manage projects of BESIX. The support of the employees is done in twofold:

- Using process descriptions that explain the working methods of BESIX.
- And by means of a software tool (Relatics) that can manage the project information.

The BPM tool works according to the Systems Engineering methodology and was initiated because of the requirements from the clients, namely the government agencies.
BESIX uses a semantics model as a basis for their design of the Systems Engineering. This model is built in collaboration with the company Semmtech[14]. The project information is managed with Relatics. Each project starts from the master model, which is then adapted along the way to the specific project. The lessons learned from the projects are then applied back into the master model (see Figure 27). This way BESIX can ensure a robust master model.
Together with the standardized organogram, the following processes are described in the BPM; requirement process, verification process, design, risk, interface, configuration, change and deviations process. With the BPM template, each employee knows how the process is managed and activity is performed.
That brings clarity and structure to the whole construction process of BESIX.

Figure 27 BPM master model. *source: BESIX Presentation, 2015*

[14] For more information: www.semmtech.com

3.4 Sub-conclusion and answering sub-question two

In this chapter Systems Engineering and its applications are explored. This paragraph concludes the chapter and provides an answer to the research question **2. What can Systems Engineering contribute to B&U?**

3.4.1 Conclusion

3.4.2 Q2.1 What is Systems engineering?

Systems Engineering

SE is defined as a systematic and interdisciplinary approach for designing, constructing and maintaining complex systems in order to provide quality products that meet the user needs. In construction project it means delivering a sound and successful project that meets the client's needs and stakeholders requirements. SE tools can create added value in the form of better project control through explicit communication and comprehensive documentation: adding cost reduction, time efficiency, risk management and decreasing the loss of resources.

Systems Thinking

Systems Thinking is central when applying SE to projects where System Thinkers such as engineers, study the system, the corresponding elements, and their correlations. For example, in a building project, a system can be the building itself that can be decomposed in subsystems and elements such as foundation, structure, and façade etc. However, understanding how subsystems and elements behave and relate to each other is critically important to appreciating the elements themselves. In essence, Systems Thinking decomposes large-scale complex building projects into small scale problems that are less complex and can be designed in parallel. Therefore, System Thinking focuses in the problem space. The core principle of Systems Thinking involve moving from a general problem to a specific problem. Providing solutions for the underlying (specific) problems and creating synergy by integrating them, will eventually resolve the parent (general) problem. Therefore, Systems Thinking approaches the project in a holistic manner and Systems Engineering provides the tools (as seen in §3.2) to apply Systems Thinking.

3.4.3 Q2.2 How is the Systems Engineering process implemented in GWW?

RWS uses the V-model for SE as seen in Figure 21 (§3.3.2). The key characteristics of the V-model in GWW-sector are customer needs, lifecycle optimization, top-down specification and working explicitly. SE-process in GWW consists of 9 core elements or steps as seen in Figure 20 and following these prescribed protocols ensures optimized decision-making and sound engineering by incorporating valid and valuable input at the project on-set.

3.4.4 Q2.3 What are the current applications of SE?

SE is widely used in the infrastructure and rail sectors, mainly because RWS and ProRail have rooted the SE method into their integrated contracts as a requirement. SE is an efficient and logical option for integrated contracts. An important similarity between SE and integrated contracts such as DBFM(O) is that 'questioning' (uitvraag) for the problem, is prepared in the form of functional specifications. SE provides methods and tools that can translate functional specifications and requirements, stated in the DBFM(O) contract, efficiently into systems specification and systems requirements. These specifications and requirements can then be through verification and validation assessed to the specification in the DBFM(O) contract.
When translating the contract specifications to system specifications, the consortium has the freedom to develop an integrated solution for the life cycle by using their expertise and innovative capacity.

Systems Engineering in B&U projects

As GWW projects provide the right ingredients for SE it is observed that B&U add human perspective to the technical mix that plays a far greater role in building design as compared to infrastructural projects.

Designing solutions for human context is derived from Design Thinking, which is in contrast with SE that is derived from Systems Thinking. Therefore, applying SE in B&U projects is concluded as far more challenging by this research.

3.4.5 *Answering sub-question two, What can Systems Engineering contribute to B&U?*

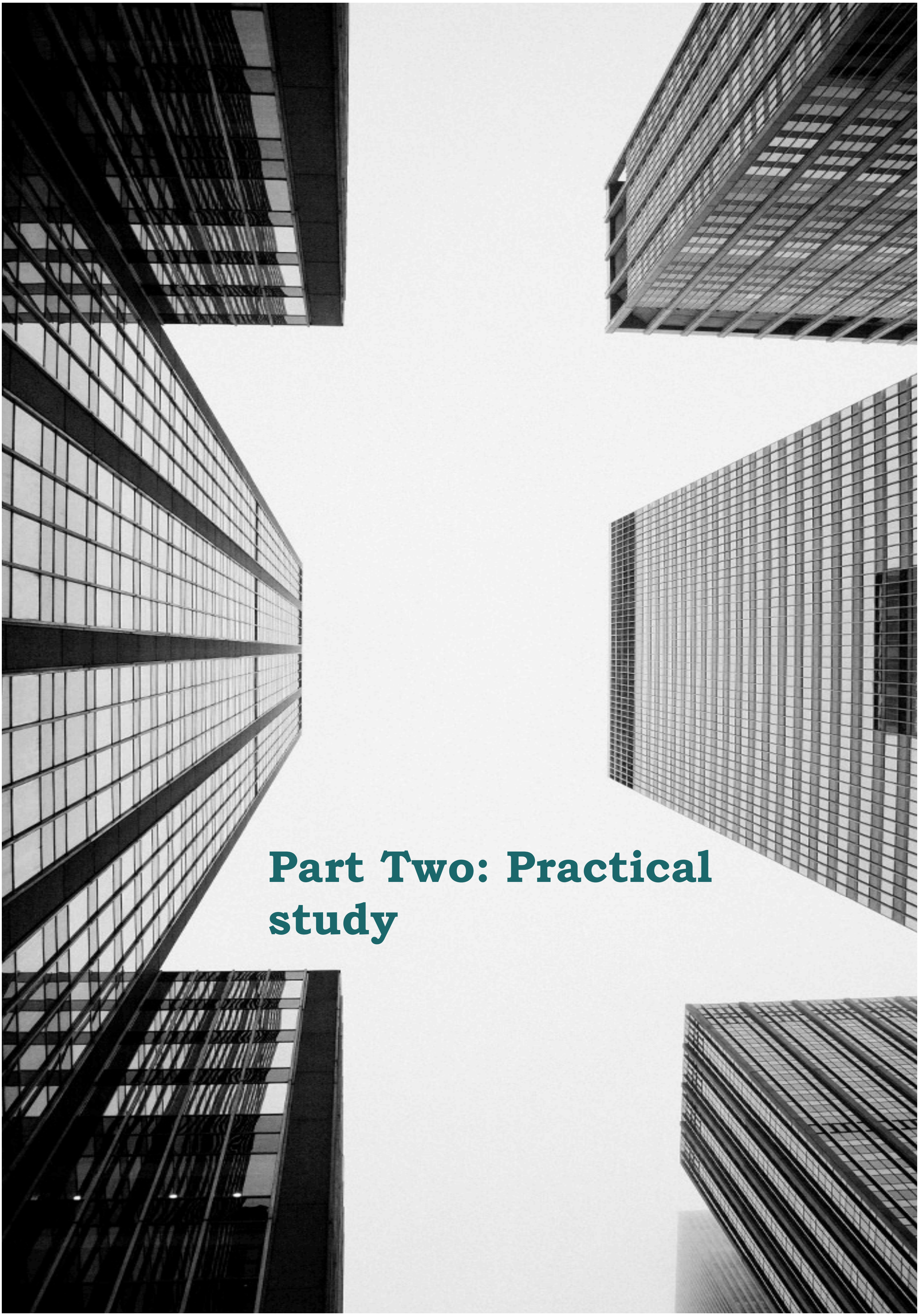
From this chapter it is observed, when using Systems Engineering toolkit (§3.2) contribution to projects is as follows;

- Better control of projects and risks, resulting in decreasing cost.
- Clear, explicit, and structured documenting of project information. Thus, better communicating.
- In line with integrated contracts because of the integrated approach, complying with the life cycle.
- Tools for transforming client's requirements in design solution. Conform the performance-based approach.

In the preceding chapter the complexity within building projects was described. What SE tools can contribute to that complexity can be seen from the table 4.

Table 4 Contribution of SE

Challenges in B&U due to integrated contracts	**Contribution of Systems Engineering tools**
Changes the contractual relationship of actors. Subsequently changing their roles.	Better control of projects and risks.
More stakeholders, due to life cycle approach, each with their own set of requirements.	Tools for transforming client's requirements into design solution.
Increasing numbers of internal organisation actors within the design process.	Clear, explicit, and structured way of documenting project information. Thus, better communicating.
Rapid technological innovations make the future unpredictable.	- Better control of projects and risks. - In line with integrated contracts because of the life cycle approach.
Different mode of reasoning by the actors involved in the design phase.	Structuring the problem space by - Tools for transforming client's requirements into a design solution. - Clear, explicit, and structured way of documenting project information. Thus, better communication.



Part Two: Practical study

4 Methodology and case projects

4.1 Methodology: propositions

From the preceding chapters: it is observed that Systems Engineering can be applied to B&U projects to manage the complexity. Likewise, the SE process in GWW projects is also examined. However, to answer the third central question (What are the findings from the practices of SE in construction industry?) it is not clear how Systems Engineering can be applied in the tender phase. Neither can the assumptions made in the research objective, for instance the role of architect and SE process in the B&U, be entirely validated from the literature study. From that perspective, in order to answer the third central question, three propositions are drawn from the literature study that will be analysed and validated through case studies and interviews. The propositions will serve as a blueprint for the practical research.

I. Systems Engineering can contribute positively to B&U projects in the tender phase.
II. The Systems Engineering process in B&U project will be different from the SE process in GWW projects.
III. An architect, due to the nature of his work can't use Systems Engineering.

4.1.1 Linking pratical study with literature study

As we have seen in the previous chapters, Systems Engineering can contribute the B&U sector in several ways. In this chapter case studies will be identified and protocols will be developed to assess the cases according to the SE-process as described in §3.2.
The SE-process as elaborated in the literature study identifies 4 core elements (see also §3.2.2);

1. Requirements analysis (step 1)
2. Functional analysis (2)
3. Synthesis (6)
4. Verification and Validation (4,5,8,9)

In the following case study, projects will be analysed on these criteria. For each case it will be investigated if these steps are performed, if yes/no than how/why not?

The following questions can be asked to perform a case study.
- How is SE used in the case projects?
- Which elements/tools are used?
- How are they applied? In what level of details are they worked out?

In order to perform a case study, document analysis and semi-structured interviews will be conducted. This will result in a list of elements/tools used in each of the cases, which can then be translated for the tender phase.

4.1.2 Selection of the case projects

To get a general understanding of the research subject this study will investigate multiple cases. Multiple cases can produce similar or contrasting results. Analytic conclusion from two cases are more powerful than a single case study and it will also construct validity and reliability of the research (Yin, 2009).
In order to do cross-case analyses for the cases, the projects have to comply with the following conditions:

- The project is done by BESIX Netherlands
- Systems Engineering is applied in the project.
- The tender phase is completed.
- The project has at least DB(F)M contract
- The contract and corresponding requirements are available.
- Procurement documents are available
- The project is in the Netherlands.

Following the above-mentioned conditions the projects suited are (Table 5):
For GWW-projects

- **Floodgate Limmel** (Keersluis Limmel), replacing a floodgate nearby Maastricht
- **Velsertunnel**, renovation of the A22 highway tunnel from Velsen to Beverwijk

For B&U- projects

- **University of applied sciences Utrecht** (Hogeschool Utrecht). Building of a new university building in Utrecht.

Table 5 Factsheet selected cases

	GWW		**B&U**
	Floodgate Limmel	**Velsertunnel**	**University of applied sciences Utrecht**
Client	Rijkswaterstaat	Rijkswaterstaat	Stichting Hogeschool Utrecht
Commissionee	BESIX	CombinatieHyacint	Spark
Start	Aug 2015	Jul 2014	Dec 2015
Completion	2018	Jan 2017	Dec 2017
Maintenance	30 year	7 year	15 year
Contract end date	2048	2024	2032
Contract value	€ 30 mln	€ 67 mln	€ 40 mln

4.1.3 Case study protocol

In the case study protocol an approach is made on what data is relevant for the research, how and with whom the interviews should be conducted. The protocol is derived from Robert Yin's book, Case Study Research: design and method (2009). Because of the nature of the research and the working method of BESIX, a difference has to be made between company specific information (e.g. tender manual, BESIX project management, master model in Relatics etc.) and projects specific information. BESIX documents are transcending documents that serve as blueprint for the project documents. The project document flows out of the overall company documents (see Figure 28).

Figure 28 BESIX transcending documents.

Data needed

The data needed for analysing is twofold. First the overall BESIX documents will be assessed and later the project specific documents.
The documents needed for the BESIX documents are;

- BESIX Project Management (BPM). A project-managing tool used by BESIX.
- Tender manual. A guide for tendering, since the manual is confidential not all the data will be readily available. The data needed for this research is the tendering process.

Then there is need for project specific data. This data will mostly come from the BPM tool, but an evaluation on how it is used on the specific project will be made. The minimum of data needed is:

- Organogram
- Contract
- Tender documents
- Project management process
- Information management/Systems Engineering documents

Interviews
Interviews will be essential in conducting this research. For each project two semi-structured interviews will be conducted in order to get comprehensive details about the projects. For the interview, a protocol has been made which can be found in appendix B. The protocol will be sent to the interviewees at least three days in advance. It consists of subject and guidelines of the questions that will be asked. Since all the interviewees are based in The Netherlands, the protocol is prepared in Dutch. Moreover, BESIX works with specialist companies on Systems Engineering as Semmtech, Neanex and Infranea. In addition, to the interviews for the cases, there will be four extra interviews with experts on Systems Engineering. That brings the total of interviews to eleven. Prior to the interviews, one test interview will be held with an employ from the Systems Engineering department of BESIX. This can give us insight to the BPM and feedback to the questions asked.
After analysing the organograms of the projects the following persons (see Table 6) are selected for conducting a semi-structured interview.

