Master's thesis

NTNU
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Department of Mechanical and Industrial Engineering

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Proposed Measures for Cost Reduction in the NTNU Campus Collection Project

Master's thesis in Engineering and ICT
Supervisor: Bjørn Sørskot Andersen
June 2022

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STATSBYGG

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Summary

This master's thesis is a collaboration with Statsbygg, which deals with the NTNU Campus Collection project. The project is managed according to the project strategy Design to Cost (DtC), which has set an absolute contract price of NOK 11.032 billion. However, at the end of March, the project was informed that it was necessary to reduce the scope and total cost significantly. Based on this, the report focuses on scalable uncertainty elements, primarily through the analytical method in cost estimation and evaluation of uncertainty drivers in the uncertainty analysis.

In order to investigate potential improvements in the project, a literature review and case study was first conducted. These focused on the use of DtC in projects and how Statsbygg uses this method in the Campus Collection project. Furthermore, data analysis of Statsbygg's cost estimates was carried out before an attempt was made to calculate lower costs using successive calculation. After conversations with representatives from Statsbygg, other aspects in which the project could achieve effects were also discussed.

The results address the successive calculation performed in two different ways. The first method calculates cost for the total project, while the second divides the megaproject into smaller subprojects and sums these costs together. The findings show that none of these calculations reduce the costs that Statsbygg has calculated using Monte Carlo simulation. On the other hand, the results indicate that calculation cost using subprojects can lower the project's total sum using a more powerful simulation tool. As this has not been tested, it can not be said that the method will give better results.

In the current cost estimate performed by Statsbygg, there is a high mark-up in uncertainty from the base estimate and up to the calculated P85 value. Much of this surcharge deals with regulatory risk. Measures have thus been proposed to choose a safer strategy with more new buildings rather than conversions where much restructuring is required. At the same time, measures have been put forward to revamp complex plots by moving the square meter to another more uncomplicated plot. It is also recommended to postpone start-up or implement measures that can increase flexibility in connection with activities that have irreversible effects. There may be alternative costs associated with initiating measures with irreversible effects. By postponing the measure, one can often take advantage of the opportunities associated with new information.

Sammendrag

Denne masteroppgaven er et samarbeid med Statsbygg som omhandler NTNU Campussamlingsprosjektet. Prosjektet styres etter prosjektstrategien Design to Cost (DtC) som har satt en absolutt kostnadsramme på 11.032 milliarder kroner. I slutten av mars fikk derimot prosjektet beskjed om at det var nødvendig å redusere omfanget og totalkostnaden betydelig. På grunnlag av dette fokuserer denne rapporten på nedskalerbare usikkerhetselementer, spesielt gjennom bruken av analytisk metode i kostnadsestimering og evaluering av usikkerhetsdrivere i usikkerhetsanalysen.

For å undersøke forbedringspotensialer i prosjektet, ble det først gjennomført en litteraturstudie og casestudie. Disse fokuserte på bruken av DtC i prosjekter og hvordan Statsbygg anvender denne metoden i Campussamlingsprosjektet. Videre ble en dataanalyse av kostnadsestimatene til Statsbygg gjennomført, før det ble forsøkt å kalkulere lavere kostnader ved bruk av trinnvis kalkulasjon. Etter samtale med representanter fra Statsbygg ble det også diskutert andre aspekter hvor prosjektet kan oppnå effekter.

Resultatene tar for seg den trinnvise kalkulasjonen utført på to ulike måter. Den første metoden beregner kostnader for det totale prosjektet, mens den andre deler megaprosjektet opp i mindre delprosjekter og summerer disse kostnadene sammen. Fra funnene viser det seg at ingen av disse kalkulasjonene lykkes i å redusere kostnadene som Statsbygg har kalkulert ved bruk av Monte Carlo simulering. Resultatene gir derimot en indikasjon på at kalkulering ved bruk av delprosjekter kan gi en lavere totalsum for prosjektet ved bruk av et kraftigere simuleringsverktøy. Ettersom dette ikke er blitt testet ut, så kan man derimot ikke si for sikkert at metoden vil gi bedre resultater.

I dagens kostnadsestimat utført av Statsbygg, er det et høyt påslag i usikkerhet fra basisestimatet og opp til beregnet P85-verdi. Mye av dette påslaget omhandler reguleringsrisiko. Det er dermed foreslått tiltak om å velge en tryggere strategi med flere nybygg fremfor ombygg hvor det kreves mye omstrukturering. Samtidig er det lagt frem tiltak om å revudere vanskelige tomter ved å flytte kvadrameter over til en annen enklere tomt. Det er i tillegg anbefalt å utsette oppstart eller gjennomføre tiltak som kan øke fleksibiliteten i tilknytning til aktiviteter som har irreversible effekter. Dette av den grunn at det kan være alternativ kostnad knyttet til initiering av tiltak med irreversible effekter. Ved å utsette tiltaket kan man ofte utnytte mulighetene knyttet til ny informasjon.

Preface

This master's thesis describes the work performed in the subject TPK4920 Project and Quality Management, Master's Thesis. The thesis was written in the spring of 2022 and counted 30 credits. The thesis is a partnership between NTNU and Statsbygg, which requested a thesis on the topic of this thesis.

The purpose of the thesis was to investigate whether there was a basis for lowering some uncertainty in connection with the NTNU Campus Collection project. The thesis is based on a cost estimate and uncertainty analysis from Statsbygg. A literature review, case study, and quantitative calculations were conducted to gain a deeper insight into cost development and uncertainty analysis estimation. The motivation behind the thesis has been to assist the Campus Collection project with an analysis of possibilities for possibly lowering the uncertainty in the project.

At times, the work with this thesis has been very challenging, especially as there have been changes in the Campus Collection project. Simultaneously, working on this thesis has helped me feel more prepared to enter the working life now that my studies are over.

Katrine Jørgensen Gjerde

Trondheim, June 7, 2022

Acknowledgement

I would like to express my gratitude to my supervisor, Bjørn Sørskott Andersen, for his guidance, support, and helpful tips along the way. Whenever I had a question, he responded promptly and provided relevant and specific feedback for improving my work. I would also like to thank my two co-supervisors at Statsbygg, Magne Lilleland-Olsen, and Asle Ødven, for explaining the data and being available for questions at any time. They have both been a major contributor during the work on this master's thesis.

K.J.G

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Abbreviations

DtC	Design to Cost
ME	Ministry of Education
NTNU	Norwegian University of Science and Technology
PBS	Project Breakdown Structure
QA	Quality Assurance
RQ	Research Question

Chapter 1

Introduction

This chapter describes the background and motivation of the thesis. Furthermore, the formal problem description, including related research questions and limitations, is presented. The structure of the thesis is introduced at the end.

1.1 Background and Motivation

NTNU's academic environment in Trondheim will be integrated into one campus on Gløshaugen from multiple locations within the next ten years. The start-up preliminary project report by Statsbygg and NTNU (2018) describes that the government will fund the construction of 92.000 square meters of new buildings and the refurbishment of up to 45.000 square meters of existing sites at NTNU. The NTNU Campus Collection project aims to create a unified, interdisciplinary, and future-oriented arena for higher education, concentrated on a campus close to the city.

According to Statsbygg's report, which describes the process and model for Design to Cost (DtC) in the NTNU Campus Collection project (2021b), the total contract price of the project is set to NOK 11.032 billion. Statsbygg is responsible for further project development and implementation of the construction project on behalf of the Ministry of Education (ME) (Statsbygg & NTNU, 2018). NTNU is the project owner, manager, and user and will ensure that the university's needs are met during construction.

At the request of the Ministry of Education and Research, the project will prepare a model and procedures for DtC. This ensures adequate cost control during the project's implementation by following a cost-controlled project development process. This is to stay within the NOK 11.032 billion absolute contract price. On the revised assignment letter for the preliminary project (2020), the Ministry of Education and Research also states that measures must be made for the project's highest potential optimization to generate the most significant possible advantage within the budgetary constraints.

On 28 March 2022, Statsbygg and NTNU received a joint letter from the Ministry of Education and Research to reduce the scope and total cost of the NTNU Campus Collection project. This requires further mapping of costs, risks, goal achievement, and consequences for NTNU's activities.

1.2 Problem Description

This master's thesis is based on previous cost estimates made by Statsbygg and aims to investigate whether alternative calculation methods can contribute to reducing existing costs. The thesis will also explore the uncertainty elements and examine whether there are any ways to reduce the estimated risk. As a result, the problem statement is reduced to a single question that the thesis attempts to answer:

Goal *How may the uncertainty elements be managed further to ensure that the project stays within the DtC contract price?*

1.3 Research Questions

Several research questions (RQs) dealing with cost estimation, uncertainty analysis, and the calculation of uncertainty factors have been established to answer the thesis's problem statement:

Research question 1 *How do Statsbygg implement DtC methods in the NTNU Campus Collection?*

Research question 2 *Is it possible to reduce the current management reserve by using other methods and models?*

Research question 3 *Are there any benefits to using a different calculation method and model?*

Research question 4 *What measures can Statsbygg implement to lower some of the uncertainty drivers?*

1.4 Limitations

The master's thesis is a quantitative description of Statsbygg's previously performed cost estimates. The thesis has limited itself to addressing the latest and most up-to-date cost estimate.

The study started with a literature review that provided a theoretical framework limiting itself to scientific publications and literature in NTNU's university library. Furthermore, a case study was conducted using documents associated with the project and conversations with representatives from Statsbygg. After finishing the thesis, it became evident that interviews with Statsbygg representatives about how they use DtC had been beneficial.

The quantitative calculation is limited to cost estimate four, and calculations are made with the 2020 kroner. The review of these figures was carried out continuously throughout the research process to ensure that the numbers were understood correctly.

1.5 Thesis Structure

This section will briefly overview the thesis's structure and content. Figure 1.1 shows the chapters of the thesis.

Figure 1.1: The structure of the master thesis.

Summary: A overview of the study completed and the conclusion obtained.

Sammendrag: A overview of the study completed and the conclusion obtained in Norwegian.

Preface: Practical information regarding the project's type, difficulty, and background. Furthermore, the thesis' major topic and motivation are also introduced.

Acknowledgement: Acknowledge to contributors and people involved in the thesis.

Abbreviations: Presentation of the shortened words or phrases used in the thesis.

1. Introduction: The thesis' background and motivation, problem description, research questions, limitations and thesis structure.

2. Theoretical Background: Theoretical and conceptual framework for the thesis and the basis for the analysis and discussion.

3. Methodology: A brief description of the research design and processes. This includes a systematic literature review, case study, data analysis, quantitative calculation method, and an evaluation of the research's quality.

4. Case Study: The case study delves into the details of the case. This includes a description of how Statsbygg applies the theory from the theoretical background in the NTNU Campus Collection and how they plan to do so further in the following implementation.

5. Analysis of the Results: The calculated data is presented and analyzed compared to the simulation done by Statsbygg.

6. Discussion: Presented findings are discussed; in light of the theoretical foundations in Chapter 3 and the research questions presented. A discussion of alternative approaches to reduce project uncertainty factors is also included in this chapter.

7. Conclusion: Sums up the whole thesis and concludes on the results.

Chapter 2

Theoretical Background

There is not much written about projects that use the DtC approach in the literature. Therefore, the literature review describes the application of this method and which projects it is suitable for. The chapter also addresses the difference between DtC and traditional project management and experiences with the method.

Furthermore, the study focuses on cost estimation and uncertainty analysis. This section deals with the estimation process and concepts within cost management. In addition, the chapter examine methods within uncertainty analyses and how to evaluate these results.

2.1 The Design to Cost Method

This section will look at how DtC can optimize and manage the development and implementation of large government projects.

2.1.1 Value-Driven Project Development

Projects are initiated to fulfill a need. A new building, for example, will facilitate better collaboration and more efficient office operations, resulting in improved services. The construction of a new road will improve traffic safety and save travel time.

The goal of value-driven project development is to coordinate the activities throughout the project and further maximize the investment's value. All major project decisions should be based on the project's overarching goals and value-creating criteria. Nonetheless, it has been observed that a lack of defined strategic goals, appropriate expertise, and consistent incentives frequently prevents projects' potential value from being realized (Lilleland-Olsen et al., 2021).

Value-driven project development entails the proper definition and execution of the project and the optimization of the company's strategy, organization, and processes. This requires strong leadership and collaboration between financier, user, and developer.

