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Early Cost estimation of Construction Projects Using Case-based Reasoning (CBR)

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Abstract

The master's thesis is the final thesis of the 2-year education in Project Management at the Norwegian University of Science and Technology (NTNU). The task is 30 credits and has been completed in the subject TBA 4910 Project management, master's thesis at the Department of Civil and Environmental Engineering. The purpose of the thesis is to first to discuss case-based reasoning (CBR) based on literature study models, which have been developed to estimate construction project costs at an early stage based on previous literature research. And secondly, to examine Norway's existing practice of cost estimation based on interviews.

I would like to thank supervisor Ole Jonny Klakegg for good guidance throughout processes. Furthermore, I would like to thank the three respondents: Olle Rudén from Bygganalyse, Håvard from Norconsult and Ruune Sagvold from Betonmast Innlandet AS, who contributed relevant information and took the time to answer questions in interviews. Without this contribution, the completion of this master's thesis would not have been possible. Finally, I would also like to thank my family.

Trondheim, June 2022

Summary

In the construction and engineering industries, cost overruns, delays in construction, and low quality have long been common challenges. Cost estimation at an early stage of a construction project is one of the essential processes in construction management. An accurate cost estimation is crucial to the success of a project and plays a major role in determining decisions and costs and cost overruns, delays in construction, and low quality.

This study aims to discuss case-based reasoning (CBR) based on literature study models, which have been developed to estimate construction project costs at an early stage based on previous literature research and existing practice of cost estimation based on interviews. The literature study of CBR will review the possible benefits CBR can offer to the cost estimation process of construction projects. The interview portion will identify the potential of the CBR method in Norway by analyzing current cost estimation practices in construction projects.

A detailed theoretical framework of case-based reasoning (CBR), accuracy, factors, importance on cost estimation of construction costs, and a summary of the construction cost estimation system in Norway have been described in this thesis. In addition, a detailed methodology of qualitative research and interviews has been explained.

The thesis seeks to answer the following two issue:

1. Is case-based reasoning (CBR) a precise cost estimation method to use in construction projects at an early stage based on theoretical literature study?

2. Comparing case-based reasoning (CBR) to existing practices for cost estimation in construction projects, what are the advantages and disadvantages?

3. What is the potential of using case-based reasoning (CBR) in Norway? Further analysis of research questions 1 and 2 and the characteristics of Norwegian construction projects will answer this question.

Keywords: Construction Projects, CBR. Cost Estimation, Methods.

Sammendrag

I bygg- og anleggsbransjen har kostnadsoverskridelser, forsinkelser i byggingen og lav kvalitet lenge vært vanlige utfordringer. Kostnadsestimering på et tidlig stadium av et byggeprosjekt er en av de vesentlige prosessene i byggeledelse. Et nøyaktig kostnadsestimat er avgjørende for suksessen til et prosjekt og spiller en viktig rolle i å bestemme beslutninger og kostnader og kostnadsoverskridelser, forsinkelser i konstruksjonen og lav kvalitet.

Denne studien tar sikte på å diskutere case-basert resonnement (CBR) basert på litteraturstudiemodeller, som er utviklet for å estimere byggeprosjektkostnader på et tidlig stadium basert på tidligere litteraturforskning og eksisterende praksis for kostnadsestimering basert på intervjuer. Litteraturstudiet av CBR vil gjennomgå de mulige fordelene CBR kan tilby for kostnadsestimeringsprosessen for byggeprosjekter. Intervjudelen vil identifisere potensialet til CBR-metoden i Norge ved å analysere gjeldende kostnadsestimeringspraksis i byggeprosjekter.

Et detaljert teoretisk rammeverk av case-basert resonnement (CBR), nøyaktighet, faktorer, betydning for kostnadsestimering av bygge kostnader, og en oppsummering av bygg kostnadsestimering systemet i Norge er beskrevet i denne oppgaven. I tillegg er en detaljert metodikk for kvalitativ forskning og intervjuer forklart.

Avhandlingen søker å besvare følgende to problemstillinger:

1. Er saksbasert resonnement (CBR) en presis kostnadsestimeringsmetode å bruke i byggeprosjekter på et tidlig stadium basert på teoretisk litteraturstudie?

2. Ved å sammenligne saksbasert resonnement (CBR) med eksisterende praksis for kostnadsestimering i byggeprosjekter, hva er fordelene og ulempene?

3. Hva er potensialet ved å bruke saksbasert resonnement (CBR) i Norge? Videre analyse av forskningsspørsmål 1 og 2 og kjennetegn ved norske byggeprosjekter vil besvare dette spørsmålet.

Stikkord: Byggeprosjekter, CBR. Kostnadsestimat, metoder.

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List of abbreviations

ANN	Artificial Neural Networks
ASCE	American Society of Civil Engineers
BOQ	Bill of Quantity
CBR	Case-Based Reasoning
CM-CBR	Construction Management- Case-Based Reasoning
GA	Genetic algorithms
NTNU	Norwegian University of Science and Technology
MRA	Multi Regression Analysis

1 Introduction

This chapter presents the background information, purpose for choosing the work, scope and limitation, research question, and thesis structure.

1.1 Background and Reasons for this Topic

Cost overruns, delays in construction time, and low quality have long been common challenges in the construction and engineering sectors (Larsen et al., 2016). Cost estimation at an early stage of a construction project is one of the essential processes in construction management (Hyari et al., 2016). Precise cost estimation is crucial to the success of a project (Ji et al., 2012) and has a massive role in making decisions and cost overruns. The influence of construction cost in the decision-making phase accounts for 80%~90% (Wu and Huang, 2008). However, studies of buildings and infrastructure projects show that accurate cost estimation at the early stage of a construction project is difficult due to limited information available at the early stage (Jin et al., 2014). Thus, estimating construction cost, the top limit of the construction cost is the primary reference in controlling the whole-process cost (Wu and Huang, 2008).

A parametric cost estimation method (e.g., cost per square meter) is widely used in the project's initial phase and reduces estimation time with minimal expense and requires minor detail (Ji et al., 2011b). However, due to its lack of precision, this method is not effective at addressing information changes (Ji et al., 2012). There have been numerous attempts to improve the accuracy and precision of construction cost estimation (Zima, 2015). Researchers have developed methods for estimating construction costs based on the limited information available during the early stages of construction. As of the 1970s and 1980s, statistical methods, linear regression analysis methods, and artificial intelligence (AI) approaches such as expert systems, neural networks (NN), and case-based reasoning (CBR) have been applied (An et al., 2007). Case-based reasoning (CBR) has recently been introduced and implied for the early-stage cost estimation of construction and engineering projects (Jin et al., 2014).