Table 6 List of interviewees

Project	**#**	**Name**	**Role**	**Company**
Floodgate Limmel	L1	Martijn van Klaarbergen	Process Manager	BESIX
	L2	Jeroen Honig	Systems Engineer	BESIX
Velser tunnel	VT1	Hugo Kruk	Ass. Technical Manager	BESIX
	VT2	Arjen Veuger	Tender Manager	BESIX
Hogeschool Utrecht	HU1	Rafke Hazen	Quality manager	Strukton
	HU2	Chaïm Barbier	Systems Engineer	Neanex
Experts	E1	Daan Oostinga	Director	Semmtech
	E2	Gijben Hornes	Director	ICOP/Briefbuilder
	E3	Fred Lohman & Rodney van der Kooij	Owner/Lead accountant	Relatics
	E4	Dik Spekkink	Owner	Spekkink consult
	E5	Dirk Lohmeijer	Ontwerpleider	QWA
BPM/Test interview	T1	Nejat Askan	SE Velser tunnel	BESIX

4.2 Floodgate Limmel

The current floodgate in Limmel nearby Maastricht is approximately 80 years old and set for replacement. The old floodgate lies on the Juliana canal, which is a bypass canal for the river Meuse. The river Meuse is part of the trans-European transport network (TEN-T) to improve the passage for heavy and bigger ships on the river Meuse. A new and broader floodgate will replace the older floodgate. This will enhance the shipping routes for Europe and The Netherlands. The current floodgate will be removed and the new floodgate will consist of two towers and in-between a vertical steel lift gate, which can be operated remotely. Moreover, a bridge to accommodate bicycles and cars will also be built next to the new floodgate (Rijkswaterstaat, 2015a).
The floodgate is meant to protect the hinterland in case of a flood from the river Meuse.
The goal of the project is to:

- Improving the navigability for larger vessels;
- To include the route in the international waterway network;
- Creating a passage for shipping class Vb of 190 meters, 11.4 meters wide and a draft of 3.5 meters.

Project Organisation and budget

The floodgate is the first DBFMO project for maritime work in the Netherlands. The organisational chart for the floodgate Limmel is shown in Figure 29. The floodgate Limmel is outsourced by RWS (OG) to the consortium Keersluis Limmel Company B.V. (KLC). KLC consists of BESIX Nederland and Rebel group (SPC). In the KLC the engineering part will be done by BESIX (EPC) and the maintenance for 30 year will done by BESIX and Agidens (MTC), both are sub-contractors of the KLC. The project is accepted for the amount of € 30 million euros.

First look at Systems Engineering

In the contract Systems Engineering is specified, RWS require KLC to work according to the ISO-15288 norm. Since the Rebel group is only contributing financially in the project. This was the first project where BESIX was sole responsible for the Systems Engineering process and therefore BESIX Project Management (BPM) was introduced and used. Keersluis Limmel can thus be seen as a pilot project for implementing BPM.

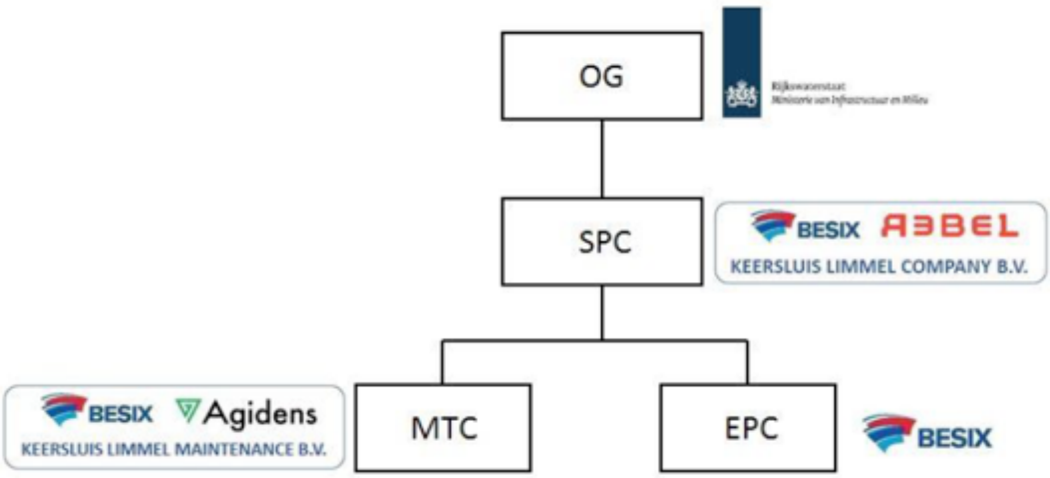


Figure 29 Organizational chart for the Floodgate Limmel. Source: BESIX

Figure 30 The new floodgate in Limmel. *source: Besix*

4.3 Velsertunnel

The Velsertunnel may not be the oldest tunnel in the Netherlands - that honour goes to the Maastunnel in Rotterdam – but the Velsertunnel is the oldest highway tunnel. The construction of the tunnel began during World War II. Because of the war the work had to be temporarily interrupted in 1942. After the war in the reconstruction time, Rijkswaterstaat continued the work. This occurred simultaneously with the expansion of the North Sea canal. A built-in bunker in the Velsertunnel reminds us of the Cold War between the Western world and the former Eastern Bloc (Ca. 1948-1990). In the bunker the tunnel, staff could take refuge during an attack. In 1957, the tunnel was open for public use.
The Velsertunnel is known for its distinctive ventilation towers, which are also called the "hyacinten”. In 2007 they got the status of national monument. Everyday about 65,000 vehicles go through the tunnel. The tunnel is regularly in the news because of the traffic accidents, often involving higher structured trucks. That causes damage to the tunnel and congestion on the road, sometimes the entire tunnel has to be closed. On average that happens once a month. The Velsertunnel is at its lowest point slightly higher than 4 meter. In the time that the Velsertunnel was built that was high enough. According to the law the tunnel is still high enough for all trucks that abide the law. But because many carriers search the limits, they often get stuck in the tunnel.

Now, almost sixty years after its construction, the Velsertunnel is due for a large-scale renovation. Rijkswaterstaat wants to modernize and replace the out-dated tunnel installations, such as the ventilation, fire extinguishing systems and the wastewater drainage. Also the escape routes will be adjusted. Thus, the escape doors are better distributed in the tunnel and shorten the escape time. To prevent damage from high vehicles and improve the traffic flow the Rijkswaterstaat increases the tunnel height by 12centimetres. After the renovation the Velsertunnel will also meet the new “Tunnelwet”. (Rijkswaterstaat, 2015b)

Project Organisation and budget

The Velsertunnel is a DBM contract that is executed by the consortium Combinatie Hyacint (the name is derived from the ventilation towers). The consortium consists of Dura Vermeer, BESIX, Spie and Croon Elektrotechniek. The project is awarded in July 2014 and is set for completion on January 2017 with additional 7 years of maintenance till 2024 (Combinatie Hycaint, 2015). The total cost of the project is € 67 million euros. Thereof is € 59,3 mln euro for the realisation and € 7,7 mln for the maintenance. (Rijkswaterstaat & Combinatie Hycaint, 2014)

First look at Systems Engineering

The contract required the use of ISO-15288 as Systems Engineering. RWS has already made a decomposition of the objects for the Velsertunnel. The decomposition was on abstract levels.

Figure 31 The iconic ventilator towers of the Verlsertunnel (BESIX)

Figure 32 Velsertunnel in 1953 (Besix)

4.4 Hogeschool Utrecht

Hogeschool Utrecht (HU) realizes at the Utrecht Science Park a new building of 20,000 m^2 for the purpose of education and research. This new project is part of the "Programma Herhuisvesting" of the HU.
HU aims to achieve a future-proof school building that meets user requirements. The client has decided to undertake the project through an integrated contract allowing optimum use of the design, implementation and maintenance knowledge of the market. HU brings the construction project through a Design, Build & Maintenance contract on the market. The purpose is for realizing the HU as an attractive and functional building that is efficient in operation throughout the life. The building-related maintenance and cleaning (management) tasks are included in this contract for 15 years. The contractor is fully responsible for the progress and quality of the implementation work in accordance with the tender specification and the accompanying sketch. The project is characterized by a great time drive, with annual curriculum of great influence on the delivery date. The start of the academic year 2017-2018 in the new building is therefore a very important milestone. (Hogeschool Utrecht & Arcadis, 2015)

Project organisation and budget
The project organisation consists of BESIX and Strukton Worksphere that forms the consortium Spark Vof. The consortium is supported by the architect Schimdt Hammer Lassen, Imd Raadgevende ingenieurs, Deerns, W4Y and Peutz. The DBM-contract is awarded for € 33,5 million euro's for the realisation and € 4.5 million euro's for 15 years of maintenance work. (Hogeschool Utrecht & BESIX, 2015)

First look at Systems Engineering
For this project, the information management system will be implemented in Relatics with the use of 3D BIM. With the aid of scrum sessions, all the requirements will be SMART and the design will be made. In order to fulfil the requirements: a verification and validation plan will be devised. Moreover, the client itself has made a decomposition of the building that is taken over by the consortium.

Figure 33 Artist impression Birdview (BESIX, 2015)

Figure 34 Artist impression, interior (BESIX, 2015)

5 Results

One of the aims of this thesis is to gain insight in the Systems Engineering process in the construction industry. Since Systems Engineering is hardly used in the B&U-sector, an analogy from the GWW-sector is made. In this chapter two GWW projects and one B&U project are analysed and subsequently their results are presented.

Therefore, eleven interviews were held, two semi-structured interviews for each case and five open interviews with experts on SE. Likewise for the case study, the projects documents are analysed for each case to understand how SE is implemented in the projects. In §6.1 the projects are analysed and in §6.2 the results of the interviews are presented.

5.1 Case projects

The client required in all three the projects (a part of) Systems Engineering. However, SE was not required for the tender phase and therefore was only used during the realisation phase. Now, the process for each project will be described. How the project integration in the tender has worked? How is the consortia managed and designed within the client's requirement? Consequently, how SE is implemented in the projects? These are few of the questions that will be answered. In general an overview of the SE-process will be given. The results for each case are divided into three subjects: tender, tools & methods and architect.

5.1.1 Floodgate Limmel

For this case two employee of BESIX were interviewed that are involved in the process and SE management. Moreover, the documents that are analysed are: the contract including the requirement and output specifications, project management plan EPC (PMP-EPC) and subsequently the underlying sub-documents: information plan, verification and validation plan, and project control plan. Furthermore, access to the Relatics database is also given to understand and analyse the project structure and if needed to analyse more documents.

Tender

As it turns out from the contract: for the floodgate Limmel Systems Engineering as ISO15288:2008[15] was required from the client (RWS). However, the requisite was not for the tender phase and Keersluis Limmel Company (KLC) did not use the SE method for the tender. The management made the decision of limiting the use of SE tooling and one system engineer supported the team one day per week. The system breakdown structure was already specified in the contract and was given by RWS.
Systems Engineering was started in the design phase after the tender has been won. A management system is implemented following the ISO 15288:2008 and capability levels according to ISO 15504-6:2016.

Tools and methods

Systems Engineering in Limmel is seen as a controlling tool and a comprehensive set of process supporting the project organisation. V&V, System Breakdown Structure, Risk management, interface management and structuring information is done in Relatics. BESIX took over the object decomposition from the RWS and added extra details. Subsequently, BESIX made the requirements SMART (Specific, Measurable, Achievable, Realistic, Time-bounded). The process and SE manager acknowledges that with using SE, specific control is possible within the project. However, SE was not used in the tender phase. If SE was implemented (setting up the system design and requirements) in the tender phase a lot of time would have been saved in the realisation phase. But there was no requirement in using SE tool in the tender phase. Thus the tender team thought they could control the project and make a bid without use of SE model tool. In order to make the Verification and Validation plan it can be seen that the requirements specifications are analysed and RBS is made. In the case of an unclear specification, RWS is notified and (if needed) SCRUM-sessions are planned. SCRUM is an effective method to solve specific problems together with client in a defined time period. Finally, the specifications are allocated to the corresponding object and process. Therefore, a SBS (System Breakdown Structure) is also made for the project. Specific for this project a separate verification plan is made for the industrial automatization system (IA), performance measurement system (Prestatie Meet Systeem, PMS) and W&E

[15]On the time of contract 15288 (2015) wasn't available. Thus 15288 (2008) was required and used.

installation (Water and Electric). This verification is done in a different software tool then Relatics. The IA system will be made and the verification will be done in the software Enterprise Architect where these will be further worked out. The validation will be done by SCRUM-session with the stakeholders of this project.

Architect
The architect has input for his design from the engineering team. The design was developed around the technical system that operates the floodgate. Hence, with the conversation with technical experts and specialist, the architect made the design. Subsequently, the design got feedback from the EPC and that the design would be adjusted. This went back and forth till the design was incorporated and adjusted around the technical solution. The integral design decision-process involved the designers and engineers from the EPC. However, the MTC was not involved because at that moment it was not existed. The MTC is started in the later phase. The client (RWS) provided an ambition document and aesthetics requirements (esthetisch programma van eisen) consisting of their vision and guidelines about how the design should be followed. Moreover, there were also physical aspects to be considered, for example the height of the gate and bridge. But as mentioned above, the point of departure for the design was from the technical system, with taking in account the ambition document and aesthetic requirements.

5.1.2 *Velsertunnel*

For this project two interviews were conducted, one with the tender manager and one with the assistant technical management who was also facilitating the SE-process. Additionally, information is also extracted from a test interview with the information manager of Velsertunnel. The project was awarded to Combinatie Hyacint V.O.F consisted of BESIX, Dura Vermeer and Spie.

The contract of Velsertunnel is built from the DBM principles, using UAV-GC-2005. On the top there is a central (basic) contract. The basic contract refers to the underlying documents as seen in Figure 35. RVT (Renovatie Velsertunnel) is the Design and Build part, and the MJO (Meerjarig onderhoud) is the Maintenance part. Subsequently, the RVT (tender) requirements are listed in the form of technical requirements and process requirements.