Figure 2.1 illustrates the essential work processes in value-driven project management. Iterative work procedures are used to assure value optimization.

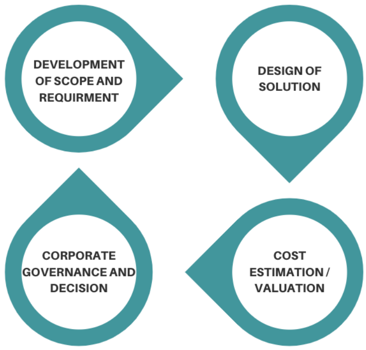

Figure 2.1: Illustration of an work process in value-driven project development.

2.1.2 What is Design to Cost?

DtC is a project management method for getting the most out of a limited budget. This method may be appropriate for projects when cost takes precedence over time and quality as a performance indicator, such as when no content or scope is specified. The strategy supports the above-mentioned value-driven project development.

Finansdepartmentet's guide for the usage of DtC (2021) states that there is no established professional definition of the term *DtC*. They define a framework for the usage of DtC in projects in the government sector and describe how the method as a project strategy differs from other strategies. As many definitions of DtC sounds somewhat alike, it has been chosen to use Finansdepartementet (2021) definition of the method;

> "DtC is a project strategy where a *binding financial* framework is established at an *early stage* in the planning within which the project

is to be carried out. The goal is to achieve the *highest possible benefit* within the set framework".

2.1.3 Traditional Project Management versus Design to Cost

Traditional project management is based on a sequential work process. Before the next step may begin, the previous one must be completed, as shown in Figure 2.2. Traditional project management usually entails determining a cost and management structure based on recommendations from Quality Assurance 2 (QA2). The contract price is based on the computed P85, while the cost baseline is based on the P50 value. In a traditional project management model, one has a portfolio mindset, which means one expects some projects to be above the cost baseline and others to be below it. Overall, the portfolio is predicted to gravitate toward the total of all of the P50 values of all the projects.

In DtC, the contract price is established earlier to encourage optimization during the preliminary project phase. After this phase, a management objective is established, for example, based on the calculated P50 at QA2, and it can be revised in the case of changed uncertainty throughout the implementation phase. As part of the Design to Cost project management model, the project's allocated costs are "absolute". The project must use effective management procedures to ensure that the contract price remains intact. Projects must have sufficient management reserves and cutting opportunities at all times. It is of the nature of the project that the uncertainty will reduce with time as the project progresses.

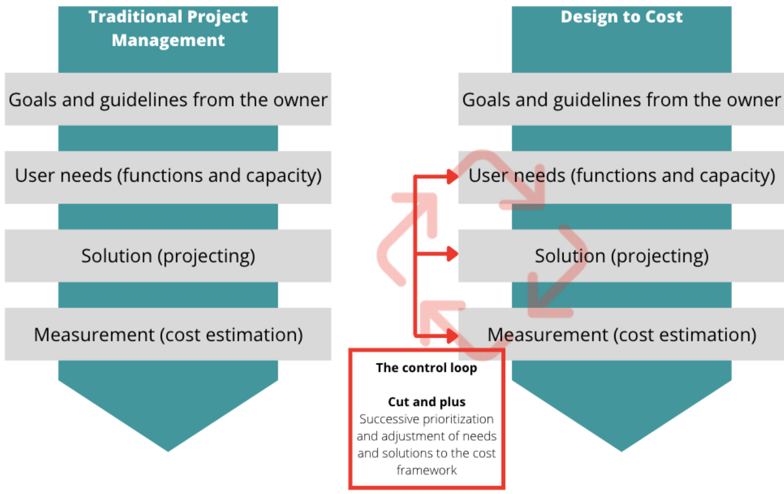

Figure 2.2: Illustration of an work process in Traditional Project Management and Design to Cost, inspired by Torgersen (2021).

2.1.4 What is Desirable to Achieve?

The government's efforts to improve cost management and place a greater emphasis on good processes for maximizing government investment in the early stages are based on research that indicates that project costs can rise dramatically without the usefulness rising in tandem (Finansdepartementet, 2021). This can, for example, be seen in Concept's work report 2019-4 (2019), where the usefulness of the projects reviewed is only calculated for both QA1 and QA2 in seven out of 34 projects. There is thus little documented that the benefit increases correspondingly with the project costs.

As previously stated, DtC is a project strategy that can achieve better cost control and benefit optimization in selected projects. The strategy encourages strong communication between the user and the project about needs and priorities, laying the groundwork for project optimization. A decision to carry out a project with DtC should be made as a guideline for the preliminary project phase, according to the guide for digitalization projects in the government's project model (2020). When planning has not progressed so far, there is more opportunity for maneuvering to identify new solutions and optimize the project.

DtC establishes a framework for the investment costs. The total cost of the measure to the government, on the other hand, is the sum of investment expenses, operation costs, and any other costs or profits over the life of the program (Finansdepartementet, 2021). Suppose the investment cost is the only consideration. In that case, it might lead to sub-optimal solutions by selecting solutions that lower the investment cost but increase the overall lifetime expenses, such as increasing operational costs. The lifetime costs are essential in determining whether a project's overall cost control is successful. Even if DtC is applied, it is critical to pay close attention to the project's long-term costs.

2.1.5 Suitable Projects

A characteristic of DtC is that cost estimation is central. This indicates that projects where cost is prioritized over time and quality, as a performance indicator, can be good candidates for DtC. Suppose cost is the highest priority, and the project must be optimized within a given framework. In that case, it will lead to different dynamics in the project than when quality takes priority, and strict requirements are defined. However, this does not mean that all projects where cost ranked as the highest performance target are suitable for DtC; instead, projects with time or quality ranked as the highest performance target are ineligible. As stated by Retolaza et al. (2021) there exist a lot of different methodologies for obtaining accurate cost estimations for projects. Finansdepartementet (2021) also confirms that there is no documentation of unique properties of projects that are better suited for DtC. Size, complexity, known/unknown technology, the composition of stakeholders, and time and change risk are all examples of such qualities.

DtC can be particularly well suited to projects that require some flexibility. According to the Merriam-Webster Online Dictionary (2022), being *flexible* is

> "characterized by a ready capability to adapt to new, different, or changing requirements".

With this definition in mind, project flexibility includes preparations for managing both internal and external uncertainty, such as scope change management, iterative decision-making, and general adaptations due to uncertain funding (Olsson, 2009). DtC can be preferable for projects that require substantial cuts and plus lists. It is reasonable to expect that the content of the cut and plus lists will be produced during the project time. Flexibility in a project refers to the ability to move functions totally or partially into and out of the project scope and the choice of standard or alternative methods for completing a task that may impact costs. DtC can also be used to choose a project's ambition level.

Finansdepartementet (2021) also states that DtC can be associated with agile development in digitalization projects to a certain extent. According to Finansdepartementet (2021), agile development has shown to give good results in ICT projects. The logic of the DtC method coincides in part with agile development, and ICT projects can therefore be well suited for DtC.

2.1.6 Core Project and the List of Cuts and Pluses

If a project is to succeed with DtC, it must first be determined which aspects of the project are the most critical to complete. This activity is an essential component of preliminary project optimization, and it entails identifying a core project and prioritizing additional functions and qualities. Simultaneously, it must be planned how the project can be scaled up or down in response to cost changes. This is referred to as scope management using cut and plus lists.

By core project, it is meant the bare minimum of functions and qualities required for the project to meet defined framework conditions and goals and provide the desired function to the end product. The core project can be defined by establishing "need-to-have" requirements for necessary functions, impacts, or performance. Additional features and qualities that will be important but not strictly necessary can be defined as "should" requirements and should be added to a priority cut list. As shown in Figure 2.3, the core project and cut list are included in the planned project scope, which must be included within the DtC framework. Additionally, a list of new characteristics and attributes is established and added to the priority plus list. The plus list contains functions and qualities that will raise the project's net benefit if the actions are performed. These are referred to as "nice-to-have" requirements.

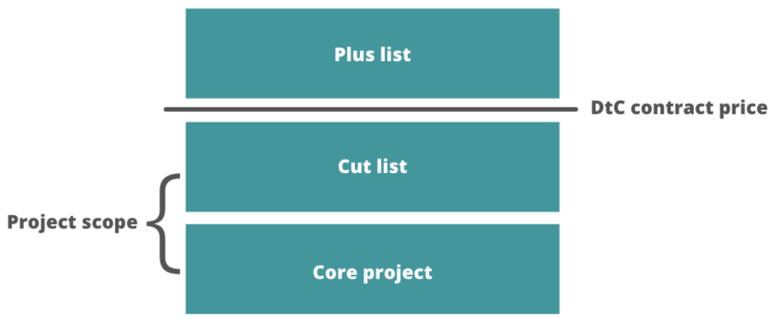

Figure 2.3: Illustration of the project scope where measures can be included from the plus list if there is enough capacity.

The cut and plus lists can be considered one priority list in practice. As a result, the cut and plus list becomes a comprehensive alternatives list, with elements prioritized based on need and the relationship between costs and benefit. Measures from the cut list must be removed from the project scope and added to the plus list if the project is likely to exceed the DtC contract price. Measures from the plus list can be included in the project scope if the cost development allows them. Berg et al. (2021) points out that projects that perceived the benefit plan as important resulted in better project success than other projects. For this reason, having a detailed plan for how the benefit is realized, rather than just which benefit should be realized, is crucial. The weighted factor in Berg et al.'s (2021) analysis was realized benefit, but they also included cost- and time control. In the same way, a cost development plan such as the cut and plus list can make the project perform better than other projects.

During the project, the scope of the cut and plus list and what is specified as the project scope will change. This is dependent on how cost-effective the project is, how the uncertainty evolves, and which measurements from the cut and plus list are accessible at the end. The DtC contract price and uncertainty will always determine which things are within the project scope (but on the cut list) and outside (and thus on the plus list).

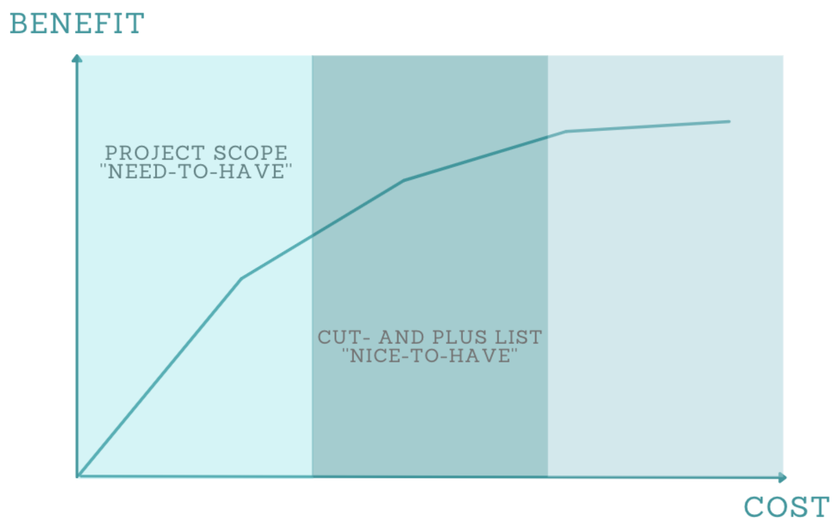

Figure 2.4: Illustration of how cost and benefit are affected during a project, Figure inspired by Finansdepartementet (2021).

When dealing with optimization within the DtC framework, there must be a good correspondence between the project requirements and the priorities. "nice-to-have" requirements can be included in the priority cut and plus list, but "the project scope must address "need-to-have" requirements.

As the project's cost rises, the benefit of the increased project scope often decreases. Figure 2.4 shows how the process of a project is according to cost and benefit. The elements within the core project provide significant benefit concerning costs. Within the core project, numerous elements provide considerable value in terms of cost. Regarding the cut and plus list, continued scope increases will result in a more excellent net benefit, but to a lesser extent. Increasing scope after a certain cost level offers little additional benefit, as illustrated by the gray field to the right in Figure 2.4.