Case-based reasoning (CBR) has been introduced to cost estimation in construction projects. A CBR is a process of retrieving similar cases, applying previously determining solutions to the new problem, and storing the new solution for future use after a successful solution is discovered (Kim and Kim, 2010). Accordingly, CBR works on the hypothesis that "similar problems have similar solutions" (Ji et al., 2012, Jin et al., 2014). In CBR, Cases are

represented by attributes describing the problem's circumstances and solution (Kim and Kim, 2010). Thus, the CBR technique explains how to determine the cost of a new project and utilizes the specific knowledge gained from a previous project to determine the cost of a new project (An et al., 2007).

This master's thesis report aims first to discuss case-based reasoning (CBR) based on literature study models, which have been developed to estimate construction project costs at an early stage based on previous literature research. Secondly, I will examine Norway's existing practice of cost estimation based on interviews. The literature study of CBR will review the possible benefits CBR can offer to the cost estimation process of construction projects. Publications on the application of CBR in construction projects indicate that CBR is already in use for construction cost estimation and other construction areas. The interview portion will identify the potential of the CBR method in Norway by analyzing current cost estimation practices in construction projects.

1.2 The Norwegian Construction Projects and the Need for Precise Cost Estimation

A precise cost estimation is always important for every construction project because an accurate construction cost estimation can lead to a successful project, as it can influence cost reduction during conceptual and schematic design (Ahn et al., 2020). Precise cost estimation in Norway is also need because a precise cost estimation of a project can avoid cost overrun. However, construction cost estimation is challenging in Norway, as it is worldwide as costs estimating is an essential factor in project planning. Cost deviations are a challenge for Norwegian construction projects, IT-development projects, oil and gas projects, and defense and aerospace projects due to scope, design, and project complexity (Danielsen et al., 2017).

For example, Norwegian authorities initiated a review of the systems for planning, implementing, and monitoring large public investment projects in 1997 because of cost overruns and delays (Samset and Volden, 2014). A steering committee with participation from the Ministry of Finance and the responsible sectorial ministries made the study and analyzed 11 case studies from the transport, defense, and construction industries and found that only three projects were completed within the original budget. Overruns were as high as 84 percent on eight of the projects, and three of them were particularly high up to 500% (Samset and Volden, 2014). There was also a study of investments sampled from 13 North

Sea oil exploration projects that had overruns between 17% and 107%. The main cause for significant cost overruns the projects were:

- Lack of analysis of alternative conceptual solutions and an incomplete analysis of societal needs.
- Premature submission of projects to Parliament.
- False assumptions and inadequate use of cost-benefit analysis.
- Lack of adequate assessment of uncertainty associated with cost estimates.

The Norwegian governance scheme emphasizes cost control by introducing a budgeted cost and a distinct, lower target cost for the agency (Volden and Samset, 2017). In the 1990s, the Norwegian government reviewed the plans for implementation, evaluation, and quality assurance for all public projects exceeding 750 MNOK (Pihl, 2017, Danielsen et al., 2017). The quality assurance scheme has two control points, QA1 and QA2, and aims to ensure the quality of the project concept and ensure that the result will contribute to Norwegian society. The first control point (QA1) was introduced in 2000 when the Cabinet started a pre-project to select the concept. This control point aims to ensure high quality in the project concept. This second control point (QA2) pertains to the quality assurance of the management base and cost estimates before the project is submitted to Parliament for funding and approval. It was introduced by the Ministry of Finance in 2005 and is intended to ensure that the project can be completed within the estimated steering goal (Pihl, 2017, Danielsen et al., 2017).

1.3 Research Quotations

This master thesis has three parts:

1. Cost Estimation of Construction Projects using Case-Based Reasoning (CBR):

This part will go primarily on the literature study of case-based reasoning (CBR) as a cost estimation method in construction projects. It will find out the effectiveness/potential of the method in cost estimation of construction projects based on literature that are studied until now by different authors.

2. Interview with a partner:

This part is mainly making an interview with a partner (5 people that work with cost estimation), on how they do cost estimation of their projects? This will help me to understand the way how the company calculates/works the cost estimation and how the existing cost

estimation of construction is taking place. For example, considering the relation to risk, cost uncertainty and cost overruns.

3. Analysis of CBR against Existing Practice:

This part will analyze the case-based reasoning (CBR) method against the existing practice of cost estimation of construction projects. This will focus on analyses of cost estimation using CBR based on the analysis of results from part 1 and interviews from part 2. The comparison

In this master thesis the following three research questions will be answered:

1. Is case-based reasoning (CBR) a precise cost estimation method to use in construction projects at an early stage based on theoretical literature study? The answer to this question will be based on a literature review that includes articles and materials already researched and published.
2. Comparing case-based reasoning (CBR) to existing practices for cost estimation in construction projects, what are the advantages and disadvantages? This research question will be addressed by part two's interviews with practitioners and part one's theoretical analysis of CBR.
3. What is the potential of using case-based reasoning (CBR) in Norway? Further analysis of research questions 1 and 2 and the characteristics of Norwegian construction projects will answer this question.

1.4 Limitations

This thesis is a qualitative research based on a literature study of case-based reasoning (CBR) and interviews to review construction projects' existing cost estimation practices. Due to time restrictions, this study is limited only to an empirical study on the CBR cost estimation method for construction projects. Thus, the author will not test self-using data from some case studies at this level. In addition, this study is limited to analyzing the existing practice of cost estimation of construction projects in Norwegian projects based on the three interviews.

Cost estimation of construction projects is a broad aspect as it ranges from the early planning stage to the execution stage. Another limitation is that the restricted time frame in this study analysis only early-phase cost estimation of a construction project both for CBR and existing cost estimation. Hence, the early stage of cost estimation of a project was investigated before the detailed design.

1.5 Structure of the Thesis

The structure of this thesis is presented as shown in figure 1. The first chapter will go through the introduction, background, research questions, limitations, and structure of the thesis to give the readers a short guideline to the report. In the second chapter, the methodology used to perform this study will be introduced. In the third chapter, the report will go through the theoretical Frameworks of related terms and concepts on CBR and construction cost estimation. Chapter four will explain detailed on existing practice construction cost estimation. Chapter five discusses the comparison CBR with existing practice construction cost estimation. In conclusion, the chapter will summarize the answer to the research questions based on chapters four and five.