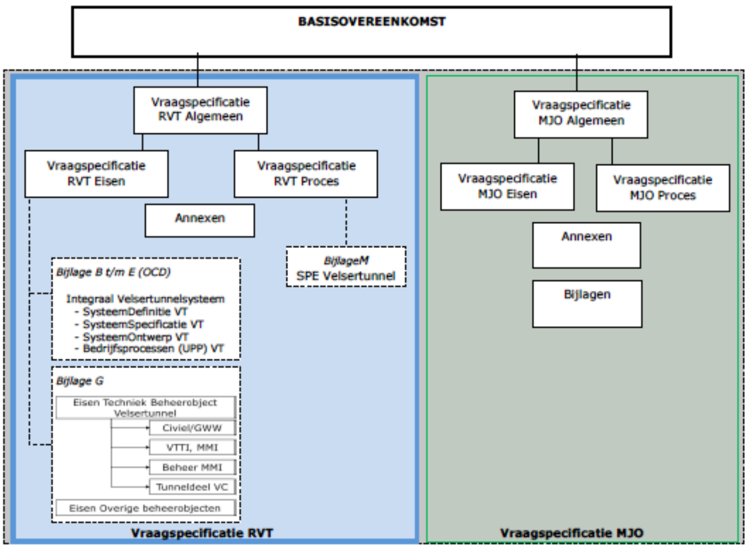


Figure 35 Velsertunnel Document structure. (BESIX, 2015)

Tender

As it turns out, using SE conform ISO 15288 was not asked for the project. Although verification and validation plan was required for the project. However, the ISO norm was required for designing and building the TTI (Technical installations for tunnels, Tunnel Technische Installaties). The client (RWS) had already given the outline of the object decomposition, which was copied by Combinatie Hyacint. Subsequently, Hyacint expanded the object decomposition further in details and coupled the requirements that were made SMART to the objects (SBS). But the object decomposition stated in the contract was not the same as used in the tender phase. The decomposition in the tender phase was distributed along the expertise of the parties that were involved in the project. The parties in the tender worked out the objects further in details, coupled it with their WBS and calculated the price for each activity.
But after the project was won, this caused problems in the sense of the decomposition was changed. From the tender it was stated that there was no real integration in the project. The decomposition of objects and work was disturbed between the companies working for Hyacint. In the end all the work was merged into one file but that was not done systematically. Therefore there was not an overall corresponding system during the tender. After the tender phase, in the realisation phase a lot of work had to be done again in structuring the objects with their WBS and corresponding payments.

Tools and methods

After the tender phase, the requirement specification and object decomposition from the client are translated in RBS, WBS, PBS, OBS and SBS, which are made and linked together in Relatics. Relatics operates as information system where the integral structure (RBS, SBS, WBS etc.), as well as the V&V plan of the project are prepared and maintained. The document management system where all the documents are stored and saved is done in SharePoint/Organice Explorer. Moreover, the TTI system is designed according to Model Based Systems Engineering (MBSE) in the software Enterprise Architect. Between all these tools, an interface agreement is created were relevant documents from SharePoint are linked to their corresponding objects, requirements and/or process in Relatics and Enterprise Architect.

Architect

Systems Engineering in the Velsertunnel can be separated in two parts. As for design there was no substantial designing needed for the project. Thus overall, SE in the project can be seen as a controlling tool to verify and validate if the requirements are met. The second and largest part of the work done is installations, thus for the TTI were ISO 15288 is required, SE is used for designing a system that complies with the requirements as specified by the client.

5.1.3 Hogeschool Utrecht

Since the project is recently awarded[16] to Spark Vof (BESIX and Strukton) the design and realisation phase is just started and the documents are being prepared. From the tender documents of both the client and Spark, the interviews from Spark's employees and access to the Relatics database of Hogeschool Utrecht (HU) an analysis is made.

Tender

For the HU an integrated contract as DBM is used. The client (Stichting Hogeschool Utrecht) has given the requirements specifications in two parts, one is the product and other is the process specification. The product refers to the deliverable product the building itself and the process specification refers to the work done to achieve the product. Additionally, a SO+ (sketch design) is also part of the contract with their corresponding annexes. The SO+ gives the aesthetic requirements and guidelines for designing the new building. The client had provided the functional specifications and Geographical Breakdown Structure (GBS). GBS is demarcations of the spaces/locations/rooms/sectors needed for the building. For the HU no *"real"* Systems Engineering or ISO 15288 was required. Only part of SE that was required was the verification and validation and that too has to be done in the software tool Relatics

[16] 14 December 2015

Tools and methods

Systems Engineering was required to validate and verify the requirements and design. For that Spark made the requirements for HU SMART.
First, during the tender phase the requirements were verified in Excel and after the project was won Spark copied it to Relatics. Including comfort requirements as acoustic, temperature, airflow and quality into Relatics. The spaces were also incorporated in Relatics just like all the other requirements agreeing to the contract.
Second, at this moment Spark is linking the spaces to their requirements. This way Spark can be sure that they validate and verify to all the requirements given to the corresponding rooms/space.
Third, that is noted from the documents and Relatics database. Although the objects are created but they are not called SBS nor can an SBS-tree be located in Relatics. For the RBS, WBS, PBS, OBS it is the same case. All these “trees” are made but not explicitly mentioned. It can also indicate that at the moment of writing Spark is still busy taking over the specifications and making them SMART.

Architect

Likewise, in the tender the client gave the permission for optimising the design. There are some requirements were Spark has got exemption. One of the top requirements for the surrounding area of HU is that the terrain should be open and accessible and in the SO+ the structural construction is not given. Instead it stated that the construction should not be seen or minimized as possible. This way Spark had some freedom in designing.
As an example, in the SO+ abasement for parking bicycles is specified and designed. But the design team of Spark removed the basement from their design, and instead the bicycle will be parked at ground level, will still validate the requirement of an open terrain around the building. This design change was approved by the client, and as a consequence reduced the cost significantly. The design changes resulted in changes in the contract and requirements. From the interviews these changes in design and requirements were not systematically documented, there were too many versions circulating. Thus it was unclear which requirements are now in the contract and which are not, it was not transparent enough. Translating the requirements into precise and unambiguous specifications was a time consuming task.
Like this example, there are several other requirements were Spark has got the freedom to deviate from the specifications. By holding SCRUM sessions with the client, the deviations made in the design are discussed and subsequently made SMART.

5.2 Interviews

In this section interviews will be elaborated that are conducted with the employees of the case projects. Also the experts on Systems Engineering in the construction industry are interviewed, their vision will be presented in this paragraph too. The transcriptions of the interviews are not showed in this research due to privacy concerns. However, the interview protocol and questions can be find in the appendix B.

In total eleven people were interviewed (see Table 6 on page 56), more interviews were not conducted because the information was saturated. Meaning no new information and concepts were observed in the data. The questions were asked with keeping the propositions in mind, therefore the questions are put under three topics: SE in Projects/General, SE and Architect and SE in B&U. The interview questions were mostly the same for everyone that is why the results are labelled under the questions asked.

Perspective of SE

As mentioned above, the interviews are conducted with employees of the projects that are from the construction sector and with experts in the field of Systems Engineering: the perspective of both the groups will differ. The employees from the construction see SE as a management tool because most of the tooling of SE is already done in the construction business. The extra addition from the traditional process for the construction industry is V&V which is done in Relatics. That is way the employees from the project will compare/see SE as V&V and Relatics.
While experts know that SE is more than V&V and Relatics. Their perspective will be over the whole SE process. The experts will explain SE from the theory point of view.
Then there is the architect, who will compare SE with his work. The architect will compare SE to the design theories and will be then motivated from that viewpoint.

5.2.1 Case projects

For each case two employees were interviewed. In this section the results of the interviews will be described and merged. From their experience of SE in GWW their vision of using SE in B&U is also asked during the interviews, which will be described here too.

SE in Project (tender)

How is Systems Engineering perceived?

The interview started on how everyone perceived Systems Engineering. From the interviews it turns out that the interviewees see SE as a control tool. Using SE helps them manage the project better. All the project information is well structured and organised, which makes it easy to understand the project. With the integrated contract the client specifies functional requirements. With using Systems Engineering it is easier to verify and validate the requirements. SE is perceived as a structured way of working and controlling information.

How is Systems Engineering process done in your project?

As it turns out for all the three projects the client had given the requirements. For the GWW project even the object decomposition was given and for the B&U project areas/rooms/spaces were also specified in the contract. The consortium took over the object/areas and worked further from there. The interviewees concluded that the requirements given by the client were not explicit enough thus the requirements were made SMART. Subsequently, RBS and then SBS were made and linked together. For the GWW project the starting point was from the objects and for B&U it was from area/spaces. SE was used as an information control tool and implemented after the tender was won. There was no input from the maintenance during the tender phase. However, V&V was asked for the all the project. For that reason a RBS, SBS, OBS and PBS was made to structure the process of verification and validation.

Does SE have an added value in the project?

All the interviewees agree that in the current form (as information management) SE has already an added value. The added value is perceived in timesaving, better control of risks, and structured working. Since the information is well structured in Relatics, it is easier to control the projects. Moreover, there are no issues with different versions. Everyone has the latest information. This ensures better control on the projects by identifying interface clashes and risks. As the most time is lost in structuring information and failure's arise of not having adequate information. SE saves the project team time and they can use that on increasing value for project.

And what if it was used in the tender phase?

SE has an added value as structuring project information, better risk of control and timesaving. Since the team have better control on the project, more time can be given to analyse the requirements and come with valuable design to score better on MEAT (most economically advantageous tender). There will be more to optimize the design. Risks can be understood easily and measures can be taken to prevent the risk. Plus, the tender team can be sure of what they deliver is the right product. However, all the interviewees point out that using SE is a management decision and the tender cost will increase by using SE. If you win, then you earn it back but if not then you have a bigger loss. On the other hand, they agree that for the next project they still advise to use SE in the tender. Better control on project can also lead to better bid thus in winning tenders. The reason for not using SE in the current three projects is financial constraints, inadequate capacity, no requisite placed in the tender and neither the requirement was felt because without SE there is enough control on the project.

SE and Architect

Role of architect in SE

The interviewees admit that the architect has a different role in working in integrated contract. But the work that the architect delivers is not much different than before. Architect now has to state everything explicitly and support his decision-making process. But all agree that the architect already validate his design implicitly, using SE he will only do it explicitly, which will not limit his freedom to design. However, there should be balance between the design and construction. The tender managers stated, the freedom could be limited because the construction company carries the biggest financial risks and therefore they have more say in it than the architect.

Soft-side of SE (aesthetic, social, psychological)
An unanimous answers from all the interviewees is that the soft-side can only be validated by visualisation that is supported by the text and dialog. Architect is a specialist in interpreting and validating the soft-side of SE. A dialog with client is important to verify and validate the soft aspects of the project. Dialog between the architect and builder is important for creating an integral design, with knowledge used from the engineering department.

SE in B&U
Are there any differences in the SE process for GWW and the SE process in B&U?
The interviewees from GWW sector who also worked in the past on B&U projects, explains that there is no difference in process. Especially the tender is done in the same way for the B&U as in GWW and the complexity by definition is not more or less in B&U. If SE process will be used for the B&U, it is assumed that the same tools are used for the B&U as for the GWW projects. Moreover, the interviewees in the B&U project also did not find real differences in the process. The use of SE is the same in both of the sectors. The only possible difference everyone agreed on is that an extra dimension is added in thinking from the facility process and GBS (Geographical Breakdown Structure). These are more important in the B&U than in GWW.

Will SE have an added value in B&U?
Yes, the added value is the same as in the GWW projects. In the B&U usually more design teams are involved, in that case it is easy working if the information is structured and unambiguous. It will help to manage the requirements and interfaces of the project. Interface management will also help the architect and technicians/specialist to work integral with each other better and manage risks early in the project and find bottleneck as early as possible.

5.2.2 Experts
Together with case interviews 5 experts were also interviewed about their vision and experiences of SE in B&U. Experts are included from the field of architecture, SE consultants and SE software/ICT sector.

SE and Architect
All the interviewees confirm that architects already use Systems Engineering implicitly. The architect starts from global needs and requirements specifications and works to detailing of the needs and requirement (see Figure 36). The Figure 36 was shown to architects without telling about SE and they acknowledged that they work also in this way. Before SE was used, architects already did validation of the design and requirements. With SE, the architect has to validate explicitly and verify their choices. This did not compromise their freedom of designing and they continued to work as they did earlier The architect/designer confirms and further added that before they had a dialog with the client and now they have the same dialog with the consortium member. In the traditional process, the input came after the tender phase.
The advantage now is that the architect can have early input from engineers and specialist, but the process of designing and work is the same. Additionally, incorporating the available technique of the builders in the design can create an extra added value.
The disadvantage is lack of time for designing, since in the traditional process, the architect had more time allotted for designing. Hence, having extensive dialog sessions. Since the tender phase has to be finished in a given time period, there is not much time left for designing and having dialogs with specialist and engineers.

The experts see the role of architect as an integrator in integrated contracts, they know how to translate the soft aspect of SE and combine all the various information gathered in the project. An architect is good in designing and since in MEAT procurement a fictive discount is also given on the design. It is important for the construction companies to deliver good design that meets the needs and demands of the client and score high on the procurement. The architect itself does not see their role changing. In fact, they see it as an opportunity to work together with engineers and combining their knowledge in the design. Moreover, all the experts agree that the soft aspects are validated with visualisation. New technologies as 3D, virtual reality or just plain drawings supported with text can help validate the soft aspect. However, a good understanding and dialog between client and designers is needed.

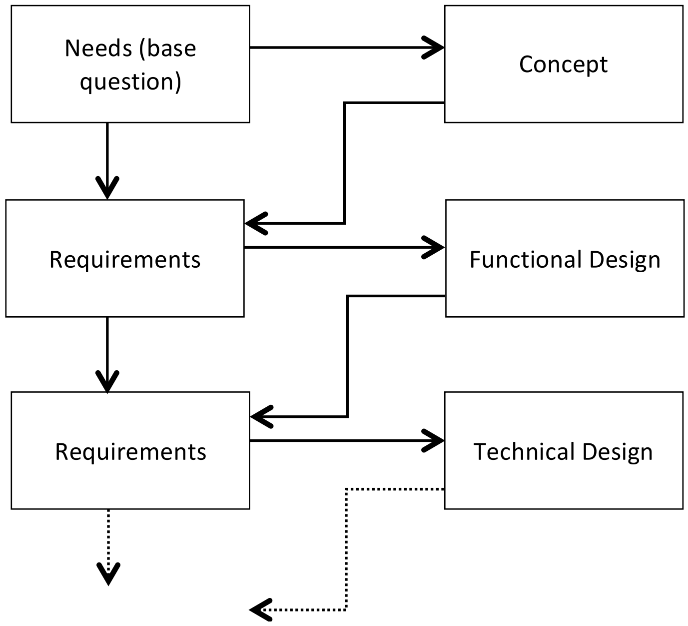


Figure 36 From general to specific. (Own illustration & adapted from interview Dik Spekkink)

SE in B&U

Are there any differences in the SE process for GWW and the SE process in B&U?