2.1.7 Experience with the Method

The DtC method has already been applied to government construction projects, such as the "Police's national emergency preparedness center". The goal of this project was to facilitate, prevent and deal with extraordinary incidents and crises and create security for the population. In 2015, the project was given a contract price of NOK 2.5 billion. The price-regulated contract price was estimated to cost NOK 2.8 billion when completed in 2020. The project was realized for NOK 2.69 billion (Lilleland-Olsen et al., 2021). According to Whist and Hjelmbrekke (2018), a fundamental reason for avoiding typical cost growth from QA1 to QA2 was the implementation of DtC as a primary methodological measure. Instead, the project's budget was cut by about 15%. It is noteworthy that the project's cost control did not come at the expense of the project's quality. Dimensioning impact targets were reached, as were all "need-to-have" and "nice-to-have" requirements.

2.1.8 Project Control and Optimization

For a DtC project to succeed, it must be completed within the DtC contract price and delivered on schedule and in satisfactory quality. It is essential to have clear guidelines from the Ministry of Ownership for preliminary and later implementation projects in order for the project to succeed.

As part of the preliminary project assignment letter, the DtC contract price should be clearly outlined, including any societal goals, impact goals, and framework conditions. It is recommended that the preliminary project establish more detailed requirements, like initiating the project scope based on "need-to-have" requirements and determining cuts and options based on "nice-to-have" requirements. Prioritization of the project scope and measures on the cut and plus list must be evaluated based on needs and the cost-benefit relationship. Additionally, there must also be a link between the project's prioritization of functions and quality and the profit realization strategy for the project. According to Berg et al. (2021), a weakness for some projects is the lack of involvement of external benefit owners when it comes to getting the most out of the measures implemented. As a result, the Ministry of Owners must have the capability to participate and the ability to make timely judgments.

The project needs to be optimized within the DtC contract price throughout the preliminary and implementation phases. It must be planned how the project can be scaled up or down according to the cost development. Finansdepartementet (2021) states that the Ministry of Owners should set the following requirements for the preparation of the cut and plus lists:

- The list of cuts and pluses must contain information about the costs and utility of the measure and when a decision to implement the measure should be made (possibly the last one may appear from the schedule).
- The list of cuts and pluses must have a priority that should be anchored with the Ministry of Owners so that decisions about which functions may have to be cut, or can be taken in / out of the project, can be made quickly. It may be appropriate to set milestones for changes in scope within the cut and plus lists (i.e., the stated time for the latest date for the implementation of cuts and additions from plus lists).
- The organization of the project should be designed to ensure the involvement of users in this process.

It is also crucial that the project has strong estimation abilities and a plan to deal with uncertainty. The cost estimates, including the uncertainty analysis, must be updated frequently, and the estimation team should be a vital member of the project management team. This must be adjusted for milestones for scope modifications (decisions on cuts/additions) and essential decision-making processes, such as approval of zoning plans, licenses, or Ministry of Ownership decisions.

2.2 Cost Estimation and Uncertainty Analysis

Behind every completed project is a cost estimate. This says something about whether the project has managed to stay within budget and how successful the project is evaluated to be. The uncertainty analysis deals with tools for estimating uncertainty and evaluating the result.

2.2.1 Terms within Cost Estimation and Management

All project participants must have a common, defined conceptual framework. Figure 2.5 reflects some of the concepts related to cost estimation, and is from Finansdepartementet's supervisor for Common conceptual apparatus QA2 (2008). A definition of each topic is also included to help build a consistent conceptual framework for this thesis and is defined in the mentioned guide:

- **Base estimate** is the deterministic sum of probable cost for all specified, specific calculation elements/cost items at the time of analysis.
- **Unspecified** are costs that are known to occur but which have not been mapped due to a lack of level detail.
- **Basic Cost** is calculated from professional and estimation resources in the project and consists of Base estimate + Unspecified.
- **Contingency** are the expected cost contribution from estimate uncertainty and event uncertainty. The potential for contingencies usually is most significant in the early phase of the project and decreases as the project develops.
- **Expected cost** is the sum of basic cost and contingency. P50 is often mentioned (although there is a slight discrepancy between the number sizes).
- **Management reserve** is a provision to achieve the desired security against exceeding the contract price. It is not expected that this item will be used in the project, and the allocation is managed at a higher organizational level than the project manager.
- **Contract price** indicates how much the decision-makers have set aside to finance the project. This quantity contains a management reserve and is often based on a calculated P85 value.

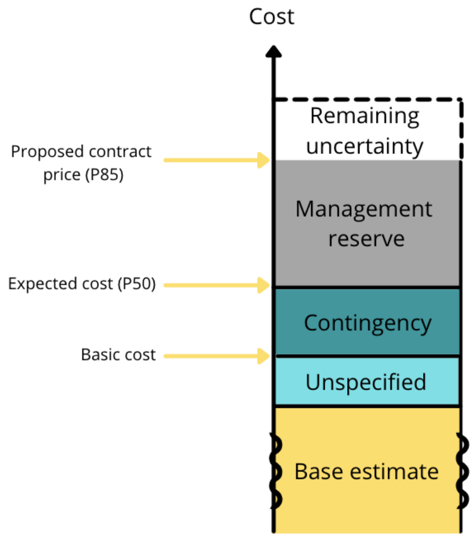

Figure 2.5: Relationship between concepts in cost estimation, inspired by Finansdepartementet (2008).

2.2.2 Estimation Process

Carrying out an estimation process takes place over a more extended period. Dreveland (2013) outlines some key stages for achieving the most precise mathematical result possible:

1. Refine the calculation and make assumptions.
2. Set up structure for base estimate.
3. Find uncertainty factors.
4. Define the basic assumption for each uncertainty factor. Model
5. Quantify base estimate.
6. Assess and quantify uncertainty factors.
7. Consider covariation.
8. Calculate.
9. Evaluate result.
10. Refine.

The first seven steps illustrate the model used during an uncertainty analysis. These steps are often very similar regardless of the choice of method. A brief description of each step follows:

Step 1: The procedure should begin with a clear outline of the project that will be estimated. This includes; what is part of the project and what assumptions are to be utilized for the estimate.

Step 2: Principles such as stochastic independence, estimate structure, and covariation set up the base estimate. The posts, however, have not yet been quantified.

Step 3: It is now time to find uncertainty factors, namely what is expected and what should be extracted from each post. Brainstorming or lists with conventional uncertainty factors are frequently used as tools in this situation.

Step 4: When uncertainty factors are used in a computation, the goal is to remove the uncertainty from the base estimate. This depends on first having a fundamental assumption in place for each of the uncertainty factors to calculate the base estimate correctly.

Step 5: After calculating the basic assumptions for each uncertainty factor, it is time to calculate the base estimate using a triple estimate for each post. Here, extreme caution should be exercised in determining the spread of uncertainty on each post.

Step 6: It is time to examine and quantify the uncertainty factors after the base estimate has been quantified. One considers what might happen concerning the basic assumption employed in the base estimate and how much of a difference there will be.

Step 7: After working through the estimate and quantifying the elements, one can examine whether there still are dependencies between posts that have not yet been captured. One can include covariation in the estimated model if this is the case.

Step 8: This step consists of calculating the result of the estimation. Depending on the method used, this usually consists of waiting while the simulation runs.

Step 9: After completing the computation, it is time to determine whether the result is usable and reasonable. Is the uncertainty contained within the requirements that have been established, and has a reasonable sum been set aside?

Step 10: If the computation result is undesirable, one must make changes. Suppose the level of uncertainty is too high in proportion to the requirements. In that case, further information should be gathered to minimize the level of uncertainty associated with the input values and to be able to detail the calculation further. It is important to remember that reducing the uncertainty in an estimate does not mean dividing posts, removing uncertainty factors, or similarly. Unless one is sitting on information that indicates that this is the right thing to do, one has only removed the uncertainty on paper.

2.2.3 Uncertainty Analysis

Austeng et al. (2005) describes an uncertainty analysis as a systematic method for identifying, describing, and calculating uncertainty. Uncertainty analysis thus distinguishes between the actual uncertainty picture on the one hand and analysis of measures and follow-up of the analysis results on the other hand.

An uncertainty analysis often contains a qualitative and a quantitative part. The qualitative section highlights the uncertainty and identifies the parts of uncertainty, their causes, and where they are anticipated to work. It further describes what impact options are available and a detailed description of the outcome space. The quantitative part, on the other hand, includes calculating numbers of probabilities, outcome spaces, and any degree of impact (Austeng et al., 2005).

Uncertainty analysis can be done in a variety of ways. The method used is determined by the aim of the analysis and whom it is performed for, who performs it, and what sources of input are accessible. Within cost estimates, a stochastic cost estimate is used when dealing with projects that contain uncertainty. There are two principal ways to calculate stochastic cost estimates; either by using analytical methods or using simulation tools (Dreveland, 2013).

2.2.4 Successive Calculation versus Monte Carlo Simulation

The successive calculation is an analytical method that uses approximation techniques to provide a result that is sufficiently accurate for cost estimation (Dreveland, 2013). Calculating expected values and standard deviations is the basis of the procedure. This is because one anticipates that the calculation's final result will be normally distributed. The central boundary theorem states that the sum of a large number of stochastic values with random distributions will tend to be normally distributed (Dreveland, 2013).

Monte Carlo simulation is a more "raw-power" method. Instead of performing the calculation once, one repeats it hundreds or thousands of times (Drevland et al., 2005). As a result, this procedure requires the use of an appropriate computer tool. The simulation engine generates new numbers for all uncertain quantities and performs calculations for each iteration. In this way, even the most extreme cases will be represented in the total.

2.2.5 Evaluation of the Results

The main output of a computation is a probability distribution for the overall investment cost of the project. This is often represented visually as an s-curve, as shown in Figure 2.6 (Austeng et al., 2005). In addition, it is common to extract relevant target numbers. This usually refers to the expected value, median (P50), standard deviation, and P85 (Dreveland, 2013).

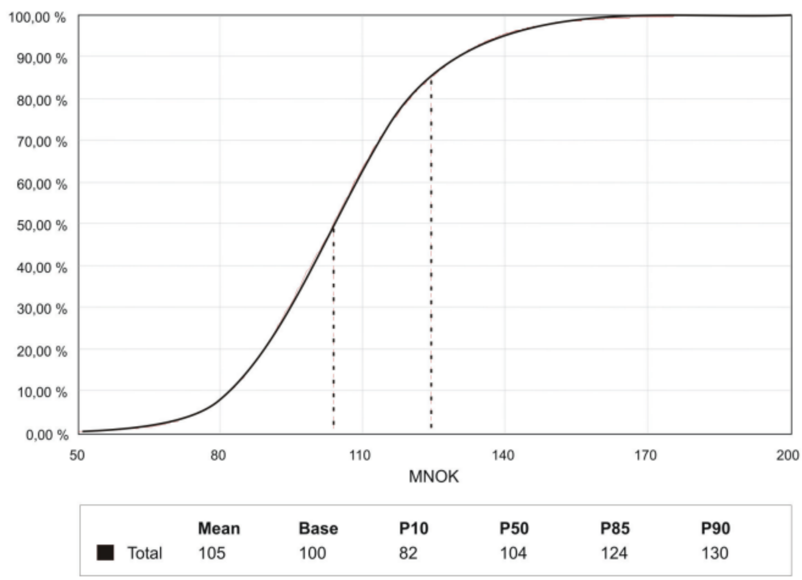

Figure 2.6: Example of a cumulative s-curve with corresponding P(50) and P(85) values retrieved from (Austeng et al., 2005).

A project is typically based on a sum that is higher in percentage than the expected value. This increases the likelihood that the budget will be fulfilled even if there is a negative effect of uncertainty. A management reserve is then made in addition to the project's projected cost (Dreveland, 2013). P85 value is commonly used in large government investment projects for the expected value plus the management reserve.

In addition to the s-curve, a tornado diagram is commonly included in the results.

The diagram shows which components contribute most to the uncertainty and to what degree each post contributes to it. Overall, the s-curve and tornado diagram help visualize how much the project will cost, how much uncertainty surrounds this amount, and where the uncertainty lies within the project.

Chapter 3

Methodology

This chapter explains the procedure used in the thesis and the limitations that have been made. This includes which approaches and models were used to ensure relevant and high-quality data.

It is essential to distinguish between method and methodology. The methods utilized to build the methodology are highlighted in this chapter.

3.1 Research Design and Method

Abutabenjeh and Jaradat (2018) makes a distinction between research design and research method. The research design is a plan for investigating a problem, whereas the research method deals with how to collect and analyze data. The different strategies for research could either be quantitative, qualitative, or a mixed-method (Abutabenjeh & Jaradat, 2018).