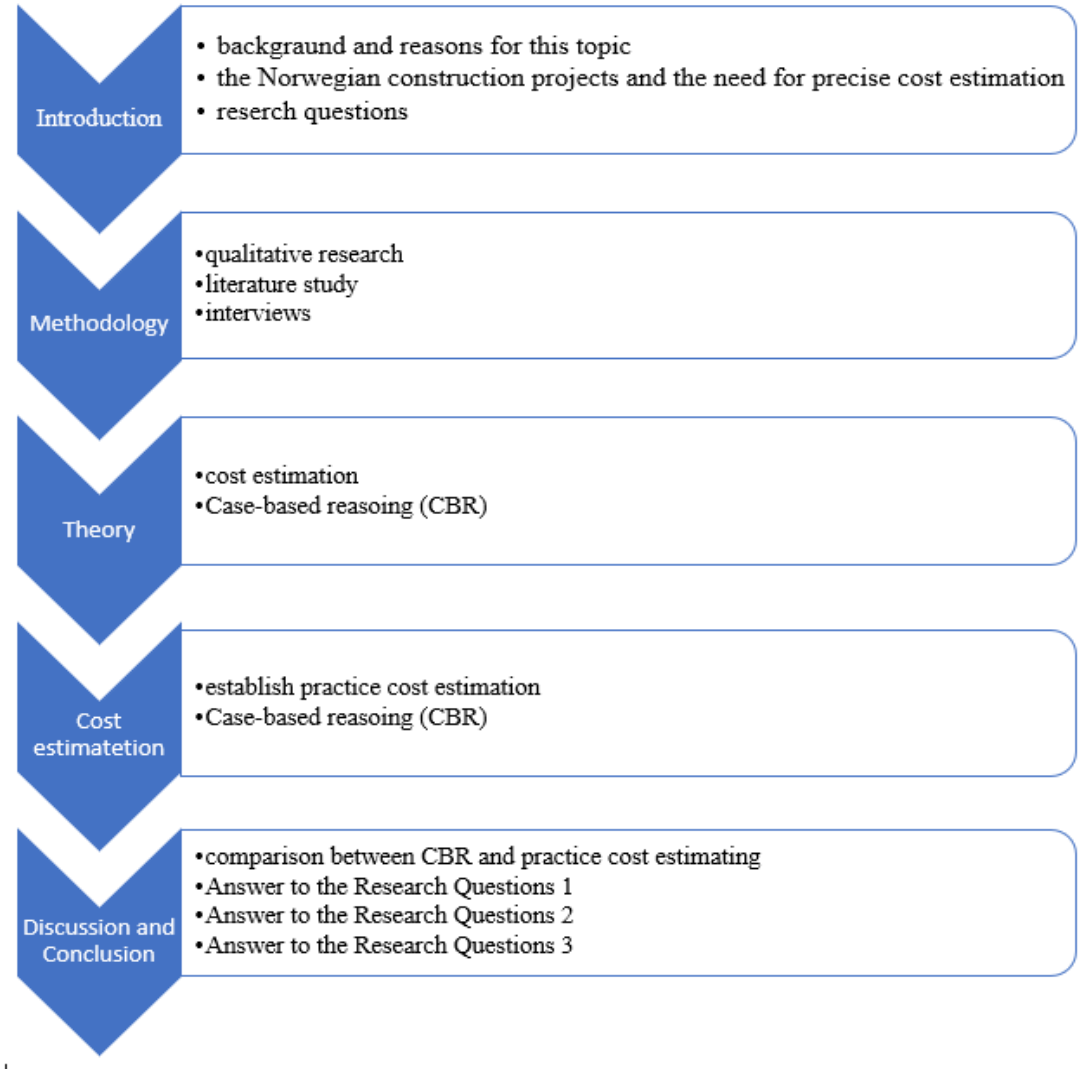

Figure 1. structure of the thesis.

2 Research Methodology

This chapter describes the different research methods and the methods chosen that to answer the research questions for this thesis. Two qualitative research methodologies were used to answer these questions: a literature study and conducting interviews.

2.1 Qualitative Research

The author relies on the qualitative method in this study since the study is based on qualitative research. Qualitative research is one in which information can be gathered from objects. Qualitative research is defined differently by different researchers. Rahman (2020) defines qualitative research as any research that results in findings that cannot be quantified via statistical methods. The term can also describe the study of people, their lived experiences, their behaviors, emotions, and feelings, the study of social movements and cultural phenomena, and interactions between different nations. Thus, qualitative research is not statistical, incorporates multiple realities, and focuses on the social meaning of issues, events, or practices by collecting non-standardized data and analyzing texts and images instead of numbers and statistics (Rahman, 2020).

2.1.1 Advantages of Qualitative Research Disadvantage of Qualitative Research

Qualitative research usually preserves the participants' perspective and can be adjusted to address new research questions as they arise. Qualitative research as a research method has both advantages and disadvantages, as summarized in table 1 (Pritha, 2022).

Advantages of Qualitative Research	
Flexibility	New ideas and patterns can be explored and adapted during the data collection and analysis.
Natural settings	The collection of data occurs in naturalistic or real-world contexts.
Meaningful insights	It is possible to design, test, and improve systems and products by using detailed descriptions of people's experiences, feelings, and perceptions.
Generation of new ideas	When researchers use open-ended responses, they have the chance to uncover new issues and opportunities that they wouldn't have imagined otherwise.

Disadvantage of Qualitative Research	
Unreliability	Because of uncontrolled factors affecting the data in real-world settings, qualitative research is often unreliable.
Subjectivity	Qualitative research cannot be replicated as the researcher is primarily responsible for analyzing and interpreting data. In data analysis, the researcher decides what is relevant and what is not, so interpretations of the same data can differ significantly.
Restricted generalizability	Small samples are often used to collect detailed information about a specific context. It is difficult to generalize despite rigorous analysis procedures since the data may be biased and non-representative of the wider population.
Labor-intensive	Although software can manage and record large volumes of text, data analysis usually has to be done by hand.

Table 1 Advantages and disadvantages of qualitative research (Pritha, 2022).

In addition, Rahman (2020) describes some benefits of using qualitative research approaches and methods as listed below.

- A qualitative approach produces the detailed descriptions of participants' feelings, opinions, and experiences; as well as interprets the meanings of their behavior.
- A qualitative study allows researchers to discover the participants' inner experiences and determine how culture shapes meaning.
- The qualitative research design is flexible, as it can be constructed and reconstructed to a greater extent.

2.1.2 Validity and Reliability

When conducting qualitative research, it is vital to consider the concepts of reliability and validity since they define the study's objectivity (Poblete and Grimsholm, 2010). The reliability and validity of research are two concepts used to assess the quality of qualitative research (Golafshani, 2003, Fiona, 2022). They can be seen as two different measuring methods showing their accuracy and credibility in qualitative research. Golafshani (2003), describes that validity and reliability are two factors that any qualitative researcher should be vigilant about while designing a study, analyzing results, and judging the quality of the study. Fiona (2022) defines the terms reliability as: reliability is a concept refers to how consistently

a method measure something while validity refers is concept refers to how accurately a method measures what it is intended to measure.

According to (Poblete and Grimsholm, 2010), reliability and validity are internal and external concepts. Internal reliability refers to the ability to agree on what is observed and heard within the study group if more than one researcher is involved. When it comes to external reliability, it refers to how well the original research can be repeated with comparable results. It may be difficult to achieve high external reliability in the future since the scene, and the setting are likely to change between the original research and the subsequent one. The internal validity of qualitative research generally comes from long-term observation of the social setting, which commonly results in excellent correspondence between observations and concepts. External validity, in contrast, is regarded by some researchers as a challenge in qualitative research since it relates to the application of findings in a variety of social settings. Qualitative researchers generally use small samples and case studies.