The interviewees do not see any differences in the SE process between GWW and B&U. The way of working and the tools used are the same and the architect has validated it too. Even the SE consultants point out that in the B&U, SE is already being used implicitly. In the B&U, PvE (Programma van Eisen, Statement of Requirements) is more prominent and is already used in the traditional contracts. In integrated contracts, the PvE is even more important because there is validation and verification asked from the client. Traditionally in building construction implicitly verification and validation was done with PvE. With SE the work is done explicitly and transparent.

Systems Engineering in B&U is already in the "DNA" in the form of PvE, only implicitly. With SE risks are managed better. The starting point of B&U is from what users will do in the building and then specifying what they need to fulfil the use. While in GWW the base is set from the function of the product and then what objects are needed to fulfil those functions.

A GWW project is seen as a technical device that has a function. For example, a bridge is a device with function to bring people from point A to point B. The main goal of a device is: it has to fulfil a function. While a building is something where people work indoors and they do not work in a device. They need sunlight, safe environment and social collaboration to work in a safe and pleasant ambiance, which can be seen as human context. That is why a building is idiosyncratic.

The work process to design a GWW or B&U product is the same; only the context in which the product is built is different. In a B&U project, the "human context" has to be incorporated with the function, while in the GWW the focus is on the function only. However, both need to be designed, hence in both the sectors an architect is needed. In a GWW sector the human context is of lesser significance than in B&U. Still, an aesthetic component is applicable for a bridge or tunnel too. An architect can combine the human context (soft side) with functions and for that reason it is understood that architect has a greater role in B&U. Conversely, there is more to combine in B&U sector but the work is not different than that in GWW sector.

Why is SE then not used in B&U?

Though the experts agree that SE can be used in B&U, the interviewees cannot give an obvious reason why it is not being utilized. A possible reason can be that B&U has several clients ranging from public, semi-private, private and own development while GWW have mostly public clients only. The GWW clients are usually more professional client and have more experiences in the projects. The B&U client is usually an one-timer, like the HU client. They are less professional and are more trusted with the traditional approach. But that should not be a reason for not using SE. Integrated contracts are hardly used in B&U. The contract is gaining more and more popularity but it is still lagging behind the GWW-sector. May be the B&U clients still find the risk too high to use integrated contract and provide functional specification.

What is the added value of SE?
The added value is a better control of project and risks. With SE the risk can be identified in the tender phase. This will help to take proper measure and come up with a comprehensive bid. Moreover, an assurance can be given that the bid is done properly and nothing is missed. Managing risk and prioritizing in importance and magnitude will be clear and known timely in the project.

SE in general (Client and Risk)
From the experts two more topics were highlighted during the interview namely, SE use from the client and Risk.

Client
The current form of SE cannot be theoretically called "*pure*" Systems Engineering. In the current form, only V&V is applied. Systems Engineering is basically working from general to specific in iteration between needs, demands and solutions. But the current form of SE is not specified in needs, but rather in solutions. The clients do not need to give solutions instead they have to specify the needs. It has to do with the contract type. If you choose integrated contracts, then you do not know what you will get and there is the ambiguity. In the contract the client already state the solutions in the form of requirements. Then the only part that is left over for the consortium is to validate and verify the requirements. There should be validation between demand and solution and that is not done in integrated contracts.

Risk
In the current setting of SE risk is an important factor, which is highlighted by all the experts. Using SE in the tender phase will give the consortium a clear identification of risks. Subsequently, the risk should be prioritized and big risks should be worked out to a level where risk is managed or more easily manageable. SE could be used risk-driven in order to persuade using SE in tender phase. However, the verification and validation should not be done into details that cost too much energy. Client has to keep the V&V for the big risk/cost. For example a V&V for an electric cable is too time-consuming instead validate for the whole electric circuit.

6 Analysis

The results of the interviews and case studies are described in the previous chapter. This chapter will provide analysis and interpretations of the results. Consequently, the propositions of the analytic framework will be discussed. As conclusion, the propositions will be presented which will lead to answering **sub-question 3: What are the findings from the practices of SE in construction industry?**

The analysis of the case projects and interviews are in-line with the topics of the previous chapter namely; Tender phase (§6.1), Tooling and methods (§6.2), and Architect (§6.3) which will be examined in this chapter. To be noted, a clear distinction between these topics cannot be made from the given results, therefore the topics in the analysis can consist some overlap.

6.1 Analysis of SE in the tender phase

It is observed from the analysis that in all the three projects, Systems Engineering was not asked for the tender phase. The client specified the requirements and objects for the GWW-projects, and requirement and GBS for the B&U project. Conversely, after the tender was won Systems Engineering was implemented in the realisation phase for all three the projects. It is also observed that for example in Limmel, BESIX is the only company in the EPC. Implementing SE in Limmel went efficiently compared to the Velsertunnel where various companies are involved in the engineering department. A possible explanation is given due to the object demarcation to firms in the tender and consequently cost relations to those objects. After the tender, objects were stipulated in the contract but the SBS mentioned in the contract was not in-line with the object demarcation of the tender. Therefore, it was not clear for the project teams which object belonged to which company.

6.1.1 SE-process in the tender

It can be seen from the tender documents that the client's did initiate the SE-process and specified the functional needs of the projects, by providing the SBS/GBS and requirements. The consortia's in the projects analysed the requirements, the objects and calculated the price. The results pointed out that there was an integral decision-making process in all the three projects. However, the integral decision-making process remained only between the architect and the engineers, the maintenance team were not involved during the decision-making.
From the interviews, it is observed that the integral design was made according to the SE method of general knowledge of problem-solution to tailoring for a specific problem-solution. In that sense, Systems Thinking is applied in the cases. Nevertheless, it is perceived by the employees that Systems Engineering is not used in the tender phase. It is because the perspective of the employees in the construction industry is that SE means verification and validation done with software tool such as Relatics. Lots of work that is done in integrated contracts was also done previously in traditional tenders. For example, analysis of requirements and scope, risk analysis, decomposition of work, making WBS etc. were also prepared in a traditional tender. The additional elements/tools in added by SE are V&V and Relatics. Thus for the employees of the projects V&V plan and Relatics were not used in the tender. Hence, the employees of the case study perceived that SE is not implemented in the tender. However, looking at the work, the documentation and the process in the case studies it can be observed that **SE is implemented indirectly in the tender phase**. That means the approach to the projects is on the bases of Systems Thinking and most of the tools used in the tender phase are the same tools that are also used in SE. Therefore, the current process is in-line with the SE-process, but in the current process information is not documented explicitly. Thus the content is not in-line with SE. Consequently, the employees perceive that SE is not being used in the tender. In reality, except using verification and validation, the employees follows the same process as the SE process. With verification and validation the tender teams are guided to write project information explicitly.
However, there was no formal use or standardization of SE in the projects. All three the projects have done SE in their own way, but implicitly all three have followed the SE-process.

Another interesting observation is that the SE-process for GWW projects is not different than that of the B&U project (HU) for the tender phase. This is also acknowledged by employees, who have worked in B&U projects as well as in GWW. In both the sectors they do not perceive the tender phase differently. The experts from both the SE and the architecture field confirm observations of the employees too. Moreover, analysing the documents there is also no variation was found in the overall SE-process for both the sectors. Though, a distinction can be found in the importance of using different SE tools more dominantly. For GWW, the functional needs in relation with SBS are important while for B&U the centre of gravity lies on the activities performed in the building in relation with the GBS. More about the tools and methods will be elaborated in paragraph §6.2.

6.1.2 Added value in tender

The added value in particular is seen in managing the risk by better control on projects interfaces. Working in Relatics is seen as profitable in structuring the project information and as consequence assessing risks better. But in all three the projects, structuring information in Relatics was done after the tender was won. Thus, the project team could not analyse the risk properly in the tender. It is observed that the employees saw the benefits of Relatics in the design and integration phase. If Relatics was used together with SE tools in the tender phase, the project team could analyse the interfaces and evaluate risk early in the project. This practical understanding from the project members is also confirmed by the experts. From theoretical viewpoint, the experts summarised SE as better control of risk and earlier risk detector in the project.
In a "no SE" approach, risk is identified too by means of risk management. But risk management is largely based and prepared from the experiences of risk managers from past projects. The added value of SE is to structure the information coherently and get a clear overview of the interfaces. As a result of interface management, clashes can be detected and potential risk can be recognized. That otherwise would not have been identified before due to complexity and vast information of projects.
With large complex projects the information is vast. Subsequently, risk can be easily overlooked or the impact of a change in design or object cannot be fully assessed for the whole project. From the literature study (§3.1.4) it was attributed, that the changes made in the concept and design phase have less impact on the cost than changes made in the later phases. By implementing SE right from the beginning, identification of risk and impact of changes can be measured and reported in the early stages. Thus reducing failure cost later on in the projects.

In short,

- The SE method is used during the tender but implicitly.
- The addition from SE is; verification and validation, working explicitly, and using Relatics compared to projects without SE.
- From the employees' viewpoint SE is seen as V&V and Relatics.
- There is no formal guide or standardization for the projects.
- The added value is seen in structuring information and identifying risk in the tender phase.

6.2 Analysis of SE tooling and methods

6.2.1 Tools

The tools and methods that are used in the projects are compared with the SE-process from chapter 3. It is perceived that the SE-process and the corresponding tools are comprehensively implemented in all three projects. However, the major part of the tooling is done after the tender phase. But the process from general to specific can be observed in the tender phase of all the three projects. In the requirement analysis (RA), the requirements are made SMART and coded so that they are traceable. Subsequently, a RBS is made and coupled with SBS, PBS, WBS, OBS and for the HU project also to the GBS.

Two examples will explain the working from general to specific. First, the design process of the floodgate Limmel and second the design process of the HU.
The design of the floodgate in Limmel is prepared with keeping the main function (protection for high rise) in mind. To validate the main function, the design is built around the (main) technical system. Thus for designing, the system was identified at first. Secondly, it was investigated which components are required. Third, the positioning of all the components was studied. After the architect had received input from the specialists and engineers, an integral design process was conducted. Sketches were created and validated with specialists. Alternations were made and more visualising was conducting until the design was validated to the functional requirements. In parallel to validating functional requirement the architect incorporated other requirements as aesthetics and so the design was finalized for the floodgate.

Secondly, for the HU a similar process can be identified. The main function for the surrounding terrain is to be open and accessible for the pedestrians. Keeping the main function in check, Spark removed the basement what was meant for bicycle parking. The bicycle parking was moved to the ground floor under the diagonally placed classrooms. Removing the basement and creatively exploiting the space under the classrooms, the architect was able to reduce the cost significantly and still validate to the top functions.

6.2.2 *Methods*

From the example above it is also observed that the GWW projects starts for functional specifications that are coupled to objects (SBS). Since the technical systems (objects) are the most important, the starting point in GWW is from the objects and from there the project is further carried out. On the other hand, for a B&U project the technical system is not the most important for the building. Rather the activities that are performed in the building are significant. Thus the starting point of the B&U project is from the activities and applications needed to perform the activities. To perform the activities there is a need of a room or area. Hence, the GBS (geographical breakdown system[17]) is made for the B&U but there is also a need of adequate applications and desired situations such as temperature, mobility, light etc. in the room to perform the activity[18]. The desired situation and applications can be achieved with technical systems. It can be seen that the importance and order of using tools is different in B&U as compared to GWW but the essence is the same as working form general to specific problem solving.

6.2.3 *Soft-side of SE*

From the results, the verification and validation of subjective requirements is perceived troublesome. Employees often fall in the trap of making everything SMART. Since SMART-method gives a good understanding in expressing the project (and the client) how the requirement can be achieved. However, not every requirement can be made SMART, some requirements as aesthetic are subjective. From (expert) interviews and documents it is clearly observed that the soft aspects of projects, as mentioned in level 3 of the habitability framework (§2.2.5 on page 21), can be validated and verified by means of visualisation and dialogs with clients. If the client does not possess adequate knowledge, a panel of architects (and other experts) can help the client with validating the soft aspects. For validating subjective requirements dialog, visualisation and text can be used. The perception of making requirements SMART is not always possible. Therefore visualisation can be a validation tool too, which is often overlooked by the project employees.

6.3 Analysis of SE and architect

6.3.1 *Role of architect*

From the results and literature study, it is discovered that the architects are naturally good in making connections and visualising relations of various aspects. The design thinking process of an architect will help the consortium in linking the dots and bringing the technical systems and the soft aspects together in the design. Therefore, from the interviews, the role of an architect is described as an integrator. It is also observed that the role is not changed due to SE but due to working in a consortium. The role of an architect is changed into that of integrator due to the integrated contracts. In integrated contracts the engineers, specialist and other experts have to collaborate and the architect, due to the nature of his work, is then best suited to combine/integrate the multidisciplinary approach for the project. Whereby SE will assist the architect to structure the project information and manage the interfaces.

6.3.2 *Working method of the architect*

One of the notions of this thesis was, due to SE the architect has to work differently. However, it is observed from the interviews with the architect, the experts and project employees that the architect does not work differently because of Systems Engineering. The project employees stated the work of the architect is the same as it used to be in the traditional approach. Moreover, the communication and process is also the same. An advantage of working in integrated contracts is that the distance between the project members and the architect is shortened whereas, in traditional approach the architect is on the client's side. As a result everything has to be done formally, which was time-consuming and involved a lot of paperwork. With the integrated approach the association with the architect is informal and closer.
The architect acknowledges the "shorter distance" with the project members. In addition the architect stated, before there were dialogs with the client about the design. Even then the architect worked through briefing

[17]Also called Ruimteboom in Dutch
[18]Source: interview DaanOostinga

from general problem to specific problem solving. Now the dialogs are the same but with the contractors instead of clients. The work delivered in a tender is not changed, in fact, it is done more efficiently. In the traditional process the input come after the tender and with an integrated approach the input comes during the tender. It ensures an integral design process and during the design there is input from the contractors. The analysis confirms the findings from the literature study (§2.2 and §2.3) too. The input from the engineers during the tender will lead to less failure in design in the later phases of the project. As a result, the design and engineering process can be efficiently coupled, with less risk involved.