The master's thesis was first formed through a collaboration between Statsbygg and NTNU in the form of the campus merger. This developed into a study involving the Design to Cost method they employ in this project. Following an initial discussion with Statsbygg, a literature review was conducted to build a knowledge base and analyze relevant literature, research data, and cost development. After analyzing how Statsbygg uses the DtC method through a case study, the thesis was then further centered on the management reserve of the Campus Collection project.

According to Creswell and Creswell (2018), quantitative research is advantageous when the main goal is to test

> "theories deductively, build in protections against bias, control for alternative or counterfactual explanations, and being able to generalize and replicate the findings".

Following the case study, the cost estimates acquired from Statsbygg were analyzed. The next step was to perform quantitative calculations to see if this could reduce the project's management reserve. Lastly, the findings were analyzed and discussed before a conclusion was made.

Figure 3.1 illustrates the research design of the thesis.

Figure 3.1: The procedure for the master thesis.

3.2 Literature Review

Oliver (2012) states that the overall purpose of a literature review is to demonstrate the research of a topic and help the reader to understand how your study fits into a broader context. One can then create a common theoretical framework as a basis for further analysis. As part of this thesis, it was necessary to develop knowledge about the DtC model and cost estimation.

There are several ways to conduct a literature review. Snyder (2019) distinguishes between three main approaches; systematic review, semi-systematic review, and integrative review. A particular research question can be answered using all of these review strategies.

One of the main differences between the strategies lies in the review's focus. The goal of the systematic review is to find and evaluate relevant research and collect and analyze data from that study. It also seeks to find all empirical data that can answer a particular research question (Snyder, 2019). On the other hand, the semi-systematic review examines how a field has progressed over time or how a topic has evolved across research traditions. This can be more beneficial when studying a broader topic. The integrative review is closely associated with the semi-semantic review; however, it focuses on introducing new perspectives to the theoretical foundation of the study topic (Snyder, 2019).

In this thesis, a systematic review method got conducted. The literature review aimed to investigate theories about how DtC could be used and operationalized to optimize and manage the development and implementation of large government projects. The study aimed to answer research questions within cost development and downscale uncertainty elements.

Based on the research questions concerning DtC and cost estimation, a systematic literature review was conducted to answer these. The goal of the systematic literature review was to build a knowledge base in cost distribution and cost development, particularly looking at management tools.

3.2.1 Search Engines in Literature Review

The literature review began with a broad search to better understand the various themes and avoid filtering out valuable materials. Three search engines were chosen to guarantee that the material was reliable and related to the thesis. One was Oria, NTNU's book, article, journal, master's thesis, and doctoral dissertation search engine. Google Scholar was also used to search for articles, dissertations, summaries, and more. The last one was Science Direct, a full-text resource in science, medicine, economics, and technology. These search engines allow users to choose reports and literature based on search criteria such as author, keywords, and publication date. It is also possible to search for the subject area that the article should include. Oria also has a feature that allows one to request books from the local library. During the literature review, this method was also applied. This was an efficient approach to searching the internet for non-existent materials.

3.2.2 Completion of Literature Review

Snyder (2019) describes that using systematic methods when assessing relevant material can reduce uncertainty so that conclusions and decisions can be made based on reliable findings. Bartels (2013) has created a successful systematic search strategy for articles, books, and other sources. The strategy consists of eight steps and was chosen to carry out the literature review:

1. Define your problem.
2. Create a search strategy.
3. Select the right bibliographic databases.
4. Search.
5. Select suitable references from those that have been retrieved.
6. Assess whether the search was satisfactory.
7. Redesign the search strategy and/or choose other databases/search tools, where needed.

8. Repeat steps 2–6, if necessary.

Step 1: The research topics were created early on to help the thesis find a focus. On the other hand, as the literature was examined, these were changed. The first research questions was related to portfolio management within a DtC grant. Furthermore, the research questions progressed regarding cost estimation, cost allocation, and uncertainty analysis. As a result, the research questions outlined in Section 1.3 Research Questions were developed.

Step 2: From the very beginning, relevant documents concerning DtC, value-driven project development, and the research report concerning the "Police's national preparedness center" were supplied from Statsbygg. Based on this, a chain search, also known as "snowballing", was conducted, which involves starting with a reliable source and then looking at and reading the references used. After discussing what data it was possible to obtain from Statsbygg, the subject area was sharpened towards cost estimation and cost development within a DtC project.

Step 3: The search engines used were Oria, Google Scholar, and Science Direct, as described in Section 3.2.1 Search Engines in Literature Review. These are all recommended by NTNU to find literature and other materials and were therefore found as reliable databases.

Step 4: To ensure relevance, keywords and phrases were used in the selected search engines. This could be Design to Cost, cost estimation, and uncertainty drivers. A review of articles published by NTNU was also examined, especially those published by the Concept program.

Step 5: The article's summary and conclusion were first read to guarantee that the selected material was relevant to the topic area. The theories and sources were also investigated. The publishing year and affiliation were additionally evaluated to ensure the quality of the literature.

Step 6: The document was considered safe if published in a peer-reviewed journal or another scientific source. However, if it was published alone, the sources and the author had to be investigated further.

Step 7: All of the findings from the literature review were compiled and compared in this step. Further research or an assessment of the literature's relevance and reliability was required if there was any uncertainty or gap in the study. If necessary, steps 2-6 had to be repeated with additional references.

Step 8: If an additional theoretical foundation was required after step 7, the steps were reviewed once more.

3.3 Case Study

The theoretical background established a framework for what needs to be in place to manage a project with DtC. Based on this information, it was decided to investigate how Statsbygg implements the NTNU Campus Collection using the DtC approach. As a result, a case study was chosen as the method of choice. A case study was selected because it is ideal for specializing in a specific area while also contributing something new to the field.

The purpose of a case study is that the researcher can search the depths of a unit and thus gain a more detailed and deeper understanding of a phenomenon. Case studies are beneficial when seeking to explain some contemporary circumstance or need an extensive and "in-depth" description of some social phenomenon (Yin, 2018). Such studies are also beneficial for answering "how" and "why" questions. Based on the research question regarding how Statsbygg uses the DtC method, it was reasonable to use this type of case study in this thesis.

Figure 3.2 describes four different design strategies for a case study. Since there are few research units and variables in this thesis, and it was desired to analyze and better understand a phenomenon in its natural setting, a case study was chosen. Thus a single case has been selected using a single unit analysis. The task is carried out in the top-left quadrant of Figure 3.2. The advantage of a single-case design is its flexible design, which means one can change research questions and data collection methods as the study develops. The case study collects information based on previous reports associated with the project and data obtained from Statsbygg. The information relates to methods used to make sure the project's cost is maximized within the guidelines established by DtC.

THE RESEARCHER'S DELIMITATION	SINGLE-CASE DESIGN	MULTIPLE-CASE DESIGN
Single unit analysis (holistic)	The researcher receives information from a single unit (an individual, a program, an institution, a group, an event, or a concept) within the study of a limited system	The researcher receives information from a single unit within the study of several systems. Each case study consists of the entire study.
Multiple units of analysis (embedded)	The researcher receives information from several units (several individuals, programs, groups, etc.) within the study of a limited system	The researcher receives information from several units within the study of several systems. Each case study consists of the entire study

Figure 3.2: Four design strategies based on Yin's (2018) framework for case studies.

The conceptual basis for how a DtC project should be established is the founding principle for the case study. The case study will also serve as a foundation for reviewing earlier cost estimates and discussing how the process should be managed in the future. This is to establish a clear grasp of what is required to keep the estimations within the targeted contract price.

3.4 Data Collection and Analysis

The research is based on comparing actual final costs with management frameworks, cost limitations, and cost estimates, which include estimates from uncertainty analyses. This section explains how the collected data were examined.

The received data contained several large spreadsheets with much information. For each completed cost estimate, the Microsoft Excel sheet contained, among other things, a compilation basis, the project breakdown structure (PBS), updated management reserves, a comparison with the start-up of the preliminary project, and a list of cuts and options. The mentioned information became most important in the analysis. Besides a spreadsheet, a Power BI overview of the costs with development from cost estimate one to four was also received. This contained the same information as the spreadsheets but with a more visual presentation of the data.

Since the spreadsheets were so large and complex, much time was spent figuring out where the various costs came from and how they had changed over time. There were many Teams meetings with Statsbygg employees and numerous email conversations.

3.5 Quantitative Method

The calculation process is based on Dreveland (2013) last three steps for preforming a estimation process, as presented in Section 2.2.2 Estimation Process. Setting up the fundamental computation and determining the uncertainty factors are the first steps. Because this computation is based on earlier cost estimations with corresponding uncertainty, this thesis focuses on the quantitative parts of the process, namely steps 8-10. These steps deal with calculation, assessment of the result, and refining. Results and refining will be further presented in Chapter 5 Analysis of the Results and Chapter 6 Discussion.

Two different methods were performed to lower the management reserves from cost estimate four. Both methods employ the same calculation procedures, but the first method assesses the entire project. The second method deals with each subproject separately and then adds up the expenses to correspond to the overall project. The calculation method will further be presented in Chapter 5 Analysis of the Results and the assumptions made. The user equipment was not included in the calculations since it was not represented in the cost estimate spreadsheets. Therefore, it was difficult to make further calculations when the basic estimate was unavailable.

All calculations are done using June 2020 kroner. The Excel sheet from Statsbygg shows that the numbers are in 2018 kroner, so these have been recalculated by using Equation 3.1, as presented below:

$$n = 2018 kroner * (1 + 4,31\%) \tag{3.1}$$

where n is the amount in June 2020 kroner.

Chapter 5 Analysis of the Results will contain the most detailed descriptions of the computations for the successive calculation. This is because if the calculating method is presented right before the results, it will be easier to grasp the reasoning around the findings.

3.6 Evaluation of the Research's Quality

Validity, reliability, and generalizability are essential principles to consider when evaluating the quality of a research design. These conditions ensure that the study can contribute to valid conclusions with low uncertainty and few misunderstandings.

3.6.1 Validity

Validity refers to how well the information gathered is relevant to the literature being researched (Ghauri & Grønhaug, 2005). According to Dalland (2012), it is also essential that the collected data are relevant to the problem description of the study. Validity can thus be utilized to assess the quality of the sources used in the literature review and analyze the findings from the quantitative calculation.

During the work on this thesis, two measures have been taken to increase the validity. The initial step was to gather data from prior studies, such as NTNU's Concept program and related publications. The second measure was holding meetings with NTNU and Statsbygg supervisors to review data and results. It is assumed that all of the data received from Statsbygg is considered valid.

The last measure was considered the most crucial in terms of reducing validity. This was due to the critical importance of ensuring that the correct data was used in the calculations. Additionally, to guarantee that the findings were always relevant and valid for the research.

Good techniques, according to Austeng et al. (2005), are a vital part of delivering valid and dependable findings in an uncertainty analysis. It is about guaranteeing correct and relevant input, processing input, and presenting findings that represent real-world conditions to the extent that they are clarified. The fact that the management reserve during the successive calculation is significantly larger than Statsbygg's estimate indicates that the validity of the calculation may be limited. It was assumed that there would be some discrepancy between the two calculations, but a deviation of NOK 1.2 billion is significantly higher than predicted. One or more calculation errors may exist that neither the supervisor nor the author discovered.

3.6.2 Reliability

Reliability refers to how trustworthy the information is. This can be done by evaluating if the tools one uses produce consistent results every time one measures an event. In quantitative studies, it is common to analyze whether the study is verifiable and whether a new study would provide the same results. In other words, high reliability means that the study can be replicated, and the results would be the same (Costner, 1989).

It is crucial that the measuring tools accurately capture what one are trying to compute in quantitative research. During the successive calculations in this thesis, a spreadsheet example generated by Concept was used to estimate total cost. Along with this, the formulas from Dreveland (2013) were applied. These formulas are also presented in Section 5.1 Completion of the Successive Calculation.

3.6.3 Generalizability

Generalizable outcomes, according to Halvorsen (2008), are those that are valid for a larger number of similar circumstances. This study's generalizability can most likely be debated. The study's primary goal was to calculate reduced but reliable costs for the NTNU Campus Collection project. The goal is specific for this project, but the methodology can most likely be applied to other large, similar projects.