The properties of validity and reliability are important to researchers and the researchers consider various types of reliability and validity, each of which addresses a different aspect of a tool (Fitzner, 2007). According Fitzner (2007) the key types of reliability and validity are shown in table 2.

Reliability type	**Description**	**Validity type**	**Description**
Test-retest reliability	The measuring scale's ability to reproduce the same results consistently over time.	Face validity	The subjective assessment of whether a tool or question is a good measure.
Interterm consistency	Test or tool results that are consistent across multiple expressions, whether written or verbal.	Content validity	This is an objective review by an expert panel to determine if the types of questions (items) adequately measure the behavior you are interested in.

Internal consistency reliability	Results that are consistent across multiple items within a test or tool.	Criterion validity	Based on how well your measurement correlates with other approaches for measuring the same behavior and predicts the outcome.
Interrater reliability	The same results are achieved by multiple test takers or interviewers. Applicable to face-to-face interviews as well as telephone interviews.	External and internal validity	Can the results be generalized to other settings or groups? If so, what caused the change or impacts.
		Construct validity	This is the degree of agreement between a theoretical concept and a measurement device or procedure.
		Concurrent validity	Are there other tools that produce similar results? Concurrent validity exists when a new test measures satisfaction with a sample and gives similar results as another measurement that has been validated in the past.

Table 2. Types of reliability and validity (Fitzner, 2007).

In this thesis, all interviews have been recorded. Despite this, the transcript material has not been forwarded to the interviewees to receive their approval for the text to ensure reliability and validity and reduce the possibility of the author's interpretation of the recorded data.

2.2 Literature Study/Review

A systematic literature review is used in this thesis paper to analyze empirical evidence on identifying and characterizing the CBR approach and existing practices in construction cost estimation. Literature reviews are summaries, analyses, evaluations, and explanations of research that have already been conducted in any given field. It is a comprehensive review of the available literature for a given research question. A literature review is a section of a primary research article that aims to provide a theoretical basis for the study described in the article (Okoli and Schabram, 2010). In that capacity, Okoli and Schabram (2010) describes literature reviews as serving multiple purposes. The literature review anchors the rest of a scholarly article. It describes existing knowledge and describes its quality and readily tells the reader the significance of previous work.

There are two primary approaches to reviewing the literature (Paré and Kitsiou, 2017). The most common approach is to write a literature review section in a journal paper or a chapter in a graduate thesis, which synthesizes the extant literature and usually identifies the gaps in knowledge that the empirical study addresses. Furthermore, the theoretical basis of the proposed study can also serve to support the existence of the research problem or validate the methods and approaches to be used in the proposed study. The second type of literature review, which is an original and valuable work of research in and of itself. Instead of providing the basis for a researcher's own work, it provides a solid starting point for all community members interested in a particular area or topic.

Literature reviews perform several functions in scientific manuscripts in research, making them vital. Paré and Kitsiou (2017) presents the importance of literature reviews as:

a. Identifying literature on a particular topic or subject
b. Determine if any trends or patterns can be interpreted in a specific research area.
c. Gathering empirical findings related to a narrow research question to support evidence-based practice.
d. formulating new frameworks and theories
e. selecting topics or questions requiring more examination.

2.2.1 Literature Search Engines and Databases

Various search engines and databases were used to gather literature information for the literature study. A list of the search engines and databases is presented in Table 3. Searches

have been conducted on the different topics using different keywords in the search engine and database to find the information needed.

Search Engine	Description
Google Scholar	Google search is a search engine for academic and scientific literature provided by Google. Among other things, Google Scholar lets you find articles, dissertations, and books based on previous searches. Google searches can also be filtered to narrow down by selecting which years you want to include.
Oria	Oria is the search engine that NTNU University Library owns and uses. Through Oria, one can access the library's printed and electronic collections, including books, articles, journals, master's theses, doctoral dissertations, music, and films. If the books or articles are not found online, they can be ordered and picked up at a library on campus.
Database	**Description**
ASCE Library	The ASCE Library is a database of the American Society of Civil Engineers. ASCE Library publishes the following publications in print and/or electronic form: journals, practice periodicals, conference proceedings, standards, manuals, and reports on engineering practice; committee technical reports; ASCE Press; Bridges wall calendar; and documents related to contracts with engineers, owners, and contractors (ASCE Library, 2022). NTNU provides free access to it.
ScienceDirect/ Engineering village	 Science Direct is a database that allows you to search for journals, articles, books, and magazines. The database is open to all students with an NTNU account.

SpringerLink	SpringerLink is a database that gives researchers access to millions of scientific documents from journals, books, series, protocols, reference works, and proceedings (springerLink, 2022).

Table 3. Search engine

2.3 Interviews

In recent years, the popularity of interviewing as a research method has grown substantially. The interview technique has also been well used in construction management research as a method for collecting and analyzing data. The interview technique is considered qualitative since it is characterized by an in-depth and holistic observation of a unique phenomenon (Hansen, 2021). A typical interview involves the interviewer and the interviewee/respondents (Qu and Dumay, 2011). This type of interview provides qualitative data instead of quantitative data. According to Qu and Dumay (2011) qualitative interviews have been categorized in various ways, with many contemporary texts loosely differentiating qualitative interviews as unstructured, semi-structured, and structured. Based on the purpose of the study, interview questions are either semi-structured or unstructured, as defined by (Donalek, 2005).

Research interviews have been widely used in conducting field studies and empirical research as a primary method of collecting qualitative data (DiCicco-Bloom and Crabtree, 2006). In the Semi-structured interviews, the researcher follows a checklist of issues and questions that wants wishes to cover (Poblete and Grimsholm, 2010). In this thesis, semi-structured interviews are chosen as a qualitative research method. Semi-structured interviews are chosen mainly because the author wished to enable interviewees to discuss their opinions freely. According to Poblete and Grimsholm (2010)), the semi-structured interview is neither a free conversation nor a highly structured questionnaire. Semi-structured interviews offer the flexibility to order the questions in a way that allows respondents to develop their ideas and elaborate on diverse topics rather than relying exclusively on concepts and questions formulated in advance. Thus, semi-structured interviews offer greater flexibility than standardized methods like structured interviews and surveys. Alternatively, in unstructured interviews, the researcher might ask a question and listen as the interviewee speaks freely.

2.3.1 Companies and Respondents

The respondents for this study are selected through contacts by the supervisor, Professor Ole Jonny Klakegg, and the author. The respondents are three, and they are from three different companies.

2.3.1.1 Companies

The three companies are Bygganalyse, Norconsult and Betonmast Innlandet AS.