6.3.3 Architect in B&U and GWW

The working method of an architect is not different as mentioned above, but still the assumptions were made at the start of this research that the architect has a greater role/power in B&U projects than in GWW. Why is that so?

As it is observed from the interviews and case studies during B&U projects the soft aspects (as mentioned in §2.2.5) plays a greater role than in GWW. Hence, it is perceived that architect have a greater role in B&U. The soft aspects also called the “human context” are much more prominent in the B&U than in the GWW. In a building a person has to perform an activity as working and living. The activity needs to be performed comfortably and safely, thus the psychological, sociological and aesthetical aspect has a prominent role. On the other hand, in GWW projects, no or minimal activity has to be performed inside the infrastructure. No one works on a road or in a tunnel, even the control and supervision of for example a tunnel is done in a separate building or specifically designed control rooms. The main goal of a GWW project is to fulfil a function.
A designer of B&U and GWW project explains it as;

“A GWW project is a technical device that has a function, and devices are made to fulfil a certain function just like a computer or a coffee machine. The main goal is to fulfil the function first and then go for the aesthetic to make it personal.
On the contrary in B&U, people work in a building and people want to work in a safe, comfortable and pleasant environment “the human context”. People don’t want to work in a device, therefore a building has to fulfil the function combined with the human context. The human context is what makes the building personal and different than the infrastructure.”

It does not mean that there are no soft aspects involved in GWW project. Aspects such as culture and aesthetics do play a role in GWW too. Only they are not leading in the design compared to the B&U. In B&U the human aspects are dominant, consequently it is perceived that the architect have more power. As the human context is dominant the architects have indeed a bigger role to play. The architect needs to combine the function of building with the human context. A good architect is the one who can attractively amalgamate these functional needs and human aspect together. This finding highlights the principles of Vitruvius (1914) as seen in Figure 7 on page 21. Vitruvius (1914) described that a good architecture would satisfy on three criteria: firmitas (firmness or durable) utilitas (usable or functional) and venustas (beautiful).

Furthermore, it is observed from the viewpoint of traditional approach in B&U. Systems Engineering method in B&U is used by the architect in the form of PvE (Statement of Requirements) and briefing. In the traditional process the architect had to validate the requirements of PvE too. With briefing the architect designed from a general problem solving to specific problem solving. The PvE in the B&U are more common than in the GWW. Thus in B&U the architect already worked implicitly according to the SE-process. With SE the architect have to explicitly show and support his decisions. Thus, explaining the design what the architect called “clarifying the design”. This will result in transparency for the later phases and also in structuring information for other team members.

6.4 Sub-conclusion and answering sub-question three

The conclusion for this chapter is presented as answers to the propositions. Three propositions are tested by the means of the analysis. It turns out that proposition I holds true, proposition II and III are not entirely true. Next, an answer is given to the third sub-question of this research.

6.4.1 Proposition I

The proposition I is: *Systems Engineering can contribute positively to B&U projects in the tender phase.*

This proposition holds true. From the literature study it is assumed that Systems Engineering can contribute positively to B&U projects, as defined below;

- Better control of projects and risks, resulting in decreasing cost.
- Clear, organised and structured way of managing project information, thus better communicating
- In line with integrated contracts because of the integrated approach, complying with the life cycle.
- Tools for transforming client's requirements in design solution. Conform the performance-based approach.

However, as there was no distinction made between the tender phase and development/realisation phase, it remains unclear how this proposition will also holds true for the tender phase. The analysis of the interviews and case study showed that with Systems Engineering the huge project information of large and complex B&U projects could be structured in an efficient way.

The SE approach is already implicitly being used during a B&U tender. Things done already in the tender are requirement analysis (PvE), decomposition, merging all the information at the end and validating to the PvE. However, for every project this occurs differently, there is no formalisation in the process nor the information is clearly specified. As a result it leads to considerable loss of time and information in the tender phase as every time a new process has to be initiated. Moreover, with the amount of information and changes along the way in the project, it is not clear in the tender and for later phases which information is valid and whether that information in actual exists. With the tools SE provide information can be structured efficiently. Thus having the right and updated project information during each phase.
Also, with the integrated approach there are more disciplines involved during the tender phase. With SE the information can be structured and everyone is on the same page, which in return will save time and as a consequence the SE tooling provides a clear overview of the project. The SE tooling will help the tender team in identifying the interfaces and risks of the projects early in the design process.

6.4.2 Proposition II

The second proposition is: The *Systems Engineering process in B&U project will be different from the SE process in GWW projects.*

This proposition is not entirely true. On one hand, from the analysis it is stated that the process of B&U is not different than the process of GWW. The tools used and the steps taken are indeed the same in the B&U and GWW. On the other hand, a distinction is made on the importance and dominance of the tools and the starting point of SE. In the B&U, the importance is on the GBS and starts with the activity process, which is dominant. While in the GWW the importance is on the SBS and dominance is on the functional specifications. Overall it can be stated that the process of general problem to specific problem is the same for both the sectors. Thus, the SE process as seen in §3.2 is the same for GWW and B&U, but the importance of the internal SE tooling is different.
In GWW the requirements are **on** the infrastructure, what can the infrastructure do? What function does the infrastructure provide? For example, a bridge needs to facilitate the transport of people from one side to the other end. In B&U the essence is what activity has to be done **in** the building. The building assists and provides a stage for the activity, which has to be performed. For example, there is a need for a healthcare activity such as an operation. A hospital building will provide the tools for performing an operation (activity).

Therefore the base for B&U is set with the activity performed and the base for GWW from the function specified. Thus the starting point is different, but both the sectors work from a broad general problem to specific problem solving. In this case the process is not entirely different but only some tools are more prominent in B&U (such as GBS) than in GWW (SBS) and vice versa.

6.4.3 Proposition III

The third and last proposition is: *An architect, due to the nature of his work cannot use Systems Engineering.*

This proposition is not entirely true. It is assumed from the interviews that the architect already uses the SE method implicitly. According to the analysis (§6.2 and §6.3) the architect implicitly follows the SE-process from general problem solving to specific.

To understand the solution for this proposition, this research has to look at the Systems thinking and Design thinking of the literature study and combine it with the analysis of this chapter.

From the literature study it is noted that Systems Engineering is a method for systematically decomposing large problems into small-scale problems. Small-scale problems are less complex, hence easy to solve compared to bigger problems. The small-scale problems in other words are the sub-systems what can be designed as parallel and on their own. The solution can then be integrated to create one comprehensive system.
On the other hand the Design Thinking of the architect deals with concrete and vague concepts, which has to be combined together. In Design Thinking decomposition and integration is not a solution to solve design problems. In Design Thinking both the precise and vague (soft aspects) ideas have to be intertwined during the design.

Thus, the reasoning of the proposition is understandable. The Design Thinking of an architect is not in-line with the Systems Thinking of SE. This also explains why this research sees SE in B&U as problematic compared to using Systems Engineering in GWW. The GWW projects are built around a technical system which can be **decomposed and integrated** while in B&U more precise and vague ideas has to be **intertwined**.

However, Systems Engineering as a tool can still be beneficial for the architect. A balanced approach of Systems thinking and Design thinking is needed according to the phase and context of the project. Systems Engineering can help the architect in understanding and unravelling the problems in projects. Especially in the early stages of the tender phase, sound understanding of the problems and requirements is needed. In structuring the information and formulating interface management the architect can have an instant overview of the interfaces and evaluate the impact of changes made in the design.
Besides, when the information and the design process are explicitly written down it makes collaboration within the project easier. Particularly, in an integrated approach where lots of disciplines have to work together clarifying the design choices can improve the value of a tender. It informs other team members the reason for the choices made and encourages them to think from that same viewpoint to add value from their expertise.
Furthermore, it also makes validation towards the client at the end easier because of structured and clear information capturing during the tender.
Nevertheless, the design problems cannot be solved with SE alone. Since a clear decomposition is difficult the sub-systems cannot be solved on their own. Therefore, Design Thinking is also needed to combine all the information and linking them with soft aspects. The Design Thinking should then be the dominant mode of thinking. The architect needs to shift when needed from System Thinking to Design Thinking and vice versa depending on the context of the project.

Pure Systems thinking is not possible for both the sectors. However, in GWW projects the design is built around a technical system. Thus, the dominant mode in GWW is Systems thinking. This also clarifies why in proposition II a SBS is important in GWW projects. In B&U the human aspects have a predominant role therefore a good balance is required of Systems Thinking and Design Thinking according to the context and phase. It also makes clear why in the analysis it is specified that the architect uses SE implicitly. Because the method is applied at the start of the tender, the architect analyses the problems and requirements according to the Systems Thinking and later the architect shifts towards the Design Thinking by intertwining the solutions.

6.4.4 Answering sub-question three, What are the findings from SE practices in the construction industry?

6.4.5 Q3.1 How is SE currently applied in the tender phase?

The case study and interviews reveal that currently SE is not actively practiced in the tender phase. However, further analysis reflects that SE principles are indirectly applied in the tender phase of both GWW as well as the B&U-sector.
To illustrate this an understanding of the tools used in the current approach has to be examined. In Table 7, the current methods and tools applied in the tender can be seen. During the traditional building tender there is a set of requirements, stated in the PvE including aesthetic guidelines. The building is decomposed in parts and solutions are designed where the WBS is coupled and this reflects the use of Systems Thinking design methodology. The only missing aspect is that there is no structured and organized method to document information output. Neither there is a systemized technique to validate and verify requirements. In this sense Systems Thinking is indirectly applied to the building sector.
Missing verification and validation also indicates that work is not explicitly recorded. Because making a V&V plan entails each requirement to be clear and ambiguously listed to the corresponding objects and process. It also explains why interviewees state that SE is not applied in the tender.

The interviewees associate SE with verification and validation performed by the software Relatics. However these are the only tools that are singularly a part of SE while all other tools relevant to this category of work are already utilized in traditional approaches. The perception of current personnel within this industry sector is that the V&V plan is not systematically prepared and neither is Relatics used making SE not applicable to the tender phase. If this misconception is corrected, the constructions workers will realize that SE tools allow construction companies to both explicitly structure and validate requirements.

Table 7 Current methods in the tender phase

Current methods applied in tender
Analysis of PvE (programma van eisen)
Analysis of briefing
Analysis of requirements and guidelines (aesthetic)
Decomposition
Work Breakdown Structure (WBS)
Risk analysis

6.4.6 Q3.2 What are the differences between GWW and B&U, with respect to SE?

Mode of thinking and starting point

The big difference between B&U and GWW is the mode of thinking. In B&U the dominant mode of thinking is Design Thinking whereas in GWW the dominant mode is Systems Thinking. This difference in thinking is largely due to the importance of soft aspects in buildings. Soft aspects are subjective topics in construction such as aesthetic, social, comfort and psychological aspects. The occurrence and importance of soft aspects in B&U is much higher than in GWW. Therefore, Design Thinking is dominant in the field of architecture. It is in contrast with GWW where Systems Thinking is the dominant mode and priority is set on technical systems of projects. Designing technical system is more suited to the SE method.

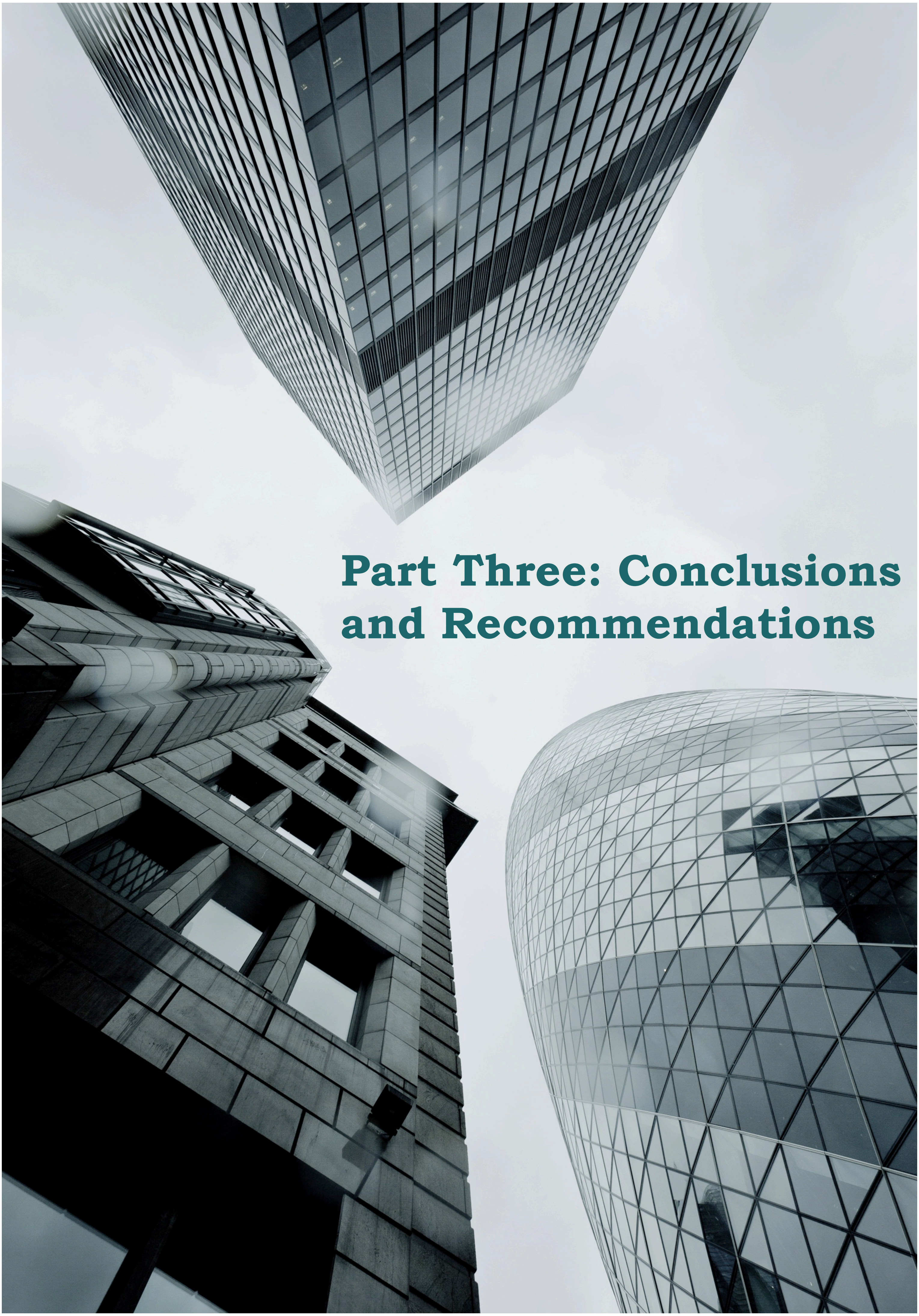
In B&U projects soft aspects play a greater role than in GWW. In B&U the importance is given to GBS and starts with the activity process while in GWW the importance is given to SBS and functional specifications. Both sectors support problem solving from general knowledge to field specific data.