Chapter 4

Case Study

This chapter presents the case description regarding how Statsbygg applies the DtC method in the ongoing NTNU Campus Collection project and how they plan to use the framework further in the implementation phase. A large portion of the information provided in this chapter is based on Statsbygg's document for describing the process and model for Design to Cost through value-driven project development used in the NTNU Campus Collection Project (2021b). It is critical to understand how Statsbygg works during this project to make subsequent improvements and, ideally, improve their cost development. On this basis, the case study answers the following research question:

RQ1 *How do Statsbygg implement DtC methods in the NTNU Campus Collection?*

4.1 Management Model

The project has received general guidelines for cost management from both letters of assignment from the ME and ME's overall management document for the project. These include developing a model and procedures for the success of DtC.

4.1.1 Management of the Overall Project

Figure 4.1 illustrates Statsbygg's suggestion for a management approach that will support ME's requirements. The project considers the given limit values suitable for providing sufficient security to complete the project within the contract price.

The Figure is divided into two phases: the preliminary project- and the project implementation phase.

	PRELIMINARY PHASE	IMPLEMENTATION PHASE
Margin to cost framework	• Calculated P85 from uncertainty analysis shall at QA2 (step 2) be a minimum of NOK 200 million below the contract price	• Calculated P85 from uncertainty analysis shall be a minimum of NOK 200 million approved contract price • The requirement must be assessed continuously throughout the implementation phase. It may be relevant to reducing the difference between the calculated P85 and the contract price late in the implementation phase.
Cut and option list	• In the preliminary project at QA2 stage 2, the cut list must contain cut measures that constitute a minimum of 5% of the contract price • The option list is actively used to highlight measures that can provide added value if the project's finances allow it	• The cut list must at all times contain cutting options that correspond to a minimum of 5% of the cost to the remaining scope of the project. • The option list is actively used to maintain the opportunity to realize added value if the project's finances allow it.
Powers of attorney	• The project management at Statsbygg, in collaboration with NTNU, is responsible for identifying cutting opportunities that ensure that costs are kept within the contact price • Proposals for cuts and incorporation of options shall be prioritized by NTNU based on data from Statsbygg • Implementation of cuts or cancellations of options is submitted to the client (ME) for approval. Value management and profit realization are very important and must appear on the decision basis	• At the start of the project after QA2, management goals are established where the project management at Statsbygg has the contingency as a reserve. The budget framework should be revised after an updated uncertainty analysis. This means that the cost baseline / P50 is expected to be able to increase with reduced uncertainty. This is an important prerequisite for being able to maximize value for the user • Reserves between management goals and the contract price are managed by the project owner at ME • Process for cuts, options, and approval as described for the preliminary project phase
Follow-up	• The total forecast for the entire project shall be updated quarterly by uncertainty analysis, or in connection with milestones. Uncertainty is also assessed in connection with monthly reports. Changes in the cost picture must be explained	• The total forecast for the entire project shall be updated monthly with an assessment of uncertainty in the project. Uncertainty analyzes are carried out as needed both per. subproject and total. Changes in the cost picture must be explained.

Figure 4.1: General guidelines for cost management, inspired by Statsbygg (2021b).

From the Figure, the limit value of NOK 200 billion has been chosen based on the experience from DtC implementation in the ”Police’s national emergency preparedness center”. The 5% of the contract price corresponds to the difference between P90 and P85 in the uncertainty analysis in May 2021.

4.1.2 Management of Subprojects

The project will be broken into subprojects by the PBS and the contract and implementation strategy during the preliminary project phase, potentially after QA2. A subproject is a small portion of a larger project that has its framework, organization, and work goals. The project's overall implementation plan specifies when and in what order the subprojects will be completed. The project's PBS can be adjusted throughout the preliminary project phase based on the project's selections and assessments.

The guidelines in the main project should be passed on to the subprojects to provide consistency, robustness, and predictability in the management of both total projects and subprojects. Ensuring that sufficient cutting opportunities are maintained throughout the project is a crucial prerequisite for developing an overall implementation plan.

The following are the overall cost management requirements for the main project concerning subprojects:

- Ensure that subproject project management adheres to the overall project management methodology.
- Manage the contract price for the subprojects, as well as the project's overall cost management.
- Update the project's overall cut and option list.
- Combine the subproject predictions into a total forecast for the project.

Since the project is still in its preliminary phase, it is unclear which framework will be assigned to each subproject compared to the overall framework. However, the following general principles should be utilized as a starting point:

- There must always be a reserve in the overall project to allow for subproject priority. This suggests that the subprojects are aiming for a P-value that is lower than the overall project's management target (the sum of reserves for the subprojects must at all times be lower than the total reserve in the project). Due to unique characteristics and uncertainties, subprojects may have different management requirements.
- The subproject must have an up-to-date cut and option list for its scope. The total of the cut list's measures must match the cut list's requirements for the entire project.
- It must be apparent when a decision must be taken to be able to apply cuts or exercise an option from the list of cuts and options. The scope of the

subprojects is decided by the main project's project management, which must be notified well in advance of this date.

- A monthly update of the total forecast for the subprojects is required, and a risk assessment. It is necessary to explain changes in the cost scope.

4.2 Management Tools

The project uses management tools maintained throughout the implementation to assist the DtC process. The following are some of the most essential.

4.2.1 Document Requirements and Gain Realization

The project's overall document requirements summarize the project's specifications and requirements. It also serves as a foundation for describing the project's construction requirements. The document should further overview the project's basis and traceability into the building schedule. The project can additionally prepare cuts and option lists based on the link between needs and overall objectives in the project scope.

During Statsbygg's project, the profit realization plan is crucial. The plan outlines how the NTNU Campus Collection project (new infrastructure and technology) benefits and how the roles and responsibilities that contribute to those benefits will be quantified. Each quality performance target is linked to the effect goals and the primary indicators in the gain realization plan to achieve the highest possible realization of the societal aim and the effect goals. Gains are realized by working methodically with quality performance targets during the preliminary project and implementation phases and basing this on project development (target analyses) for priority (cuts and options).

4.2.2 Cost Estimation, Uncertainty Assessment and Uncertainty Management

Cost estimating aims to ensure that the project scope always remains within the agreed-upon parameters, and cost estimates must therefore be obtained regularly. When a project's scope needs to be adjusted, a decision foundation can be formed by calculating expenditures on the project's many components or measurements (based on the PBS).

Cost development should be followed for both total cost and subelements. The same applies to benchmarking/comparison with relevant project references. The project is planning to carry out uncertainty analyses in connection with the publication of cost estimates, as described in Section 4.3 Today's Status. This is typically done quarterly or at essential milestones in the project. Besides providing a quantitative and qualitative assessment of the project's cost and uncertainty, the analyses should also identify any crucial decision points.

The work done between each uncertainty analysis is a critical success factor for the success of DtC. This work includes working systematically with the identification and implementation of measures that reduce risk and increase opportunity as it proceeds to reduce the uncertainty as it progresses. Priority uncertainties with measures should be recognized by project management and included in follow-up planning.

4.2.3 Documentation of Cost Estimates

Cost estimates must be documented, including the basis for estimates and how they came to be. This documentation is essential in ensuring a uniform understanding of the cost estimate. The estimates should also show cost development and comparisons with other projects. In line with this, the documentation should include the following:

- Summary of recent results: cost estimate and uncertainty analysis with comments.
- Estimate and area development.
- Overall description of the assumed concept.
- Project maturity (and possible estimate classification).
- Assumed progress plan.
- Assumptions, scope and limitations.
- Background for selection of unit prices.
- Estimation model.
- Estimation method.
- Benchmarking.
- Basic documents.
- Estimation team.
- Quality assurance.

4.2.4 Cut and Option List

Statsbygg is responsible for determining an appropriate decision basis to enable the project management on a cost-effective basis within the allocated funds/framework. This means a defined basic scope and appropriate level of security within the contract price. It is important for a cut and option list to be prepared and maintained, as well as an effective contract price to further secure the costs and optimize gains within the project's framework. The project is done in collaboration with NTNU. Statsbygg estimates the measures on the list, while NTNU as a user has the best sense of which measures provide the highest return on investment. Furthermore, the user is responsible for prioritizing the measures on the cut and option list and helping the project design and define the basic scope. It means that NTNU determines which measures can be cut, followed by those that should be included in the scope if the economy provides an opportunity for this. This is an essential part of value management for the project.

In an appropriate PBS, the work is supported by a list of cuts and options. The project uses a cut and option list to decide whether a measure will have a positive cost effect. At each decision time, an overall assessment is conducted. The cut list will include projected measures and are a part of the project scope. The option list displays measures that are desired by the user but are not prioritized as highly as the ones on the cut list. The measures are not implemented until it is decided to introduce them in the project scope. The ranking in the list is temporary, and it is not necessarily the next item on the list that is taken in or out. At each decision point, an overall evaluation will be made. The cut and option list are kept up to date throughout the process.

4.2.5 Delivery Planning

To establish success with DtC, it is crucial to deliver critical information in the project development at the right time. This requires excellent demands on the delivery of information, particularly in the programming and engineering processes. As the project matures, it is crucial to identify which deliveries are prioritized to achieve milestones. This gets the project on track and clarifies enough information as a basis for important decisions.

4.3 Today's Status

Cost estimates have been collected regularly to offer a basis for Statsbygg's success with DtC. In the current plans, the following assumptions have been made:

- An uncertainty analysis is performed twice a year for the entire project, including user equipment.

- Statsbygg updates cost estimates, including uncertainty analysis, once a quarter to maintain track of the project's cost evolution and provide a foundation for scope management. Specific times are adjusted according to project milestones.
- Extensive updating of cuts and option lists occurs at the same time as the cost estimate, i.e., once a quarter.

The cost estimates must be updated every quarter to keep track of the cost development. As of November 2021, four cost estimates have already been established. Figure 4.2 presents the preliminary milestones for the cost estimation development.

VERSION	PHASE	PROJECT STATUS AND ESTIMATES USE / PURPOSE	DATE
v1	Start-up	Update after start-up preliminary project	April 2021
v2	Downscaling	Main analysis basis for downscaling	June 2021
v3	Downscaling	Update 1 after downscaling	September 2021
v4	Downscaling	Update 2 after downscaling, basis / reference for cost management through the preliminary project phase	November 2021
v5	Construction program	User input for construction program obtained. Basis for prioritization	April 2022
v6	Construction program	Construction program completed and planning basis adopted. The basis for prioritization and sketch design	Oktober 2022
v7	Sketch- and preliminary project	Status spatial planning. Basis for prioritization and sketch design. Different maturation for different parts of the project. Assumed greatest maturity for infrastructure. Parts of the cost estimate are "bottom up"	December 2022
v8	Sketch- and preliminary project	Solution proposal sketch project. The basis for KS2. Parts of the cost estimate are "bottom-up"	March 2023
v9	Sketch- and preliminary project	Status sketch design and contractor involvement. Parts of the cost estimate are "below and up"	June 2023
v10	Sketch- and preliminary project	Status sketch design and contractor involvement. Parts of the cost estimate are "below and up"	September 2023
v11	Sketch- and preliminary project	The basis for a decision on the preliminary project (updated after QA2). Parts of the cost estimate are "bottom-up"	November 2023

Figure 4.2: Preliminary milestones for the cost estimation. Dates are based on the contract and implementation strategy. Figure inspired by Statsbygg (2021b).

In November 2021, the project provided a basis for quality assurance which, among other things, included implementation and contract strategy, as well as a basic scope with an associated cost estimate that is within the project's contract price. This estimate will be a basis for cost management through the preliminary project phase. During this phase, the cost estimates will gradually receive more information in line with the project's maturation.

4.3.1 Cost Estimation Four

The values from cost estimate four are used as a basis in this thesis calculation. This is because it is the most recent and updated cost calculation. Table 4.1 shows the base estimate, contingency, and management reserve, as well as the P50 and P85 values, which are all included in the cost estimate.

Key amounts		
Base estimate	**6 540 000 000**	
Contingency	1 249 000 000	19,1%
P50	**7 790 000 000**	
Management reserve	1 778 000 000	23%
P85	**9 568 000 000**	
The projects standard deviation	1 641 000 000	21,3%

Table 4.1: Results from cost estimation four performed by Statsbygg, rounded to the nearest million.

The anticipated cost is approximately NOK 9.56 billion, as shown in Table 4.1. The project's total value, including the user equipment, is NOK 10.94 billion, which is less than the absolute contract price of NOK 11.032 billion. The previous cost estimates tended to be higher than the budgeted amount. Still, once some areas were reduced, and the quality of several buildings decreased, Statsbygg managed to stay within the contract price.