1. Bygganalyse

Bygganalyse was established in 1986, and its employees own the company. Bygganalyse's primary focus areas are construction economics and descriptions, with the company completing between 400-600 projects per year for private and public builders, individuals, contractors, architects, and other consultants' figure 2.

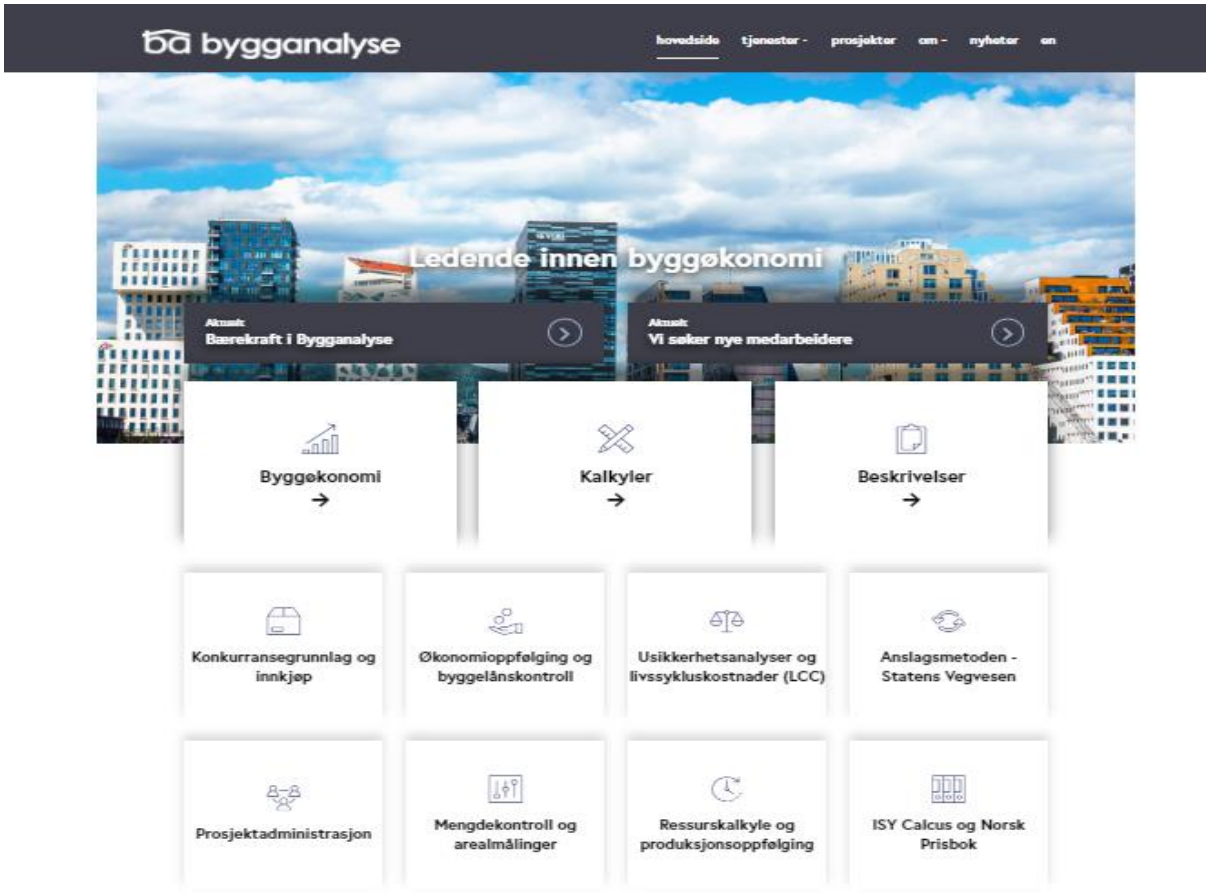

Figure 2. Bygganalyse home page

2. Norconsult

Norconsult is a consulting company that wants to make tomorrow's society a little better than today. Norconsult provides sustainable, efficient, and socially beneficial solutions backed by professional knowledge and innovation. Every year, Norconsult solves thousands of small and large assignments for private and public clients. Its expertise includes construction, real estate, transport, renewable energy, water and sewage, industry, environment, security, architecture, planning, and information technology.

3. Betonmast Innlandet AS

Betonmast Innlandet AS is a solution provider in the building and construction industry. The company performs all construction work, including schools, commercial buildings, homes, shopping centers, and care homes. Betonmast Innlandet AS was established as Toten Building and Engineering in 1977 and had a strong reputation in its field. Highly qualified professionals carry out all concrete and carpentry work within the company with a sizeable in-house production facility. Betonmast Innlandet AS has Hadeland, Toten, Gjøvik, Hamar and Lillehammer as its area.

2.3.1.2 Respondents

The three respondents are Olle Rudén from Bygganalyse, Håvard from Norconsult and Ruune Sagvold from Betonmast Innlandet AS.

1. Olle Rudén is an engineer and Senior Advisor Building Economics in Bygganalyse company. He is Chairman of the Board and have a 30 years' experience in the field.
2. Håvar Slåtten is a civil engineer working in Gjøvik office.
3. Ruune Sagvold is a calculator at Betonmast Innlandet AS. He has many years of experience as a timber worker.

3 Theoretical Review

In this chapter, the literature review undertaken for this study is summarized and forms the theoretical framework for the study. There are two parts: theory on general construction cost estimation and CBR in construction cost estimation.

3.1 Cost Estimation

This section describes the definitions and concepts of cost estimation, the types/ elements of cost estimation, the importance of accurate estimation of construction costs, and factors affecting construction costs' accuracy. Additionally, it talks about different types of cost estimation. It mentions previous work to create a list of factors that may affect cost estimation for building construction projects.

3.1.1 Definition and Concept of Cost Estimation

In general, cost estimation in a construction project is the near prediction of the actual cost of the project. However, different researchers and experts define cost estimation differently. The process of cost estimation defined by Bakr (2019) as the prophetic operation of quantifying the amount of financial resources required to set up the budget of the project. The cost estimating was also defined by Asal (2014) as a technical process of predicting costs of construction. Cost estimating describes as the basis for project management, business planning, budget preparation, and cost and schedule control (Asal, 2014).

In general, Cost estimation of a project is the process of forecasting the probable cost for the due fulfillment of the project objectives, to the prescribed workmanship covered by specifications for various items of works and to the stipulated time schedule (The Constructor, 2020). Asal (2014), also considers that cost estimation is the determination of quantity and the predicting or forecasting “within a defined scope” of the costs required to construct and equip a facility, to manufacture goods, or to furnish a service. It also includes establishing financial plans, estimates and project’s budget and involves the cost control procedures required to avoid the cost overrun (Bakr, 2019).