GWW projects begin from functional specifications coupled with SBS objects that are considered a matter of priority before moving further. Conversely, in a B&U project the technical system is not the most vital element for the building, rather the purpose it serves and the needs it is meant to address hold more weightage. Therefore the starting point in the B&U project is from GBS activities and their related application.

What are the findings from practices of SE in the construction industry?

- SE is indirectly used in the tender phase
- SE is perceived as V&V and Relatics
- Lack of SE standardization is observed in the tender phase
- The starting point of SE in B&U is from the activities needed and of GWW the functions performed
- In B&U the emphasis is placed upon different tools compared to the tools in GWW.
- In a B&U-tender a balance is needed in Systems Thinking and Design Thinking.

With these findings and results from the literature study: an answer to the main question (What question), provide lessons learnt and specify how SE can be implemented in a B&U tender.



Part Three: Conclusions and Recommendations

7 Conclusions

This chapter will highlight conclusions drawn from the research beginning with an initial overview of the research area followed by an analysis of the main research question in §7.2.

7.1 Research overview

The thesis began by addressing the need of adopting a different approach towards infrastructure design projects. The preliminary study in chapter one identify that architectural design and development is increasing in complexity due to size, utilization of technology and the influence of stakeholders on a buildings life cycle. Moreover, construction companies have a heightened sense of awareness and accountability with regard to their social responsibilities and as such they are more inclined towards eco-friendly designs requiring sustainable approaches. All of the above demands an adaptable and flexible policy towards construction projects.

Consequently the changing laws and regulations require clients to move away from traditional approaches (prescriptive driven design) to performance-based approaches such as integrated contracts. The performance-based approach involves forming consortiums which include architects, specialists and engineers from different disciplines to contribute and collaborate seamlessly as an interdisciplinary team.

The objective of this research was to explore the application of Systems Engineering (SE) in the B&U-sector as a performance-based approach applied by construction companies within integrated contracts, especially in the tendering phase.

This concept is unclear for construction companies in The Netherlands and requires investigation in the following research area: *What lessons can be learned from SE in the GWW-sector in order to assess the tendering phase of the B&U-sector and how can SE be processed in a B&U tender*. This thesis elaborates upon the benefits and challenges of SE integration in a theoretical study and practical study.

The theoretical study explored the challenges in B&U and the contribution of SE to overcome those challenges.

Challenges in B&U due to integrated contracts	Contribution of Systems Engineering tools
Changes the contractual relationship of actors. Subsequently changing their roles.	Better control of projects and risks.
More stakeholders, due to life cycle approach, each with their own set of requirements.	Tools for transforming client's requirements into design solution.
Increasing numbers of internal organisation actors within the design process.	Clear, explicit, and structured way of documenting project information. Thus, better communicating.
Rapid technological innovations make the future unpredictable.	- Better control of projects and risks. - In line with integrated contracts because of the life cycle approach.
Different mode of reasoning by the actors involved in the design phase.	Structuring the problem space by - Tools for transforming client's requirements into a design solution. - Clear, explicit, and structured way of documenting project information. Thus, better communication.

In the practical study the current practices in SE were assessed for two GWW projects and one B&U by means of a case study and (expert) interviews followed by an analysis. The findings from the practical study identified that:

- SE is indirectly used in the tender phase
- SE is perceived as V&V and Relatics
- Lack of SE standardization is observed in the tender phase
- The starting point of SE in B&U is from the activities needed and of GWW the functions performed
- In B&U the emphasis is placed upon different tools compared to the tools in GWW.
- In a B&U-tender a balance is needed in Systems Thinking and Design Thinking.

7.2 Answer to the main research question

What lessons can be learned from the SE method in the GWW-sector in order to assess the tendering phase of the B&U-sector and then how can SE be processed in a B&U tender?

To provide a comprehensive answer to this research question, it will be addressed in two part i.e. Part A (§8.4.1) and Part B (§8.4.2).

Part A: What lessons can be learned from the case projects?
Part B: How can SE be processed in a B&U tender?

7.2.1 Part A: What lessons can be learned from the case projects

From the 3 central questions the following findings were identified and combined:

- (1) SE is indirectly used in the tender phase, in the form of general to specific.
    - (a) V&V and Relatics are added as tools with SE. Other tools are indirectly used.
    - (b) There is lack of standardization for SE in the tender phase.
- (2) In B&U a balance is required in Systems Thinking and Design Thinking.
    - (a) In B&U the activities of building form the starting point for SE.
    - (b) The importance of tools is different in B&U and GWW. B&U gives significance to GBS and in GWW the importance is on SBS.

The followings sections will elaborate on what lessons can be learned.

(1a) SE is indirectly used in tender phase

The tools and methods used in the current tender process for both the sectors are similar to tools and methods used in SE except for the addition of verification and validation plans and information model as Relatics. Project personnel do not view SE from a comprehensive point of view and consider it to encompass V&V and Relatics. Personnel must undergo training to understand that SE is more than just a V&V plan and a means to structure information in Relatics.

In SE each task is a forethought that is explicitly documented and supports efficient communication and synchronized understandings during tendering. The work performed by the tender team will not change but it will be officially recorded and organized. The tools currently utilized can be correlated to SE tools as seen in Table 8. Linking all this information and developing an interface management system enables the tender team with a clear overview of the project and interrelated elements and actors. This creates more value over time by identifying impact and possible risks at early stages. Once the tender is achieved, transition to the next phases will proceed efficiently.

Table 8 Current methods translated to SE tools

Translation to SE tools →	
Current methods applied in tender	**Systems Engineering tools**
Analysis of PvE (programma van eisen)	Requirements analysis (RA)
Analysis of briefing	Requirements analysis (RA)
Analysis of the requirements and guidelines (aesthetic)	Requirements analysis (RA)
Decomposition	System Breakdown Structure (SBS)
Work Breakdown Structure	Work Breakdown Structure (WBS)
Risk analyses	Risk analyses/interface management
? (Excel)	Validation & Verification
? (Excel)	Relatics

(1b) Lack of standardization for SE is observed in tender phase

There was lack of standardization of SE tooling in the tender. Every project team had its own tender. However, after the tender was won, standardization such as BPM (BESIX Project Management) has been utilized. The lessons drawn from here are, if there is a larger degree of standardization for tender phase such as for the "BPM tender", understanding and using SE tooling will be easier. As mentioned earlier, numerous tools are already used implicitly but if those tools can be transformed into a standardized process, it will facilitate the use of SE. Moreover, the process from tender to realization will be efficient and seamlessly completed without the loss of information.

Almost all construction companies have a tender manual where the tender process is written down and followed. If a tender manual can be linked and optimized, for example to the BPM, the tender process and consequently the next phases can be performed systematically and efficiently. However, it should be noted that a tender process obtains sensitive information that companies are reluctant to share because it can cause competitors to benefit from the tender. Therefore, standardization of SE in a tender is complicated. Nevertheless, the process of SE tools can be developed as a blueprint.

(2a) The starting point of B&U is from the essential activities required and of GWW is the functions performed.

This finding illustrates the difference in B&U and GWW. In the first findings it was stated that SE is used indirectly for both the sectors and the tools used are the same but the starting point for B&U sector is different than that of the GWW, therefore tool significance is different.

GWW is built around a technical system, which can be decomposed and integrated. B&U on the other hand cannot be clearly decomposed, thus the design of soft aspects and building systems have to be combined. In B&U there are more soft aspects involved, therefore tighter cooperation is needed in the architect and collaborative abilities with the design team for the tender. Also since the soft aspects have to be incorporated to the project, more dialogue is required compared to GWW.

The tender team has to keep it in mind that everything cannot be clearly decomposed and integrated in the B&U. Thus, a balanced approach of Systems Thinking and Design Thinking is required. At the beginning of a tender, Systems Thinking is the dominant mode of thinking and consequently Systems Engineering should be applied. When all the information is structured and analysed it will be easier to create the design and see the consequences of each aspect. Gradually a transition towards Design Thinking is needed to achieve syntheses. This thinking process already happens naturally and instinctively but knowing how this transition works and why this method is applied will further facilitate the team to comprehend different roles within projects and therefore enhancing collaboration.

(2b) The importance of tools is different in B&U and GWW. B&U gives significance to GBS and in GWW the importance is on SBS.

As mentioned above B&U starts with an activity process and subsequent activities happen in spaces, rooms, facilities etc. Therefore in B&U the importance is given to GBS (Geographical Breakdown Structure) and it starts with the activity process while in GWW the importance is given to SBS (Function and System Breakdown Structure) and functional specifications. Both sectors support problem solving from general knowledge to field specific data.

GWW projects begin with functional specifications coupled with SBS objects that are considered a matter of priority before moving further. Conversely, in a B&U project the technical system is not the most vital element for the building, rather the purpose it serves and the needs it is meant to address hold more weight. Therefore, the starting point in the B&U project is from GBS activities and their related application.

The added value of Systems Thinking to Design Thinking

From the above, it can be concluded that Systems Thinking should be the dominant mode in the beginning of the tender and gradually a transition should be made towards Design Thinking. But why should the tender start with Systems Thinking?

Design Thinking is a human-centred approach and requires designers to be inside the problem to design the solution. It focuses on the solution space where designers view the problems from different angles and proposes solutions by experimenting and applying an iterative process.

Systems Thinking aims at being holistic by understanding a system from the apparent issue and decomposing the system to sub-systems that highlight other hidden influential factors that were earlier not apparent but are connected to the problem. System Thinking focuses on the problem space and the approach will give a broader view of problems and causalities within the sub-systems. The Design Thinking in turn can propose solutions tackling the wider context of the problem. It will give designers a chance to increase their understanding of the problem and potentially increase innovation by removing barriers and applying concrete solutions.

7.2.2 Part B: How can SE be processed in a B&U tender?

Mode of thinking

The mode of thinking is the first and foremost element to be understood by the tender team in B&U projects. The tender team must be aware that Systems Thinking is not solely applicable to a B&U project. Systems Thinking should be combined with Design Thinking during the tender phase by using Systems Engineering tools from the outset of the tender. Meaning that all the information should be documented explicitly in Relatics and relations between different components of the information should be made explicit only then the solution should be explored.

The added value of SE at the start is to structure the information coherently and pre-eminently view the interfaces of objects, as a result to identify issues and risks. With large complex projects, the information is vast and risk can then be easily overlooked or underestimated as the impact of a design change or object cannot be assessed in terms of its eventual impact with reference to the whole project. The literature study concluded that the changes made in concept and design phases have less impact on cost than changes made in later phases. Therefore, implementing SE tools from project inception results in measured impact and detailed reporting during syntheses.

This further supports validation and verification processes. It should be noted that for B&U: not everything could be explicitly verified or validated in text. Soft aspects are validated and verified with dialogue and consultation with the client. It also means, that the architect will play a greater role later in the tender because he has better knowledge of Design Thinking. Therefore, the architect could be appointed as a consortium leader or integrator, who can work as a mediator between the engineers and specialists for making design decisions.

Steering

The tender manager should steer his team to risk-driven SE in the tender phase. Risk-driven SE is the evaluation of interface management and risk analyses that should be applied from larger to smaller risk. Interviews noted financial constraints, capacity, lack of client prerequisites, and sufficient project control as reasons for not using SE in the tender phase. Capacity is a company related issue and linked to financial limitations. Client not requesting the use of SE is a problem that must be investigated from the client's side and is not in the scope of this research. Sufficient project control addresses risk-driven SE. It was noted that risks were not properly managed and prioritized causing problems in later stages of the project. When risks are prioritized, major risks can be controlled right from the start. With SE tooling risks can be identified in the tender and with interface management the impact of alterations can be seen. Risk can then be prioritized by implementing regular risk-sessions with the architect, so that the architect can make the design according to the risk prioritization.

Tooling

Thirdly, in B&U the work should be done by keeping in mind the activities needed in the future building. Therefore an activity process is required but GBS is also important. Unlike GWW, in the B&U the process of tender will commence from activities performed in the building and GBS linked to those activities. Therefore, it is advisable to use Relatics as representation where the activities and GBS are coupled together. The soft aspects play a bigger role and the tender manager should incorporate more interactive sessions with the architect, by considering to work from one location with architect, design team and engineers during the tender. The architect then could be appointed as a consortium leader or integrator, who can work as a mediator between the engineers and specialists for making design decisions. This will improve the cohesive atmosphere during the tender and possesses a higher probability of the process running efficiently.

8 Recommendations

The research objective of this thesis; *is to explore the Systems Engineering method in the tendering phase of the B&U-sector by comparing to the current practices of SE in GWW-sector of BESIX Nederland to ultimately give recommendation to the tender manager*. In this chapter six recommendations are presented to the tender manager of a construction company. Furthermore, recommendations for further research are given in §8.2

8.1 SE for the tender phase

1. Gain knowledge of SE tools and current practises

It was observed that during the tender phase SE is used indirectly which clarifies that tools utilized during traditional tendering are to a large extent similar to tools used in SE, as seen in Table 7 (§7.4.2). Moreover, for designing buildings general to specific problem solving is also applied. One of the main principles of SE is that programs, tasks, activities and their relationships are clearly stated and communicated. Therefore it is important for the tender team to gain knowledge of SE tools to appreciate the difference between their conventional work and the versatility of SE so that acceptance and usability is achieved at the time of tender. These tools transparently record the project plan allowing fluidity of idea exchange within the tender team and across the construction phases. Acquisition of knowledge and acceptance of SE will amplify the correct SE implementation.

2. Understand the perspectives of various thinking methods

B&U projects require an accurate equilibrium for different types of thinking namely, Systems Thinking and Design Thinking. As different disciplines will work together it is recommended that the tender manager should be aware of varying perspectives and consequently the thought-process behind their proposed ideas. Designers, especially architects have a more design-centric thinking while engineers are more process-centric. In B&U, the dominant mode of thinking shifts from Systems Thinking to Designers Thinking and the tender manager must understand the background of both approaches in order to efficiently balance operations.