According to the status statement outlining the project's cost level (2021d), the most crucial uncertainty for cost estimate four was "U2 Authorities, stakeholders, and interfaces" or "Myndigheter, interessenter og grensesnitt" in Norwegian. That is uncertainty regarding changes in central and local government laws and regulations and uncertainty concerning government processing. This contains the outcome of the zoning plan work, the framework application, and other permits from Trondheim municipality and the authorities. These include order restrictions, degree of utilization, antiquarian considerations, and other relevant requirements. Interfaces to other projects run by NTNU or other parties are also included (Statsbygg, 2021d).

Statsbygg performed the cost estimate by first determining costs for each subproject and then adding them together before completing an uncertainty analysis for the total project. The analysis' input data were incorporated into a Monte Carlo simulation model using 10 000 simulations. The result depicts the entire cost as an outcome space, as well as which components and drivers are most critical to the ultimate cost's outcome (Statsbygg, 2021c). Dovre Group Consulting conducted the uncertainty analysis, including detailed documentation of estimate uncertainty and uncertainty drivers (Dovre Group Consulting, 2021).

In a conversation with Magne Lilleland Olsen, he explained a mark-up in uncertainty from the base estimate and up to the calculated P85 value. This surcharge is estimated to be 46% and is a vast number, and it is considered that it does not need to be so prominent to land the project. This is also a reason to try to reduce project uncertainty.

4.3.2 PBS

During the preliminary project, the structure surrounding the project has altered. As of cost estimate four, the project PBS is illustrated in Figure 4.3.

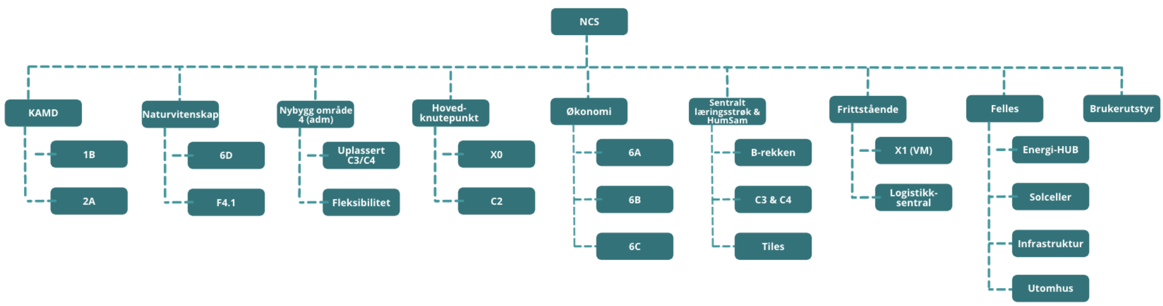

Figure 4.3: The project breakdown structure as of cost estimate four. The different subprojects are listed in their Norwegian name to prevent any misunderstandings

4.3.3 Cut and Option List

There were countless hours spent between March 28 and May 25 looking for ways to cut millions on the current cost estimate. In cost estimate four, it was planned to make cuts on The Science Museum and ESFRI, but more cuts were needed to be made to reduce the scope and total cost of the project.

Asle Ødven stated that the anticipated fifth cost estimate, which was supposed to arrive in May, had been canceled. Statsbygg and NTNU have been asked to describe 2-3 alternatives with a significantly reduced scope compared to the project framework that has been defined so far. As a result, efforts in recent months have centered on identifying many cost-cutting opportunities.

Chapter 5

Analysis of the Results

This chapter summarizes the findings of the computations that have been carried out. Each calculation is compared against Statsbygg's simulation that is presented in Section 4.3.1 Cost Estimation Four. Chapter 6 Discussion delves deeper into the discussion of the results and how they might be improved. The complete documentation of the results is attached to the master's thesis, but since this is sensitive data from Statsbygg, this will not be published along with the research. Further information is given in Appendix A. The process for completing the successive calculation is explained before the thesis deals with the calculated results. The calculations in this chapter are rounded to the nearest million.

5.1 Completion of the Successive Calculation

In this method, a gamma distribution is used. The method also uses triple estimates as input. The most common are P10 as the lower limit, P90 as the upper limit, and P50 as the mode. The thesis is also this input that is used in this calculation.

When calculating the expected value (E), also called mean, and standard deviation (σ) for the post in question, different formulas are used based on which quantile is used. Equation 5.1 and Equation 5.2 represents the mean and standard deviation for the P10/P90 quantile based on Dreveland (2013) formulas.

$$E = \frac{P(10) + 0,41ML + P(90)}{2,41} \tag{5.1}$$

$$\sigma = \frac{P(90) - P(10)}{2,53} \tag{5.2}$$

The variance for each post is further calculated by taking the standard deviation raised to 2. Calculating the variance's product is more complicated since the mean of uncertain quantities comes into play. When calculating uncertain quantities, one must consider the sum of the posts (P) and an uncertainty factor (f). To account for all the uncertainty for a factor f, one must first calculate the total for P x f, then subtract the uncertainty for P that is already factored in, as shown in Equation 5.3.

$$\sigma_U^2 = (\sigma_P E_f)^2 + (\sigma_f E_P)^2 + (\sigma_P \sigma_f)^2 - \sigma_P^2 \tag{5.3}$$

By taking the square root of the variance, one can get the standard deviation for the uncertainty quantities. The mean for the uncertainty factors is further computed using Equation 5.4.

$$E_U = (E_f - 1)E_P \tag{5.4}$$

Summarizing the mean of unknown quantities is a straightforward process, as presented in Equation 5.5. To get the total standard deviation, one summarizes the variance of each post and takes the square root of the total variance, as shown in Equation 5.6.

$$E_{sum} = E_A + E_B + ... + E_n = \sum_{x=A}^{n} E_x \tag{5.5}$$

$$\sigma_{sum} = \sqrt{\sigma_A^2 + \sigma_B^2 + ... + \sigma_n^2} = \sqrt{\sum_{x=A}^{n} \sigma_x^2} \tag{5.6}$$

The total expected sum of the project is then summarized by adding together E_P and E_U. In the same way, one can get the total variance of the project simply by adding σ_P^2 and σ_U^2.

5.1.1 Assumptions during Calculations

In the calculations, an attempt has been made to reduce the costs by calculating both for the entire project and for each subproject. The following are some assumptions made during the calculations.

The estimated uncertainty and uncertainty drivers for the building plots are based on a workshop on 10 May 2021 done by Dovre Group Consulting (2021). Some of the estimated uncertainty and uncertainty drivers have been updated since this workshop, and the further calculations then follow the structure of the updated note from Statsbygg (2021d). Since the PBS also has changed after the publication of quantification of uncertainty assessments for buildings and user equipment in May 2021 (Dovre Group Consulting, 2021), some assumptions on the various uncertainty drivers had to be made in the computation. Firstly, "Rokade" and "Uavhengige (VM/SPH)" have been removed in the PBS for cost estimate 4, whereas "HumSam" and "Sentralt læringsstrøk" have been combined into a cluster. There have also been conducted some new clusters; "Naturvitenskap", "Frittstående" and "Nybygg område 4 (adm)". The different assumptions for doing the calculation are:

- "HumSam" was set to -2,50% for P10 and 17,50% for P(90) while "Sentralt læringsstrøk" was set to -2,50% and 20%. The author then chose to set the combined cluster, "Sentralt læringsstrøk og HumSam", to -2,50% and 20% to facilitate the greatest uncertainty.
- Assume that "Økonomi og innovasjon" in cost estimate two and "Økonomi" in cost estimate four are the same because they both contain the identical building plots.
- "Naturvitenskap" has one of the same plots as "Rokade", which is 6D. Plot A.4 from "Rokade" has been abolished, whereas "Naturvitenskap" also includes plot F4.1. Because "Naturvitenskap" and "Rokade" include some of the same plots, the "Naturvitenskap" uncertainty is then set to the same level as "Rokade" in cost estimate two, namely -7.5% for P(10) and 25% for P(90).
- "Nybygg område 4" contains some plots deployed from "Rokade", the uncertainty for this cluster is set to the same as for "Rokade". The uncertainty driver for "Nybygg område 4" is thus -7.5% for P(10) and 25% for P(90).

5.1.2 Division of Cost Elements within Post

Each subproject is separated into different posts in the cost estimates obtained from Statsbygg. However, the cost estimates and the uncertainty analysis include different posts. After a conversation with Asle Ødven, the posts from the cost estimate are therefore divided into the posts from the uncertainty analysis, as illustrated in Table 5.1. This guarantees that the expenses are set to the appropriate uncertainty factor. The costs from the cost estimates are thus included in the posts from the uncertainty analysis in the computations.

Uncertainty posts	**Posts for cost elements**
1.1 Tomteerverv	• Tomteerverv
2.1 Tomtekostnad - geoteknikk	• Geoteknikk nybygg/påbygg
2.2 Tomtekostnad - riving, forsterkning og følgekostnad på bygg, bro, etc.	• Riving av komplette bygg (eks. bygningsmasse) • Diverse riving ved ombygging, forsterkninger og følgekostnader i eksisterende bygg med påbygg. Bro etc. • Forsterkning for påbygg
3.1 Ombygning arbeidsplassareal, læringsarena og knutepunkt	• O1 Ombygging Læringsarenaer • O2 Ombygging Arbeidsplassarealer • O3 Ombygging Knutepunktarealer
3.2 Ombygning spesialareal	• O4 Ombygging Spesialarealer inklusive laboratorier
4.1 Nybygg arbeidsplassareal, læringsarena og knutepunkt	• N1 Nybygg Læringsarenaer • N2 Nybygg Arbeidsplassarealer • N3 Nybygg Knutepunktarealer

4.2 Nybygg spesialareal	• N4 Nybygg Spesialarealer inklusive laboratorier
5. Vitenskapsmuseet, inkl. Generelle kostnader [1]	
6. Senter for psykisk helse, inkl. Generelle kostnader [2]	
7. Utomhus	• Infrastruktur/Utomhus
8. Infrastruktur	• Infrastruktur/Utomhus
9. Energi/miljø	• Energi/miljø
10. Generelle kostnader	• Økte adm. kost. pga. 1 års utvidels

Table 5.1: Categorization of posts

[1] The posts in cost estimate four include The Science Museum or "Vitenskapsmuseet". As a result, there are no post included in the uncertainty analysis post.

[2] After the contract price was reduced to NOK 11.032 billion, the mental health center or "Senter for psykisk helse" was removed from the project. This is why there are no post in this post.

5.2 Successive Calculation of the Overall Project

Table 5.2 presents the calculated costs for the project using a successive calculation. It is worth noticing that the costs are somewhat higher than in Statsbygg's simulation, particularly the management reserve and the standard deviation.

Key amounts		
Base estimate	**6 666 000 0000**	
Contingency	1 274 000 000	19,1%
P50	**7 931 000 000**	
Management reserve	2 857 000 000	36,0%
P85	**10 789 000 000**	
The projects standard deviation	2 757 000 000	34,7%

Table 5.2: Results from successive calculation of the overall project

5.2.1 Base Estimate, P50 and P85 Value

We can see a progressive increase in the successive calculations when looking at the base estimate and subsequent P50 and P85 values compared to Statsbygg's Monte Carlo simulation. Equation 5.7 depicts the percentage increase in the base estimate due to using this approach. Further follows Equations 5.8 and 5.9, which show the P50 and P85 values increase.

$$\left(\frac{6666 - 6540}{6540}\right) 100\% = 1,93\% \tag{5.7}$$

$$\left(\frac{7931 - 7790}{7790}\right) 100\% = 1,81\% \tag{5.8}$$

$$\left(\frac{10789 - 9568}{9568}\right) 100\% = 12,76\% \tag{5.9}$$

The difference between the P50 and P85 values is substantially more significant than the base estimate and the P50 value. The gap between the base estimate and the P85 value, which is as high as 62%, demonstrates this. This represents a 16% increase over the Statsbygg simulation. Further, a generated graph is presented in Figure 5.1 by visually illustrating the numbers from Table 5.2 in an s-curve that describes the cumulative probability light to avoid exceeding the cost.