3.1.2 Elements of Cost Estimating

Cost estimation is much more than just a simple list of project costs (Paige, 2021). Each work component is described, including the assumptions behind each cost, inclusions and exclusions, and risks associated with the project. Cost estimation includes two main categories: direct costs and indirect costs (Asal, 2014, Kullvén and NYBERG, 2014) as shown in figure 3.

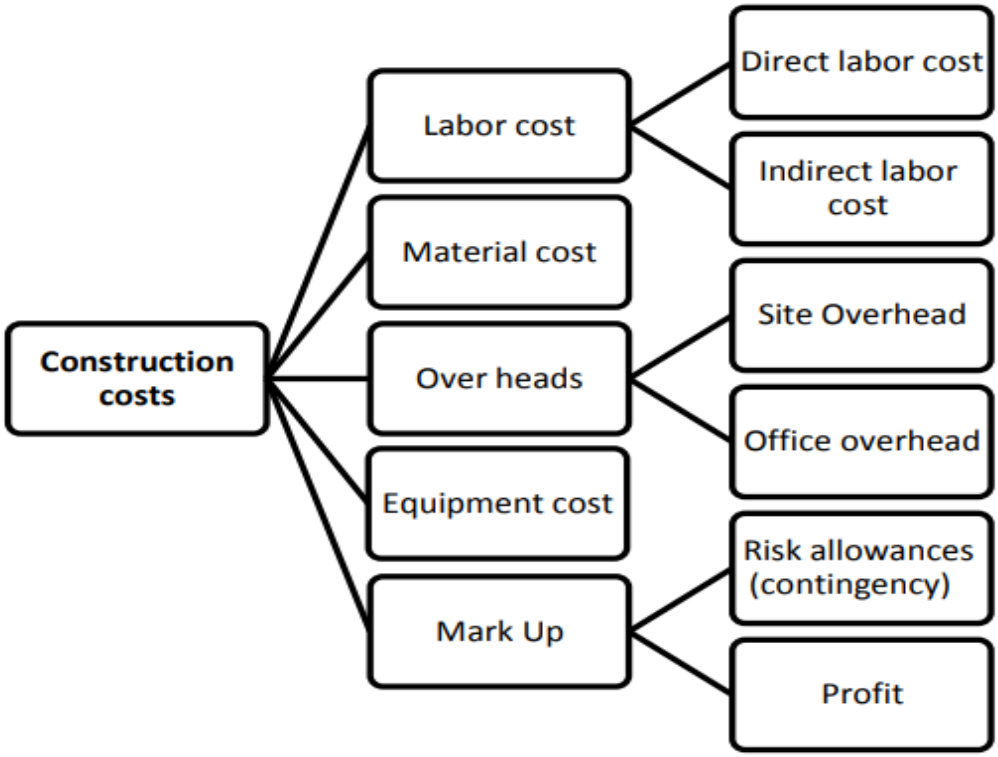

Figure 3. Classification of construction cost (Shehatto, 2013).

Direct costs: the direct costs are associated directly with the project which are related to completing the work required for its completion (Paige, 2021, Asal, 2014). Labor, materials, equipment, travel costs, etc., are some of the costs included in direct costs as described below (Lucidchart, 2019). Lucidchart (2019) describes travel costs as expenses incurred to complete a project. Travel costs include gas, airline tickets, and hotel stays that are spent on completing the project.

Labor costs: the labor cost of a project is the sum of salaries and time spent by human resources (Paige, 2021, MURRAY, 2021). Each project has a labor rate and hours estimate. Staff salaries and wages for contractors working on the project are also included in labor costs (Lucidchart, 2019). MURRAY (2021) states that labor costs are the most expensive part of a project.

Materials costs: the material costs are the costs associated with buying and maintaining materials for a project. Material costs vary significantly according to market demand and supply, quantity required, and transportation costs to the job site (South Bay Construction, 2020).

Equipment and facility costs: equipment and facility costs refer to the costs of the equipment and facilities necessary to produce the project's deliverables or accomplish the project's objectives (Lucidchart, 2019). Facility costs are incurred by a business when it uses a working space that it does not own (Paige, 2021). Several factors affect equipment costs, including equipment capacity and the price difference if the equipment is rented rather than owned (South Bay Construction, 2020).

Vendor's and subcontractor's costs: vendor's and subcontractor's costs are the costs associated with hiring a third-party contractor (Paige, 2021). Specialty trades are usually employed as subcontractors to accomplish portions of the project. Their quotations should consider labor, materials, and equipment costs in the same way as the general contractor (South Bay Construction, 2020).

A risk/continuity cost: A risk/continuity cost is an additional cost added to the estimate to account for unforeseen costs (such as travel, technical support, client visits, and admin costs) (Paige, 2021).

Indirect costs: the indirect costs are those expenses that do not become part of the final product but are necessary to complete the project (Asal, 2014). The indirect costs include field administration, direct supervision, capital tools, contractor's fees, insurance, taxes, land acquisition, permits, design fees, office support, on-site utilities, electricity, waste disposal and mobilization (Paige, 2021, South Bay Construction, 2020, Kullvén and NYBERG, 2014). Indirect costs must be always accurately estimated to avoid failure in a construction project.

3.1.3 Accuracy of Cost Estimation and its Importance in Construction Projects

The term accuracy in cost estimation describes how close an estimate is to the actual value. The accuracy of estimating may also refer to the level to which the end price outcome may differ from the single point value used in the project's estimate (Bakr, 2019). Accurate cost estimation by professional construction estimators is critical in creating and maintaining a feasible budget of project costs (South Bay Construction, 2020). The purpose of cost estimation is to predict the quantity, cost, and price of the resources required to complete a job within the project scope. Cost estimates are used to bid on new business from prospective clients and to inform your job and budget planning process (Paige, 2021).The accuracy of cost estimating in a construction project is essential because it significantly affects the construction industry. For instance, it may seriously affect the contractor's ability to compete

successfully with other contractors and significantly impact the contractor's profit (Asal, 2014).

In the early stages of the project, accurate cost estimating is a significant for all contract participants, including the client, contractor, consultant, and other team members. It is important to compare forecasts of similar nature and size to establish parameters of possible effects of this degree of accuracy. Bakr (2019) and South Bay Construction (2020) describes the importance of accuracy in construction cost estimation as follows:

- The level of accuracy related to cost estimation at the tender stage is a very significant indicator of the analysis's effectiveness. If an estimator estimates a higher cost than the actual one, the estimator may lose the client's trust.
- The accuracy of the estimate may be determined by the difference between the initial estimate and the minimum acceptable bid.
- An estimate's accuracy is determined by the estimator or estimators involved in its preparation, the way it was conducted, the knowledge of the project, and the other factors considered.
- Always estimators 'initial estimate will be the same as the project's final price
- Make important choices
- determining the feasibility and profitability of a potential project
- make important decisions about changes in project design and/or materials that affect cost positively or negatively
- an accurate estimation keeps all parties focused on delivering a project on time and under budget.
- developer and construction company accountable for increased costs and overruns.