It is recommended to initiate the tender phase as Systems Thinking and unravel each requirement and subsystem to comprehend interfacing between various elements as seen in the Figure 37. Applying Systems Thinking and using SE tools will map out connections clearly and allow development of a verification and validation plan from the start. As the tender progresses further, more and more soft aspects will have to intertwine with the design. Hence, it is recommended to move gradually from Systems Thinking towards Design Thinking for a greater quality of synthesis. Therefore, the tender manager should not provide rigid solutions to architectural demands. Rather he must learn to inject the knowledge and skills in the design process and possibly give alternatives so that the architect can make the design decision.
The added value of this approach is that Design Thinking defines the solution space and looks for innovative solutions. The input from Systems Thinking towards Design Thinking is that it will structure the information in the solution space and capture causalities and interactions accordingly. It will provide a bird's eye view towards the solution and expand the 'radar' for Design Thinking by anticipating unforeseen consequences in other subsystems. In addition, interface management can be made during the early phase of tender where the consequence of design changes can be shown.

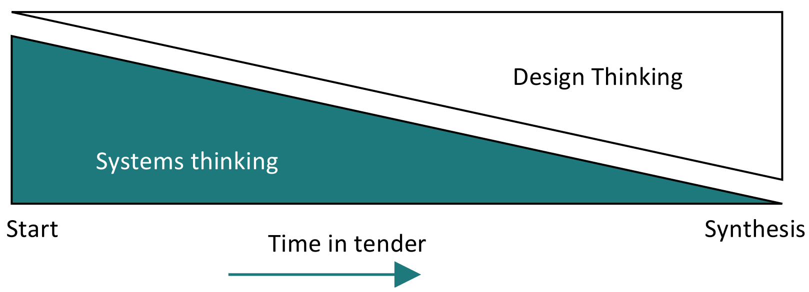


Figure 37 Systems Thinking vs. Design Thinking in the tender phase

3. In B&U the architect must have a leading role in the tender phase.
In B&U there is a need of a balance in Systems Thinking and Design Thinking and architects are qualified to implement Design Thinking, recognize interfaces and their relations. In B&U soft aspects have a larger role than in GWW projects, therefore it is recommended during the tender to give the architect a leading role in the tender phase. In B&U the soft aspects have an effect on the entire system and architects are naturally better at recognizing those effects. Moreover, they have specialized in soft aspects and can make adequate links, roles and relations.
Engineers on the other hand specialize in certain technical systems. In B&U soft aspects are equally of, or sometimes of greater dominance than technical systems. Hence, the architect knows best how to connect the technical sub-systems together with soft aspects to make one comprehensive system. The architect can only create a respectable design if he has unambiguous and complete information. The role therefore of tender manager should be to provide precise and clear information to the architect.

To be noted: This does not signify that the requirement of an architect is of any less importance in a GWW project. In GWW the soft aspects are less imperative and the dominant functions are technical systems, thus the architect has less influence in GWW. Therefore, in GWW the architect does need a lead role and can prepare the design around technical systems. While in B&U the technical systems have to be intertwined with the soft aspects, which means that Design Thinking is more applicable hence the architect needs a greater role in B&U.

4. In B&U more interactions are needed than in GWW
The fourth recommendation for the tender manager is to have more interaction with architect and designers in a B&U project than in a GWW project. This recommendation comes forth from lessons learned in the conclusion. In B&U projects there is greater need of collaborations and trust between the designers and engineers. Ideally, working from one location can have significant impact in collaboration and interaction between both disciplines. As it was mentioned during the interviews, projects where parties worked from one location experienced better control and created more value in the project.

5. Standardization of SE for the tender
It was observed that there is no formal standardized process of SE in the tender. To implement SE efficiently in the tender it is recommended to create a formal process of SE for the tender phase that can be seen as a blueprint for each project. The blueprint should consist of the working-processes the construction company undertake. In the working-processes it should be written what steps should be taken in the tender, those steps can be derived from the tender manual. For instance, prioritizing risk with together with the architect as mentioned in the conclusion.

The advantage of standardization is twofold.
First, BESIX has standardization in the form of BPM (BESIX Project Management) for the realization phase but there is no such tool for the tender phase. Therefore, a BPM Tender can be developed that can be linked to other phases. A blueprint will make SE competent to use and will assist the tender team to understand SE better. It will also take out the hassle of setting up a new information system for each project. Moreover, the transition from the tender phase to realization phase will run efficiently with minimum loss of information.
Secondly, from the interviews, it was observed that employees in the realization phase could not distinguish the reasoning behind some decisions. In addition, they pointed out that information was lost because it was not ordered structurally. It was time consuming to find the correct information and the employees were therefore dependent on input of the tender team.
Thus, it is recommended to establish a standard SE process for the tender linked to the realization phase. The realization team will make information transparent and establish the precise format that will save time and inaccuracies on later stages. The teams in later phases, will then be less dependent on the tender team and it will become more apparent to them as to how to record information in the tender to head off possible issues at the project onset.

6. Use SE from the beginning of the tender process
To attain the maximum value out of the tender it is recommended to apply SE from the beginning of the tender phase. This recommendation is in line with the second recommendation (perspective of various thinking methods, §8.5.2) mentioned in this paragraph. To attain maximum value, a SE kick-off meeting should be conducted. In the meeting, the scope and goal of SE should be discussed, this will ensure everyone is on the same line. Further, the implementation of Systems Engineering method should also be discussed, the point is to get clear for the tender team how Systems Engineering will be applied. Consequently, a second SE meeting can be conducted during the tender to evaluate and adjust Systems Engineering method.

The reasoning for this recommendation comes from Systems Thinking. As seen in Figure 37 it is recommended to commence with Systems Thinking. Therefore, it is suitable to start SE from the beginning of the tender phase. Especially when there is a standardization process, it will be easier to start with SE. In one project SE was applied in the later phase of the tender to develop the verification and validation plan. The vast accumulation of information that was required was altered so much along the process, that it caused uncertainty about accuracy of the data in hand. Eventually SE and the verification and validation plan in Relatics were rejected and not used for the tender. If SE was used from the beginning this would not have happened and the changes would have been systematically documented. It would also have been easier to prepare the verification and validation plan. This recommendation emphasizes the previous recommendation for the need of SE standardization in the tender. If there had been a standardized process, the tender team could have processed the information correctly and effectively.

8.2 Recommendations for future furesearch

The conclusions and recommendations provided in this research are based on implementing Systems Engineering for the tender phase in the B&U. These results are the first steps in the research area that require further examinations. Therefore, recommendations are given for further research.

Quantitative research
The eleven qualitative interviews in this thesis are based on expectations and experience of interviewees in the three case projects. Moreover, the propositions were made which channelled the interviews and research towards the architect-engineer relationship. Therefore, the conclusions drawn from these interviews cannot be generalized. To increase the reliability and representations of the research, it is recommended to perform a quantitative research. Since this thesis identified the architectural-engineering relationship, the quantitative research can than investigate the strength and effects of the relationship.

More case projects
The research was focused on the projects of BESIX Netherlands, and has only investigated three projects. In this, thesis generalization is made from the fact that SE is applied (more or less) in the same way by all the construction companies and therefore the results will not vary. However, every company have his own process and method for implementing SE thus the recommendations can be different for other companies. Therefore to generalize the recommendations the applicability of SE can be improved by conducting research for more projects across several construction companies.

Scope tender phase
The scope of this thesis has limited itself to the tender phase of construction project. For accurate implementation of Systems Engineering in the B&U all the phases of construction cycle have to be considered. Further research can be performed for other phases of the life cycle of building.

Client's viewpoint
The thesis has investigated SE from the viewpoint of the civil industry and provided recommendations for construction companies. However, this report has identified that SE is initiated from the clients-side and subsequently not all clients request Systems Engineering in their contracts. Therefore, it is recommended to also examine SE from the viewpoint of the client. In particular, a study can be performed in what can the client learn from construction companies to efficiently initiate SE for B&U projects.

Lessons learned from other B&U project
At the start of this research not many B&U project were managed according to SE. Therefore, the literature study showed some limitations on SE in B&U. But the use of SE method is increasing extensively in the building construction. Therefore, in the future further research can be conducted on how the SE is implemented in B&U projects and what lessons can be learned from other buildings projects.

Appendices

Abbreviations

B&U	Burgelijke&Utiliteitsbouw. Residential and non-residential buildings
EPC	Engineering, Procurement and Construction
FBS	Functional breakdown system (Functieboom)
GBS	Geographical Breakdown System (Ruimteboom)
GWW	Grond, Weg en Waterbouw and stands for the infrastructure sector.
MTC	Maintenance
OBS	Organisation Breakdown System (Organisatieboom)
PBS	Process Breakdown System (Procesboom)
PMP	Project Management Plan
PvE (SOR)	Statement of requirements. In dutchProgramma van eisen
RA	Requirement Analysis (Eisen analyse)
RBS	Requirement Breakdown System (Eisenboom)
RVB (Rijksvastgoedbedrijf)	Rijksvastgoedbedrijf formerly Rijksgebouwendienst is a government agency that is responsible for the government real estate.
RWS (Rijkswaterstaat)	Rijkswaterstaat is a government agency that is responsible for the road and water infrastructure.
SBS	System breakdown function (Objectenboom)
SE	Systems Engineering
SPE	Special purpose entity
V&V	Verification and Validation
WBS	Work Breakdown System (Activiteitenboom)

Appendix A Research background

Theory: desk research
A desk research is characterised by: the use of existing material with reflection, the absence of direct contact with the research object and the material is used from a different perspective than at the time of its production (Verschuren & Doorewaard, 2010). Initially a scientific literature will be conducted to get the state-of-art knowledge and know-how in Systems Engineering. The literature study will examine the existing materials in order to answer the two central questions and provide insight for the third central question. Furthermore, the absence of SE with the B&U sector will be explored and SE will be examined from different perspectives. In line with this research it will be examined from the GWW sector. The goal of the literature study is to find variables that are important for Systems Engineering in construction projects in the GWW as in the B&U. The literature study will be used as a foundation for further exploration of the research study and will result in propositions. Therefore propositions are made from the literature study.
Since the literature study is an iterative process with new research material emerging later on in the study. The literature study will be carried throughout the research and were needed the report will be adjusted.

Practice: Case study and interviews
After the desk research, a case study will be conducted. Since there is little experience in using Systems Engineering in the building sector an analogy from the GWW-sector can be made (Baudains e.a., 2014; Emes e.a., 2012; Geyer, 2012).BESIX already implement SE in few of their GWW-projects. From that viewpoint this research can learn a lot from those projects and it is also a good starting point for developing a theory for the B&U-sector. Furthermore, BESIX just started using SE for B&U therefore only one project is available for the B&U-sector. Hence, two GWW projects (Velser Tunnel and Keersluis Limmel) and one B&U project (Hogeschool Utrecht) are chosen for the case study (See Table 9). The GWW projects are chosen as case study because in both of the projects Systems Engineering is applied. Both the projects are further in the execution phase and SE is widely used and optimised. Subsequently, the project Hogeschool Utrecht for the B&U is chosen because, it is the first B&U projects of BESIX were SE will be applied. Hogeschool Utrecht is acquired recently (December 2015) and the work is in early stages.
Parallel with the case study, case related interviews would be held to get knowledge of how SE is applied and experienced in the projects. The key is to observe the Systems Engineering process in the GWW-projects and make a cross-case analysis. The observation of the GWW projects will also provide an answer on the research question 3, ‘What are the findings from the practices of SE in construction industry?’ For the cases a case protocol will be developed according to the book of Robert Yin’s Case Study Research: Design and Methods. In the case protocol the data collection will be analysed. What information do I need? Which documents will be relevant? How many persons to interview? Are several of the questions that will be answered.

Table 9 Case selection

Sector	**Project**	**SE applied**	**SE phase**	**In progress/completed**
GWW	Velser Tunnel	Yes	Advance phase	In progress since Jul 2014
GWW	Keersluis Limmel	Yes	Advance phase	In progress since Aug 2015
B&U	Hogeschool Utrecht	Yes	Start up phase	In progress since Dec 2015

Afterwards open interviews will be held with experts in Systems Engineering to get insight to their experiences and expectations of SE in B&U. Interviews will be held after the literature study because it is important to gain knowledge first about the differences in SE. These differences will be presented to experts in order to come with a sound solution and/or discussion during interviews. Since, at the moment there is less information about the research objects it is hard to finalize how the expert interview will be conducted. After the desk research it will be more prominent to make a research design. Were it will be stated how the methods will be applied. For all the interviews different protocols will be developed.

Appendix B Interview protocol (Dutch)

For conducting interviews an interview protocol has been prepared. Semi-structured interview will be held, meaning that the respondent can prepare his/herself for the interview. Two protocols are made, one for the experts (external) and one protocol for BESIX employees (internal). Both the protocols consist of an invitation letter, guidelines for the interview and questions to be asked during the interview. The protocol will be send at least three days before the interview. Since the interviewees are Dutch/Flemish speaking, the protocol is prepared in Dutch for the convenience of the interviewees. Moreover, two interviews will be held as preparation. In those interviews feedback will be given on the interviews and questions asked.

The timeline of the interview is as follows;

- Send interview invitation
- Plan a meeting
- Three days prior to the interview send interview guidelines and questions
- Conduct interview (approximately 60 min)
- Transcribe and process the interview
- Feedback from the interview
- Analyse the interviews
- Once the research is finished the public report will be send (if required)

B1 Protocol for BESIX employees

B1.1 Uitnodiging brief

Onderwerp: Uitnodiging interview BESIX intern

Geachte uitgenodigde,

Middels deze brief wil ik u vragen voor een mogelijkheid om een interview te houden voor mijn afstudeeronderzoek.

Mijn naam is Usman Ishfaq en studeer MSc. Construction Management & Engineering aan de TU Delft. Als laatste onderdeel van mijn studie ben ik momenteel bezig met een afstudeeronderzoek binnen BESIX. Ik verwacht dit onderzoek in april af te ronden.