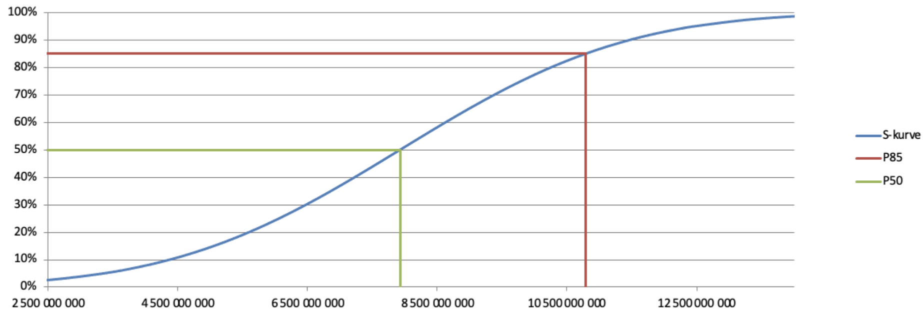

Figure 5.1: S-curve of the overall project

Table 5.2 and Figure 5.1 show that this strategy is very near surpassing the stated contract price. However, because this estimate excludes the uncertainty analysis for the user equipment, the project's entire cost will almost certainly exceed the contract price if this is included. With this in mind, using this strategy with the revised uncertainty factors to reduce project uncertainty is probably not the best option.

5.2.2 Contingency, Management Reserve and Standard Deviation

This calculation has also resulted in a significant increase in contingency, management reserve, and standard deviation, as shown in Table 5.2. Contingency is relatively unchanged but has increased by 2%, as seen in Equation 5.10. The management reserve has grown from NOK 1.778 billion to 2.857 billion, a 60% rise. Equation 5.11 illustrates this further. On the other hand, the standard deviation has increased the most, by up to 68%, compared to the Monte Carlo simulation, as calculated in Equation 5.12.

$$\left(\frac{1274-1249}{1249}\right)100\% = 2,0\% \tag{5.10}$$

$$\left(\frac{2857-1778}{1778}\right)100\% = 60,7\% \tag{5.11}$$

$$\left(\frac{2757 - 1641}{1641}\right) 100\% = 68,0\% \tag{5.12}$$

Because the aim was to minimize this value, the enormous value of the management reserve demonstrates that this is not an appropriate approach to include. It, on the other hand, has nearly doubled in size.

5.2.3 Uncertainty Drivers

As illustrated in Figure 5.2, a tornado diagram was created to investigate which uncertainty factors cause the management reserve to be so big. The diagram includes seven uncertainty posts for the entire project, and the eighth post is separated into local conditions for each subproject.

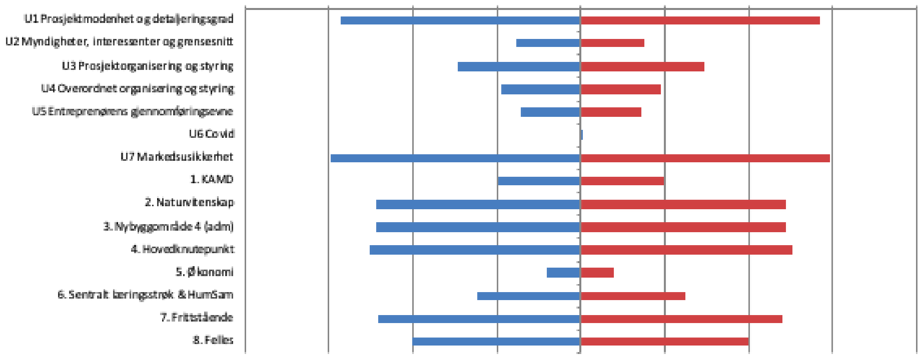

Figure 5.2: Tornado diagram for uncertainty drivers

"U7 Market Uncertainty", or "Markedsusikkerhet", is the most pronounced uncertainty driver, as it is the largest block in Figure 5.2. This is uncertainty regarding the general market's development, which is dependent on the supply-demand balance, economic conditions, margin adjustments, and industry productivity. The driver also accounts for the uncertainty around market fund spreads, which is determined by Statsbygg's market attractiveness, the project's attractiveness, and the project's timing compared to other significant contracts in the region (Dovre Group Consulting, 2021).

In Figure 5.2, it can be shown that "U2 Authorities, stakeholders, and interfaces", or "U2 Myndigheter, interessenter og grensesnitt", have a deficient level of uncertainty in reference to Statsbygg's calculation. The most significant uncertainty in past cost estimates has tended to be "U7 Market uncertainty," and this method has proven to give out the same result. This uncertainty driver includes the choice of procurement and contract strategy. The division and size of the various subprojects can significantly impact the attractiveness of the project and supplier prices.

5.2.4 Evaluation of the Results

Overall, the project's base estimate is not that far from Statsbygg's calculations. This is because the calculation relies on Statsbygg's set costs, and the base estimate is based on the expected value of these values. The same applies to the P50 value, which is "only" NOK 140 million higher than their estimations. There is a significant increase in uncertainty from P50 to P85, with the project increasing by NOK 1.220 billion compared to Statsbygg. This is a 12.76% gain, as seen in Equation 5.9. These findings show that, in this case, this is not a better strategy to utilize than the Monte Carlo simulation.

5.3 Successive Calculation of Subprojects

Table 5.3 illustrates the base estimate for each subproject and the associated contingency and management reserve. After adding together the base estimate and the contingency of all subprojects, one gets the P50 value for the whole project. Furthermore, adding the management reserve to the P50 gives the whole project's P85 value.

Key amounts			
Subproject	**Base estimate**	**Contingency**	**Management reserve**
KAMD	1 469 000 000	283 000 000	450 000 000
Naturvitenskap	507 000 000	104 000 000	170 000 000
Nybyggområde 4 (adm)	391 000 000	79 000 000	132 000 000
Hovedknutepunkt	450 000 000	148 000 000	176 000 000
Økonomi	601 000 000	98 000 000	182 000 000
Sentralt læringsstrøk & HumSam	2 000 000 000	443 000 000	709 000 000
Frittstående	281 000 000	37 000 000	100 000 000
Felles	776 000 000	134 000 000	256 000 000
Total amount	**6 408 000 000**	1 330 000 000 (19,4%)	1 946 000 000 (23,8%)
Total P50		**8 170 000 000**	
P85 for the whole project			**10 117 000 000**
The projects standard deviation		2 101 000 000	25,7%

Table 5.3: Results from successive calculation of subprojects.

5.3.1 Base Estimate, P50 and P85 Value

In terms of the findings for the successive calculation of subprojects, Table 5.3 shows an increase in the P50 and P85 values for this calculation similar to Section 5.2 Successive Calculation for Overall Project. The main difference between the overall project calculation and the subprojects calculation is that the base estimate for subprojects is lower than Statsbygg's Monte Carlo simulation, as shown in Equation 5.13. Equations 5.14 and 5.15 show the discrepancy between Statsbygg's estimates and the calculated value for P50 and P85. As presented, the P85 value is still higher than Statsbygg's calculated value.

$$\left(\frac{6408 - 6540}{6540}\right) 100\% = -2,02\% \tag{5.13}$$

$$\left(\frac{8170 - 7790}{7790}\right) 100\% = 4,88\% \tag{5.14}$$

$$\left(\frac{10117 - 9568}{9568}\right) 100\% = 5,74\% \tag{5.15}$$

In this calculation, the difference between the base estimate and the P85 value is 57.8%, which is slightly lower than the successive calculation of the overall project, but about 12% higher than Statsbygg's Monte Carlo simulation.

Since an s-curve was calculated for each subproject, it was considered unnecessary to include them all in this result. As previously mentioned, they are attached to the thesis, and this is because there will be a lot of pictures and redundant information if included. The s-curve for the entire project, on the other hand, will have a P85 value of NOK 10.117 billion, as indicated in Table 5.3. When adding the cost of user equipment, which is currently around one billion NOK, the cost is roughly NOK 100 million higher than Statsbygg's contract price.

5.3.2 Contingency, Management Reserve and Standard Deviation

Compared to the Monte Carlo simulation, this calculation has increased contingency, management reserve, and standard deviation. Equation 5.16 shows that the contingency has increased by 6,5%, which is slightly higher than the estimate for the entire project. Equations 5.17 and 5.18 show that the management reserve and standard deviation are slightly higher than the Monte Carlo simulation but far lower than the successive calculation of the overall project.

$$\left(\frac{1330 - 1249}{1249}\right) 100\% = 6,5\% \tag{5.16}$$

$$\left(\frac{1946 - 1778}{1778}\right) 100\% = 9,45\% \tag{5.17}$$

$$\left(\frac{2101 - 1641}{1641}\right) 100\% = 28,0\% \tag{5.18}$$

Although the management reserve is higher than Statsbygg's estimate, this computation demonstrates that this method has potential. This value is less than 10% higher than the Monte Carlo simulation, whereas the calculation of the overall project is up to 60% higher. The standard deviation is not as high as computed for the overall project. This calculation's standard deviation is at 25.7%, which is 28% higher than Statsbygg's simulation as shown in Equation 5.18. This is not a considerable increase compared to Statsbygg's model, which gives a 21.3% standard deviation.

5.3.3 Uncertainty Drivers

The same seven uncertainty factors from Section 5.2 Successive Calculation of the Overall Project are examined in terms of uncertainty drivers for each subproject. Each subproject is examined independently for the eighth uncertainty factor that concerns that subproject. It was decided not to include the tornado diagram for all subprojects, similar to the s-curves. The results of the tornado diagrams are very comparable to the whole project's successive calculations. U7 Market Uncertainty is the most dominant uncertainty among the eight subprojects.

5.3.4 Evaluation of the Results

If one disregards the base estimate, this method increases all other costs, which is consistently above Statsbygg's cost estimate. The results are not far from Statsbygg's prediction, indicating that this strategy may perform better for regular, multi-million projects than massive, multi-billion projects. Compared to Statsbygg's calculation, the predicted P85 value increases by approximately 550 million. The contract price is slightly surpassed, but not nearly as much as when using a successive calculation for the overall project. With only a 5.7% increase in the costs that Statsbygg has already computed, this strategy produces a better result. On the other hand, the method does not result in the expected cost decrease.

5.4 Comparison of the Results

Both of these strategies have been found to increase the cost beyond the base estimates, as described in Sections 5.2 Successive Calculation of the Overall Project and 5.3 Successive Calculation of Subprojects. The cost development of all three techniques is visualized in Figure 5.3 and Figure 5.4. The labels refer to the different methods used during the calculations.

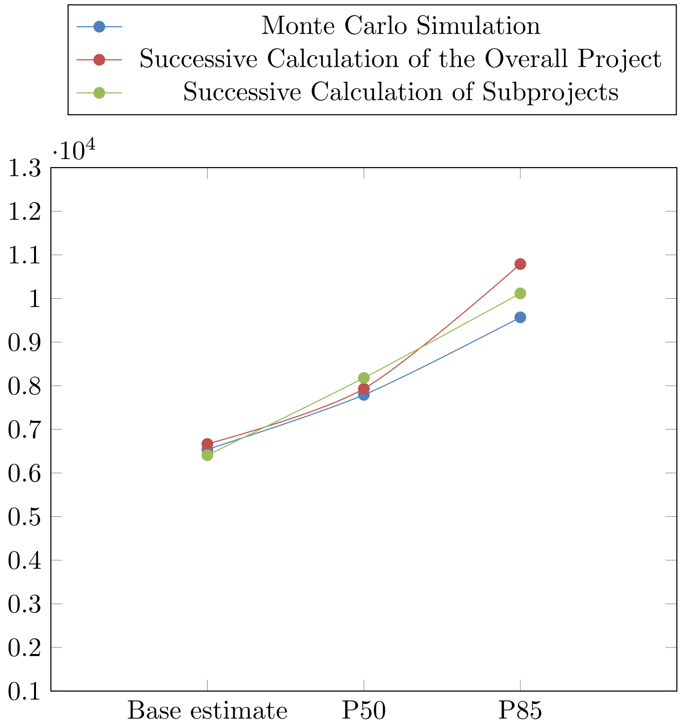

Figure 5.3: Graph illustrating the cost development.