3.1.4 Advantages of Accurate Cost Estimates

Cost estimation aims to determine an accurate and cost-effective estimate of the costs of a project, analyzing different methods for its implementation. Moreover, data accuracy is the key to accurate estimates. Thus, the cost estimation process involves a large amount of information collection about the project, the likely consumption of resources, and future changes in their costs. Therefore leveraging previous job data and learning from past projects is the key to creating accurate estimates. (Paige, 2021). According to the Paige (2021), some of the benefits associated with producing accurate cost estimates descried below.

Accurate planning: Develop a work breakdown schedule that assigns work to your staff, adheres to projected timelines, and accurately predicts the tasks and resources required to complete work.

Increase profit margins: Many factors (like unexpected events, poorly scoped work, or inflation) can increase the cost of a job throughout its life cycle, affecting the completion of the job within budget and profitability targets. A correct estimate accounts for expected and unexpected costs and protects your profit margins.

Improve resource management: With better knowledge of the tasks and timelines necessary to complete work, one can assess the specific skills needed to complete each deliverable, identify resourcing gaps, hire additional people, and take on new projects confidently.

Improves client relationships: When clients know the reasoning behind a project's cost, they are more likely to trust your expertise and expect changes to the cost estimate as the project progresses, resulting in better working relationships.

Improved reputation and repeat business: Delivering projects on time and on a budget will ensure happy customers, continued business, and references.

3.1.5 Factors Affecting Accuracy Cost Estimation

Previous studies suggest that many factors can affect the accuracy of an estimate (Aibinu and Pasco, 2008). Table 4 lists factors that affect the accuracy of cost estimation in a construction project (Ibrahim and Elshwadfy, 2021, Hatamleh et al., 2018, Aibinu and Pasco, 2008).

Researchers	**Region**	**Factors affecting accuracy of cost estimate**
Akintoye (2000)	UK	Project complexity followed by technological requirements, project information, project team requirement, contract requirement, project duration and market requirement.
Enshassi et al.	Gaza Strip	Location of the project, segmentation of the Gaza strip and limitation of movements between areas, political situation, and financial status of the owner.
Elhag et al. (2005)	UK	Absence of alterations and late changes to design (no “design-as-we-go” on site philosophy), management

		team (suitability, experience, performance), priority on construction time/deadline requirements, variation orders and additional works (magnitude, timing, interference level), completeness and timeliness of project information (design, drawings, specifications), intensity/ complexity of building services, quality of design and specifications, complexity, level of competition and level of construction activity, certainty of project brief.
Chan and Park (2005)	Singapore	High technological level; contractor's specialized skills; and public administered contract have significant effects on cost. Other factors include contractor's technical expertise; owner's level of construction sophistication and contractor's financial management ability.
Toor and Ogunlana (2008	Singapore	Lack of resources, poor contractor management, shortage of labor, design delays, planning and scheduling deficiencies, changed orders and contractors' financial difficulties were also highlighted during the interviews. Notably, problems such as "multicultural and multilingual environment causing ineffective communication", "large number of participants of project" and "involvement of several foreign designers and contractors".
Odusami and Onukwube (2008)	Nigeria	Expertise of consultants, quality of information and flow requirements, the project team's experience of the construction type, the tender period and market condition, extent of completion of pre-contract design, and the complexity of design and construction.
Verster and Ramabodu	South Africa	the change in scope of work on site, incomplete design at the time of tender, contractual claims (extension of time with cost), lack of cost planning

		and monitoring of funds, and delays in costing variations and additional works.
Alumbugu et al. (2014)	Nigeria	Experience and skill level of the consultants, Project teams experience on the construction type, clear and detail drawings and specification, completeness of cost information, accuracy and reliability of cost information.
Azman et al. (2013)	Malaysia	Contract period, use of mean of the bids, availability of design information, proper cost planning, using of historical cost data.
Clear and detailed drawings and the number of drawings, specifications, and project documentation. Experience and skill level of estimators. Completeness of cost information, accuracy, quality, and details. Materials (price intensity, availability, quality, imports). Experience on a similar project. Accuracy of the bill of quantity (BOQ). Management team (suitability, experience, performance). Financial capability. Quality of assumptions used in preparing the estimate. Project complexity of design and construction. building function, type of contract. conditions of contract. contract sum and period. number of bidders. procurement basis. project sector (public, private, or joint).		

Table 4. Factors that affect the accuracy of cost estimation

3.2 Case-Based Reasoning (CBR)

This section describes the literature review for the case-based reasoning. It discusses and explains the historical background, definition, and concept of CBR, attributes, and similarities of CBR, four phases of CBR, development/construction of CBR, and CBR in construction cost estimation.

3.2.1 Historical Background and Concept of Case-Based Reasoning (CBR)

The inspiration for the CBR concept was derived from the role of reminding in human reasoning and how people acquire new skills and form hypotheses about new situations based on their past experiences (Ji et al., 2012). In other words, CBR is a type of human reasoning that reflects how people typically solve problems. The concept of case-based reasoning (CBR) was first originated from the work of cognitive scientists Shepperd and Schofield in 1977 (Ji et al., 2011b) as an alternative to expert judgment and algorithmic methods to estimate software costs (Li et al., 2009).

As Ji et al. (2012), noted, CBR has been used in various fields such as medical knowledge discovery, managerial decision support, educational applications in healthcare management, and diagnosis of power transformer faults. Additionally, experience-oriented sectors like construction, where analyzing past projects is critical to preventing recurrences. The construction industry has recently focused on case-based reasoning as a decision-making tool. In this context, various CBR studies have been conducted, more specifically, to estimate costs, select international markets, decide when to manufacture, plan/schedule production, safety hazards identification, and litigation outcomes prediction (Ji et al., 2012).

3.2.2 Definition of Case-Based Reasoning (CBR)

There is no universally accepted definition of Case-Based Reasoning (CBR), but most of the definitions are similar to some level to each other; as such, Shokouhi et al., 2014 defined Case-based reasoning (CBR) as artificial intelligence (AI) concerned with solving problems by reusing past experiences. That is case-based reasoning is an approach to problem-solving and decision-making where new problems are solved by finding one or more similar previously solved problems and reusing them in new problem situations.

KETLER, K. (1993) agree with Li et al. (2009) that Case-based reasoning is a computerized method that attempts to analyze solutions that were applied to solve problems in the past so that they can be used to solve the current case through analogy or association. CBR's basic

concept is simple when estimating a new project, and similar historical projects are selected to predict a new project's cost based on similarity measures.

Jin et al. (2014) defined CBR as a kind of data mining technique that can solve a new problem by deducing situations used previously to solve existing problems and reusing information from such cases to solve the new problem. This idea is rooted in the notion that similar solutions can address similar issues. As such, the main objective of this method is to retrieve previous cases related to the current one effectively.