Mijn afstudeeronderwerp is Systems Engineering in Burgerlijke en Utiliteitsbouw (B&U). Systems Engineering (SE) staat op dit moment veel in belangstelling. Vooral ook omdat grote opdrachtgevers, zoals overheid instanties, Systems Engineering eisen in hun contract. De infra-sector is een voorbeeld waar Systems Engineering al word toegepast. Daarom is mijn onderzoek ook gericht op, wat kunnen we leren van Systems Engineering proces in de GWW-sector en hoe kunnen we dan een vertaalslag maken naar Systems Engineering in de B&U.

Doel van het interview is om kennis op te doen van Systems Engineering binnen BESIX. Voornamelijk gaat het om, hoe kunnen we SE toepassen al vanaf de tender fase. Daarnaast zal het huidige SE proces van het project Keersluis Limmel, Velsentunnel en Hogeschool Utrecht ook onder loep worden genomen. Het interview gaat daarom ook om inzicht te krijgen op de visie en ervaring van de geïnterviewde voor Systems Engineering. Het interview duurt maximaal één uur en inhoudelijke vragen worden tijdig voor het interview verstuurd.

Ik hoop u hiermee voldoende geïnformeerd te hebben en dat we spoedig een afspraak kunnen inplannen.

Met vriendelijke groeten,

Usman Ishfaq

B1.2 Interview protocol

Context van het interview
Dit interview protocol maakt deel uit van mijn afstudeeronderzoek voor de studie MSc. Construction Management & Engineering aan de Technische Universiteit Delft.

Het onderwerp van mijn onderzoek is Systems Engineering in Burgerlijke en Utiliteitsbouw (B&U). Specifiek is mijn onderzoek gericht op, hoe kunnen we binnen BESIX Systems Engineering (SE) toepassen vanaf de tender fase voor de B&U projecten?

Inde literatuur blijkt dat Systems Engineering niet optimaal wordt benut door de B&U-sector. Gebouwen zijn complexe systemen die steeds ambitieuzer in schaal en techniek worden gebouwd. De groeiende invloed van de vele stakeholders, de wet- en regelgeving en steeds maar veranderde eisen van de opdrachtgever maken een B&U-project een complex werk. Gebouwen van de toekomst dienen dan ook flexibel, dynamisch en robuuster te zijn. Gebouwen moeten kunnen anticiperen op de *life-cycle* veranderingen om zo toch te voldoen aan de wensen van de markt. Daarnaast veranderd ook de rol van de opdrachtgevers, van traditioneel bouwen naar prestatiegericht bouwen. Dit zorgt ervoor dat traditionele manier van bouwen niet meer geschikt is voor B&U-projecten.
In andere industrieën met hoge complexiteit en prestatiegericht bouwen, zoals de infra, is Systems Engineering methode met succes toegepast. Mede daardoor zijn er ook kansen om Systems Engineering toe te passen in de B&U-sector.

Doel van het interview
Sinds enkele jaren maakt BESIX Nederland gebruik van Systems Engineering (SE) in infrastructurele projecten. Vanuit de opgedane kennis en ervaringen kan veel geleerd worden. Dit interview wordt daarom ook gehouden met het doel om lessen uit Systems Engineering binnen BESIX te trekken. Een aantal Systems Engineers, Proces managers en Tender managers worden geïnterviewd binnen BESIX. Om zo de SE proces te observeren en kennis op te doen voor het gebruik van SE in de aanbestedingen. Behalve werknemers van BESIX worden ook externe experts op Systems Engineering geïnterviewd voor hun visie en kijk op B&U-projecten.

Inhoud van interview
Het Interview wordt enkel door mijzelf afgenomen en het inhoud gaat over;

- Observeren van het Systems Engineering proces binnen BESIX.
- Hoe kan SE tijdens de aanbesteding fase al gebruikt worden.
- Visie van de geïnterviewde op de bovenstaande.

Het interview (ca. 60 min)
Introductie (ca. 10 min)
- Kennismaking en introductie
- Toelichting interview

Systems Engineering binnen BESIX (ca. 15 min)
- Wat verstaat u onder Systems Engineering?
- Hoe ziet u het SE proces binnen BESIX?
- Wat zijn u ervaringen met SE binnen uw project? Is er een meerwaarde?
- Wat kan anders/beter? En waarom?

Systems Engineering in de tenderfase (ca. 30 min)
- SE wordt niet of nauwelijks gebruikt bij tenderfase. Wat kan de reden zijn dat van SE niet wordt gebruik gemaakt? En wanneer kan SE dan wel gebruikt worden, speelt het type aanbesteding en/of contract-vorm een rol (EMVI,DBFMO)? Hoe?
    - Tijdens de tenderfase wordt nauwelijks gebruikt gemaakt van SE. Voornaamste reden is dat het financieel niet aantrekkelijk is. Wat is uw mening hierover?
- Denkt u dat tijdens de tender fase SE een meerwaarde kan creëren? Waarom wel/niet? Zo ja, hoe?

- In het tender handboek staat onder strategie -> opzet SE (indien nodig/nuttig). Welke criteria worden gebruikt om te bepalen of SE wel of niet gebruikt wordt?
- Architect heeft veel meer macht bij B&U projecten dan bij infra projecten. Dat heeft effect op het (ontwerp) processen daarmee ook op SE. Welke verschillen denkt u dat er zijn tussen B&U en Infra op SE?
- B&U-projecten hebben veel meer interfaces (raakvlakken) dan infra, dat zorgt ook voor veel meer clashes. Denkt u dat SE daar een oplossing voor kan bieden? Zo ja/nee, waarom en hoe?

Afsluiting (ca. 5 min)
- Wat verder ter tafel komt
- Terugkoppeling interview
- Benaderbaar voor meer vragen
- Bedanken.

*INTERVIEW VRAGEN ZIJN TER INDICATIE EN VOOR CONSISTENTIE, TIJDENS EEN INTERVIEW KAN ER AFGEWEKEN WORDEN.

Resultaten van het interview
In totaal zijn twee infra-projecten en twee B&U-projecten gekozen als case studies voor mijn onderzoek. De resultaten van mijn interviews vanuit infra-projecten worden toegepast/gestimuleerd in B&U-projecten. Zo wordt nagegaan waar B&U projecten verschillen ten opzichte van infra-projecten in de context van Systems Engineering. Ieder gesprek word teruggekoppeld aan de geïnterviewde voor opmerkingen, wijziging en goedkeuring.

Werkwijze van interview
Richtlijnen voor het interview zijn als volgt:
- Voor het interview wordt 90 minuten ingepland, streven is om het interview in circa 60 minuten af te ronden.
- Interview is gericht op projecten van BESIX. Voor informatie buiten BESIX word in principe niet gezocht. Geïnterviewde kan/mag zijn eigen ervaringen vertellen.
- Alle informatie wordt vertrouwelijk behandeld en uitwerking van het interview wordt naar de desbetreffende persoon gestuurd voor wijzigingen/opmerkingen en goedkeuring.
- Als er geen antwoord op vragen kan worden geven vb. door project of bedrijf gevoelig informatie, dan zal naar een benadering of verwijzing gezocht worden.
- Geïnterviewde mag een vraag weigeren te beantwoorden zonder enig uitleg.
- Interview wordt met toestemming opgenomen.
- Na afronding van mijn onderzoek wordt het eind verslag toegestuurd naar de geïnterviewde(n).

B2 Protocol for Experts

B2.1 Uitnodiging brief

Onderwerp: Uitnodiging interview

Geachte genodigde,

Middels deze brief wil ik u vragen voor een mogelijkheid om een interview te houden voor mijn afstudeeronderzoek.

Mijn naam is Usman Ishfaq en studeer MSc. Construction Management & Engineering aan de TU Delft. Als laatste onderdeel van mijn studie ben ik momenteel bezig met een afstudeeronderzoek binnen BESIX. Ik verwacht dit onderzoek in april af te ronden.

Mijn afstudeeronderwerp is Systems Engineering in Burgerlijke en Utiliteitsbouw (B&U). Systems Engineering (SE) staat op dit moment veel in belangstelling. Vooral ook omdat grote opdrachtgevers, zoals overheid instanties, Systems Engineering eisen in hun contract. De infra-sector is een voorbeeld waar Systems Engineering al word toegepast. Daarom is mijn onderzoek ook gericht op, wat kunnen we leren van Systems

Engineering proces in de GWW-sector en hoe kunnen we dan een vertaalslag maken naar Systems Engineering in de B&U.

Doel van het interview is om kennis op te doen van experts voor het toepassen van Systems Engineering in de B&U. In het (literatuur) onderzoek is gebleken dat SE nauwelijks word toegepast in B&U. In vergelijking met GWW speelt binnen B&U de architect en ruimte bepaling een veel prominente rol voor SE. Het interview gaat daarom ook voornamelijk om inzicht te krijgen op de visie van de geïnterviewde voor Systems Engineering in de B&U. Het interview duurt maximaal één uur en inhoudelijke vragen worden tijdig voor het interview verstuurd.

Ik hoop u hiermee voldoende geïnformeerd te hebben en dat we snel een afspraak kunnen inplannen.

Met vriendelijke groeten,

Usman Ishfaq

B2.2 Interview protocol Experts

Context van het interview
Dit interview protocol maakt deel uit van mijn afstudeeronderzoek voor de studie MSc. Construction Management & Engineering aan de Technische Universiteit Delft.

Het onderwerp van mijn onderzoek is Systems Engineering in Burgerlijke en Utiliteitsbouw (B&U). Specifiek is mijn onderzoek gericht op, hoe kunnen we Systems Engineering (SE) toepassen vanaf de tender fase voor de B&U projecten?

Sinds enkele jaren maakt de overheid gebruik van Systems Engineering (SE). In de literatuur blijkt dat Systems Engineering niet optimaal wordt benut door de B&U-sector. Gebouwen zijn complexe systemen die steeds ambitieuzer in schaal en techniek worden gebouwd. De groeiende invloed van de vele stakeholders, de wet- en regelgeving en steeds maar veranderde eisen van de opdrachtgever maken een B&U-project een complex werk. Gebouwen van de toekomst dienen dan ook flexibel, dynamisch en robuuster te zijn. Gebouwen dienen te kunnen anticiperen op de *life-cycle* veranderingen om zo toch te voldoen aan de wensen van de markt. Daarnaast veranderd ook de rol van de opdrachtgevers, van traditioneel bouwen naar prestatiegericht bouwen. Dit zorgt ervoor dat traditionele manier van bouwen niet meer geschikt is voor B&U-projecten.
In andere industrieën met hoge complexiteit en prestatiegericht bouwen, zoals de infra, is Systems Engineering methode met succes toegepast. Mede daardoor zijn er ook kansen om Systems Engineering toe te passen in de B&U-sector.

Doel van het interview
Dit interview wordt gehouden met het doel om de toepasbaarheid van Systems Engineering in B&U-sector te onderzoeken. Een aantal Systems Engineers, Proces managers, Tender managers en SE consultants worden geïnterviewd. Van de opgedane kennis en ervaringen in recente jaren kan veel geleerd worden. In het interview gaat het om inzicht te verkrijgen op de visie van geïnterviewde(n) op SE in B&U-projecten. Tijdens het interview wordt merendeel van de aandacht aan de tenderfase besteed.

Inhoud van interview
Het Interview wordt enkel door mijzelf afgenomen en het inhoud gaat over;

- Toepassen van SE in burgerlijke en utiliteitsbouw.
- Hoe kan SE tijdens de aanbesteding fase al gebruikt worden.
- Visie van de geïnterviewde op de bovenstaande.

Het interview (ca. 60 min)

Introductie (ca. 10 min)

- Kennismaking en introductie
- Toelichting interview

Systems Engineering in de tenderfase (ca. 45 min)

- Tijdens de tenderfase wordt nauwelijks gebruikt gemaakt van SE. Voornaamste reden is dat het financieel niet aantrekkelijk is. Wat is uw mening hierover?
- Zijn er ook andere reden waarom SE niet gebruikt wordt? En wanneer kan SE dan wel gebruikt worden, speelt het type aanbesteding en/of contract-vorm een rol (EMVI,DBFMO)? Hoe? Welke criteria worden gebruikt om te bepalen of SE wel of niet gebruikt wordt?
- Denkt u dat tijdens de tender fase SE een meerwaarde kan creëren? Waarom wel/niet? Zo ja, hoe?
- Kunt u een reden geven om SE juist wel te gebruiken in tenderfase?
- Architect heeft veel meer macht bij B&U projecten dan bij infra projecten. Dat heeft effect op het (ontwerp)proces en daarmee ook op SE. Welke verschillen denkt u dat er zijn tussen B&U en Infra op SE?
- B&U-projecten hebben veel meer interfaces (raakvlakken) dan infra, dat zorgt ook voor veel meer clashes. Denkt u dat SE daar een oplossing voor kan bieden? Zo ja/nee, waarom en hoe?
- …….

Afsluiting (ca. 5 min)

- Wat verder ter tafel komt
- Terugkoppeling interview
- Benaderbaar voor meer vragen
- Bedanken.

*INTERVIEW VRAGEN ZIJN TER INDICATIE EN VOOR CONSISTENTIE OVER ALLE INTERVIEWS, TIJDENS EEN INTERVIEW KAN ER AFGEWEKEN WORDEN.

Resultaten van het interview

In totaal zijn twee infra-projecten en twee B&U-projecten gekozen als case studies voor mijn onderzoek. De resultaten van mijn interviews vanuit infra-projecten worden toegepast/gestimuleerd in B&U-projecten. Zo wordt nagegaan waar B&U projecten verschillen ten opzichte van infra-projecten in de context van Systems Engineering. Ieder gesprek word teruggekoppeld aan de geïnterviewde aan de hand van de onderstaande template. Hetzelfde template word ook tijdens het interview gebruikt als richtlijn en notities.

Werkwijze van interview

Richtlijnen voor het interview zijn als volgt:

- Voor het interview wordt 90 minuten ingepland, streven is om het interview in circa 60 minuten af te ronden.
- Alle informatie wordt vertrouwelijk behandeld en uitwerking van het interview wordt naar de desbetreffende persoon gestuurd voor wijzigingen/opmerkingen en goedkeuring.
- Als er geen antwoord op vragen kan worden geven vb. door project of bedrijf gevoelig informatie, dan zal naar een benadering of verwijzing gezocht worden.
- Geïnterviewde mag een vraag weigeren te beantwoorden zonder enig uitleg.
- Interview wordt met toestemming opgenomen.
- Na afronding van mijn onderzoek wordt het eind verslag toegestuurd naar de geïnterviewde(n).

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