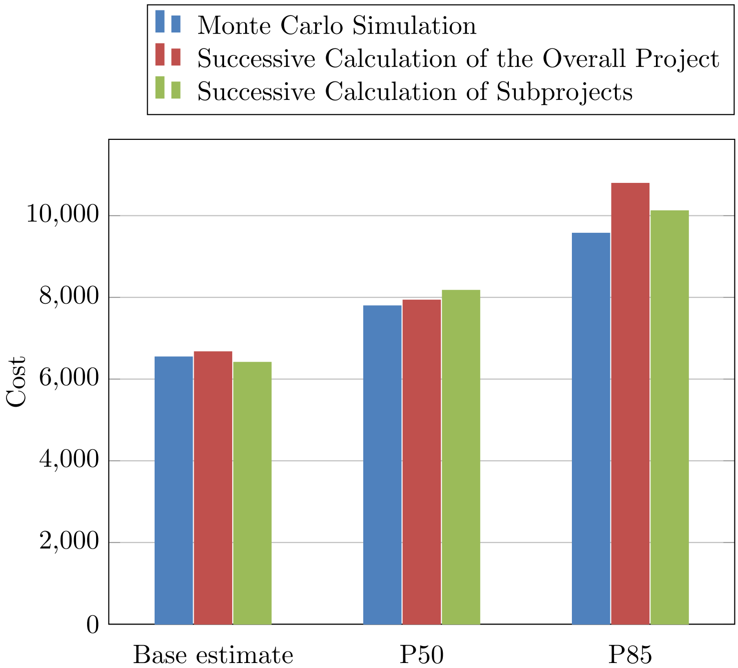

Figure 5.4: Histogram illustrating the cost development.

Based on the cost development of the three methods, the Monte Carlo simulation appears to be the most effective. The successive calculation for subprojects, on the other hand, has a noteworthy evolution in that it starts cheaper than the Monte Carlo simulation and gradually gets more expensive. The cost discrepancies between the successive computation also suggest that this strategy would work better for million projects rather than billion, as the outcome of the subproject calculation is over NOK 700 million less than for the overall project.

Chapter 6

Discussion

This chapter compares the preceding chapter's analysis to the theoretical foundation presented in Chapter 2 Theoretical Background. Through conversations with Magne Lilleland-Olsen and Asle Ødven, some aspects also emerged that could help lower the uncertainty in the project. This chapter will thus further investigate potential measures for reducing project uncertainty, as well as their advantages and disadvantages. The discussion aims to address the research questions and provide a foundation for uncertainty reductions that Statsbygg may consider applying. The following are the research questions that this chapter deal with:

RQ2 *Is it possible to reduce the current management reserve by using other methods and models?*

RQ3 *Are there any benefits to using a different calculation method and model?*

RQ4 *What measures can Statsbygg implement to lower some of the uncertainty drivers?*

6.1 Selection of Method

The results obtained from using the Monte Carlo simulation and the successive calculation should result in somewhat the same results assuming the same model structure (Dreveland, 2013). A few uncertainty elements were altered during the calculations to investigate whether the total amount could be reduced, as described in Section 5.1.1 Assumptions during Calculations. This produced slightly different results than the Statsbygg simulation. As shown in Section 5.4 Comparison of the Results, the Monte Carlo simulation has proven to give the best results.

On the other hand, it has been demonstrated that running an uncertainty analysis for each subproject rather than the entire megaproject produces better results using a successive calculation. As described in Section 4.3.1 Cost Estimate Four, Statsbygg sums up all of the costs for each subproject and does an uncertainty analysis of the total project cost. This process was tested in the Successive Calculation of the Overall Project. However, the method did not produce a better outcome. The technique was altered during the Successive Calculation of Subproject. The emphasis was changed to do an uncertainty analysis for each subproject and combine all P85 values into a total sum. As described in Section 5.4 Comparison of Results, this process gave the best result using successive calculations. It can thus be discussed how this technique had performed in conjunction with a Monte Carlo simulation. Using the simulation method, this technique could have produced a lower cost because the Monte Carlo simulation can execute this loop thousands of times and thus create better results. Unfortunately, this was not tested in this thesis due to a lack of equipment that could provide this result.

When using successive calculations, emphasis is placed on calculating uncertainty for the entire project (Austeng et al., 2005; Drevland et al., 2005). The successive calculation for subprojects thus contradicts literature regarding this type of calculation as the author has not found literature that uses this procedure. Considering that this method has proven to give a lower cost than the calculation for the entire project can thus be an indicator that the method can provide value for Statsbygg if used together with a Monte Carlo simulation.

6.2 Multiple Smaller Projects

According to Welde et al. (2019), larger projects have a somewhat higher chance of exceeding the P50 estimates than smaller ones. Although it is not guaranteed that a smaller project will be less complex than a larger one, megaprojects often have a higher level of uncertainty and duration (Raaholt, 2009). The Campus Collection project is defined as a megaproject because of its complexity, cost, and size. If each subproject is considered a project, it can theoretically be classified as a smaller project or a project of average size. Their cost ranges from a few hundred million to two billion. Thus, if each subproject is treated as a separate project, one will most likely be able to reduce some project uncertainty. The project's uncertainty picture is defined by a high level of uncertainty concerning the project's size, length, and complexity. This includes, among other things, a tight plan with little slack, plots distributed over a large geographical area, and parallel construction projects with several contractors (Statsbygg, 2021a). It was planned to compare the uncertainty drivers to Dovre Group Consulting's analytical model, but this was not possible to access. As a result, this section will further investigate elements that could help lower the uncertainty when dividing the megaproject into multiple smaller projects.

The driver "U3 Project organization and management", or "U3 Prosjektorganisering og styring" include the consequence of the project being a megaproject and going on for a long time. This driver includes threats because it is a vast and complicated organization in multiple phases simultaneously and inadequate management of costs, progress, and risk. When examining each subproject, these factors can be minimized. Each subproject will be less complex individually, and the project itself will take less time to complete than the entire megaproject. This can be used as a starting point for reducing some of the pessimistic P90 values for this driver. On the other hand, dividing the project into smaller separate projects will result in more relationships across projects since more stakeholders will be involved in different projects. Due to the dispersed project organization, this can lead to even worse communication. In this way, the project split can yet appear like a megaproject. According to Zhai et al. (2009), the project managers' communication skills are more critical in megaprojects due to the many stakeholders involved.

6.3 Safer Strategy

Statsbygg has set up an offensive strategy, according to Magne Lilleland Olsen, in which it wants maximum volume and regulated buildings. This has resulted in a 46% increase in uncertainty from the base estimate to the computed P85 value. Magne himself stated that this was a very high proportion of uncertainty and that the project would likely not require as much to land.

According to Statsbygg's uncertainty analysis (2021d), the primary source of uncertainty is "U2 Authorities, stakeholders, and interfaces", and regulatory risk falls within this driver. As a result, prioritizing the elimination of this uncertainty is desirable. Adopting a slightly safer approach could be one way to reduce the high amount of uncertainty. This involves selecting safer options that do not pose a significant regulatory challenge. This might entail a closer collaboration with the municipality of Trondheim.

Within the uncertainty driver "U2 Authorities, stakeholders and interfaces", it is also interesting to discuss the challenge of choosing between building new or rebuilding buildings. This goes within "interfaces" that can address everything from existing facilities/buildings, planned maintenance or operational work, or other projects. Which plots one chooses to build on is quite important.

6.3.1 New Building versus Rebuilding

When determining whether to build new or rebuild, Sørland and Klungerbo (2021) emphasizes the issue of finances. However, there is no agreement on whether conversion or a new building is the most profitable option. In Norway, on the other hand, new construction is more common than rebuilding, despite research showing that rebuilding uses fewer resources than new construction (Sørland & Klungerbo, 2021). In terms of sustainable considerations, more rebuilding may be required to meet the climate goals. The assessment of whether it is most appropriate with a new building or conversion, on the other hand, depends on several factors. The adaptability of a building may affect the possibilities for expansion, area efficiency, and the possibility of satisfying technical requirements that will further impact the finances of a project. Trondheim is vulnerable to quick clay landslides; this must be considered when completing the project.

Sørland and Klungerbo (2021) also mentions that a cost-benefit assessment must be made in this decision, in which one considers the costs of the options and the potential rental income. Due to difficult ground conditions, the danger of fast clay landslides, and the protection of buildings and the outdoors, there are a few challenging plots in the Campus Collection project. Statsbygg may consider dropping a challenging plot and relocating a few square meters to another to lessen project uncertainty.

In terms of finding safer solutions, integrating less within the project will be advantageous. This may mean choosing to build new instead of remodeling. However, this depends on each building and its expectations and condition. Anyhow, there are often higher risks and uncertainties associated with remodeling projects (Baker et al., 2017).

6.3.2 Risk Reduction Activities

For measures that have irreversible effects, and there is particularly great uncertainty associated with profitability, consideration should be given to postponing the start-up or implementing activities that can increase flexibility. Adding flexibility to a service's manufacturing process can add value. For example, uncertainty about future demand for particular services can be an issue for new construction, impacting how the structure should be constructed. The building can be altered in response to variations in demand by allowing for flexible utilization. Another possibility is to facilitate the possibility of varying the production method. This means one will not rely on a single technology that may be outdated or poorly suited to future needs. A project's flexible design allows it to adapt to changes in unpredictable circumstances, increasing flexibility (Direktoratet for økonomistyring, 2018).

There may be an alternative cost associated with the immediate initiation of some measures with irreversible effects and uncertainty. This cost represents the value of delaying the start-up. The option's value is frequently tied to the potential for additional information to be utilized by deferring the measure. A meaningful measure may prove unprofitable if critical uncertainty elements are present. One can opt-out of loss situations if one waits for more information about such issues (Direktoratet for økonomistyring, 2018).

Chapter 7

Conclusion

This chapter summarizes the discussion chapter's findings and concludes with the results. The research questions and goal are then addressed, and recommendations for further research are made. The master's thesis research questions were:

RQ1 *How do Statsbygg implement DtC methods in the NTNU Campus Collection?*

RQ2 *Is it possible to reduce the current management reserve by using other methods and models?*

RQ3 *Are there any benefits to using a different calculation method and model?*

RQ4 *What measures can Statsbygg implement to lower some of the uncertainty drivers?*

The master's thesis is based on a literature review, a case study of the Campus Collection project, and conversations with Statsbygg representatives. This was done to investigate how people work in a DtC project and how Statsbygg employs this method to complete the Campus Collection project. From these parts, it turned out that project optimization through cuts and option lists is fundamental to carrying out the project within the absolute contract price. At the same time, cost estimation and uncertainty analysis have played an essential role in staying within the given contract price.

In an attempt to reduce costs, an analytical method was conducted instead of the Monte Carlo simulation, which Statsbygg uses. It can be argued that using successive calculations and a slightly changed model, it is not possible to reduce the entire project's costs or the management reserve. On the other hand, the method appears to function better when the megaproject is broken into subprojects rather than the entire project.

Based on conservation with representatives from Statsbygg, it is argued that there is a basis for being able to lower some uncertainty related to the uncertainty drivers in the project. Choosing a safer strategy while estimating costs for each subproject can support lowering the uncertainty driver "U2 Authorities, stakeholders and interfaces" and "U3 Project organization and management".

All this leads to the problem statement that the thesis addresses, namely:

Goal *How may the uncertainty elements be managed further to ensure that the project stays within the DtC contract price?*

Determined from the research questions and results from the calculation, choosing a safer strategy when carrying out the Campus Collection project is advantageous. It is also recommended to examine the use of cost estimation for each subproject instead of the total project. This can probably remove some uncertainty regarding the project's size and complexity, but not all, as the project still extends over a longer time.

In order to be able to reduce the uncertainty associated with the uncertainty drivers, it can also be helpful to have a close dialogue with the municipality of Trondheim concerning regulatory work. The decisions related to building new versus rebuilding are also something one must consider. From the literature, it turns out that there is often a higher risk and uncertainty when rebuilding; therefore, it is suggested to build new buildings on plots with high uncertainty.

7.1 Further Work

The results show that the successive calculation for subprojects results in a lower cost for the total project and the management reserve. Based on this, it is recommended to try a similar calculation with a Monte Carlo simulation to see if this can provide a basis for lowering the management reserve.

A further recommendation is to investigate the possibilities of implementing a safer strategy when using new buildings where it requires a lot of restructuring work. In addition, it is recommended to look at opportunities to implement risk reduction activities during the implementation phase.

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Appendix A

Excel sheet

Two documents have been attached to the thesis, and these are the quantitative calculations made for the successive calculation.

The succcessive calculation of the overall project can be found in the file: Successive_Calculation_Overall_Project.xlsx. The successive calculation of sub-projects can be found in the file: Successive_Calculation_Subprojects.xlsx.

The documents are not attached to the thesis since it is sensitive information for Statsbygg.

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