2.2.3 CBR Publications in Construction Cost Estimation

Many studies have used the CBR technique to predict construction costs in the planning stage of a project by knowing the value of previous experiences in predicting construction costs and other areas like duration, dust, and sustainability (Jin et al., 2012). The author presents the application of CBR in construction cost estimation that are published over years as shown in table 5.

Researchers	**TITLE**
(Ji et al., 2012)	Case Adaptation Method of Case-Based Reasoning for Construction Cost Estimation in Korea
(Jin et al., 2014)	Improving Accuracy of Early-Stage Cost Estimation by Revising Categorical Variables in a Case-Based Reasoning Model
(Kwon et al., 2019)	Compensation Cost Estimation Model for Construction Noise Claims Using Case-Based Reasoning
(Kim and Kim, 2010)	Preliminary Cost Estimation Model Using Case-Based Reasoning and Genetic Algorithms
(Ji et al., 2011b)	Military Facility Cost Estimation System Using Case-Based Reasoning in Korea
(Hyari et al., 2016)	Conceptual Cost Estimation Model for Engineering Services in Public Construction Projects
(An et al., 2007)	A case-based reasoning cost estimating model using experience by analytic hierarchy process
(Jin et al., 2012)	MRA-based revised CBR model for cost prediction in the early stage of construction projects

(Relich and Pawlewski, 2018)	A case-based reasoning approach to cost estimation of new product development
(Hu et al., 2016)	The application of case-based reasoning in construction management research: An overview
(Ahn et al., 2017)	Covariance effect analysis of similarity measurement methods for early construction cost estimation using case-based reasoning
(Ahn et al., 2020)	Performance evaluation of normalization based CBR models for improving construction cost estimation
(Zima, 2015)	The Case-Based Reasoning Model of Cost Estimation At The Preliminary Stage Of A Construction Project
(Hyung et al., 2019)	Improved similarity measure in case-based reasoning: a case study of construction cost estimation
(Zhou et al., 2021)	A CBR-based power engineering cost estimation method
(He, 2014)	A framework of combining case-based reasoning with a work breakdown structure for estimating the cost of online course production projects
(Thibault et al., 2006)	A Framework for Using a Case Based Reasoning System Applied to Cost Estimation
(Wu and Huang, 2008)	Application of a case-based reasoning method in estimating the power grid project cost
(Yau and Yang, 1998)	Case-Based Reasoning in Construction Management
(Ketler, 1993)	Case-Based Reasoning: An Introduction
(Watson, 1999)	Case-based reasoning is a methodology not a technology
(Shokouhi et al., 2014)	An overview of case-based reasoning applications in drilling engineering
(Finnie and Sun, 2003)	R 5 model for case-based reasoning
(Jung et al., 2020)	Construction Cost Estimation Using a Case-Based Reasoning Hybrid Genetic Algorithm Based on Local Search Method
(Morcous et al., 2002)	Modeling Bridge Deterioration Using Case-based Reasoning

Table 5 CBR publications on CBR application on cost estimation over years.

3.2.4 CBR Publications in Years

The case-based reasoning (CBR) approach is widely used in construction management (CM) research due to the related ways of solving problems. No systematic review has examined CBR use in previous CM studies. As a result, we need to know how CBR is currently used in CM. Using content analysis, Hu et al., (2016) evaluates CM-CBR articles published between 1996 and January 2015 in an extensive literature review. According to Hu et al., (2016), CBR applications in CM research became more popular after 2006, with a majority coming from South Korea. Furthermore, 17 CBR application fields are outlined, with research interests primarily concentrating on construction cost estimation, construction tendering, bidding, procurement, and environmental and sustainability management.

Hu et al., (2016) reviewed the CM-CBR publications over time and found an average of 4.74 publications per year from 1996-to-2014, and the most publications in 2014 reached 11. The publications are illustrated in figure 4 and clearly shows that the average annual number before 2006 was less than four and has increased since then. The publication trend also increases in recent years.

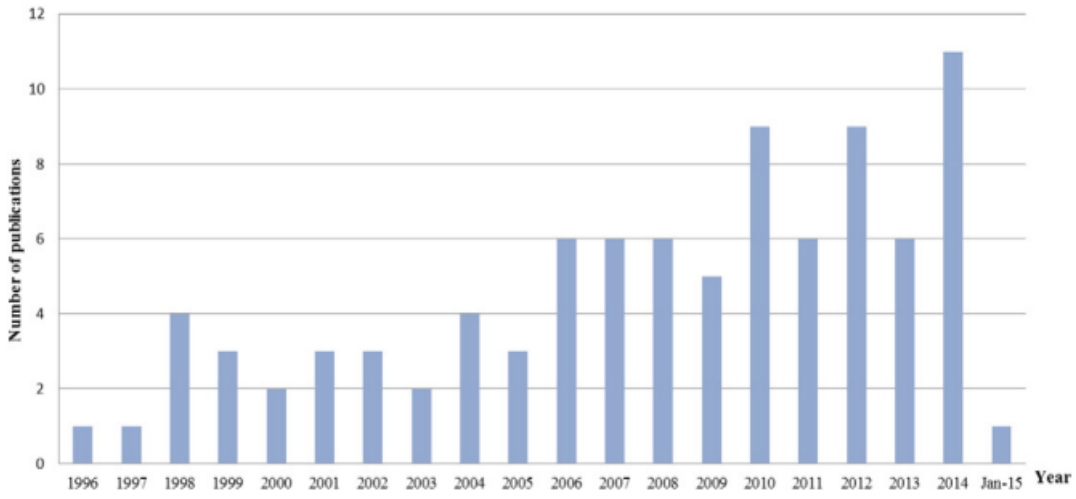

Figure 4. Publications trend of CM-CBR in years (Hu et al., 2016).

Geographically, the application CM-CBR is distributed differently. It is more dominant in the far East part of the world. Hu et al., (2016) have reviewed the publications from 2006 to 2014 about the application of CM-CBR based on geographical areas and found that 34 articles are published in the South Korean context, which accounts for 37.4% of all articles, followed by Taiwan (7), Australia (6), Canada (6), and United Kingdom (6). In addition, 3.3% of articles are multi-country based, and 9 publications do not specify their research context as shown in figure 5 and table 6.

Code	Countries	Number of publications	publications %
1	South Korea	34	37
2	Taiwan	7	8
3	Australia	6	7
4	Canada	6	7
5	United Kingdom	6	7
6	United States	4	4
7	Singapore	4	4
8	Turkey	4	4
9	Hong Kong	2	2
10	China	1	1
11	Egypt	1	1
12	Greek	1	1
13	Iran	1	1
14	Portugal	1	1
15	Switzerland	1	1
16	Multi-country	3	3
17	Unspecified	9	10
total		91	100

Table 6. CBR publication based geographic distribution (Hu et al., 2016)

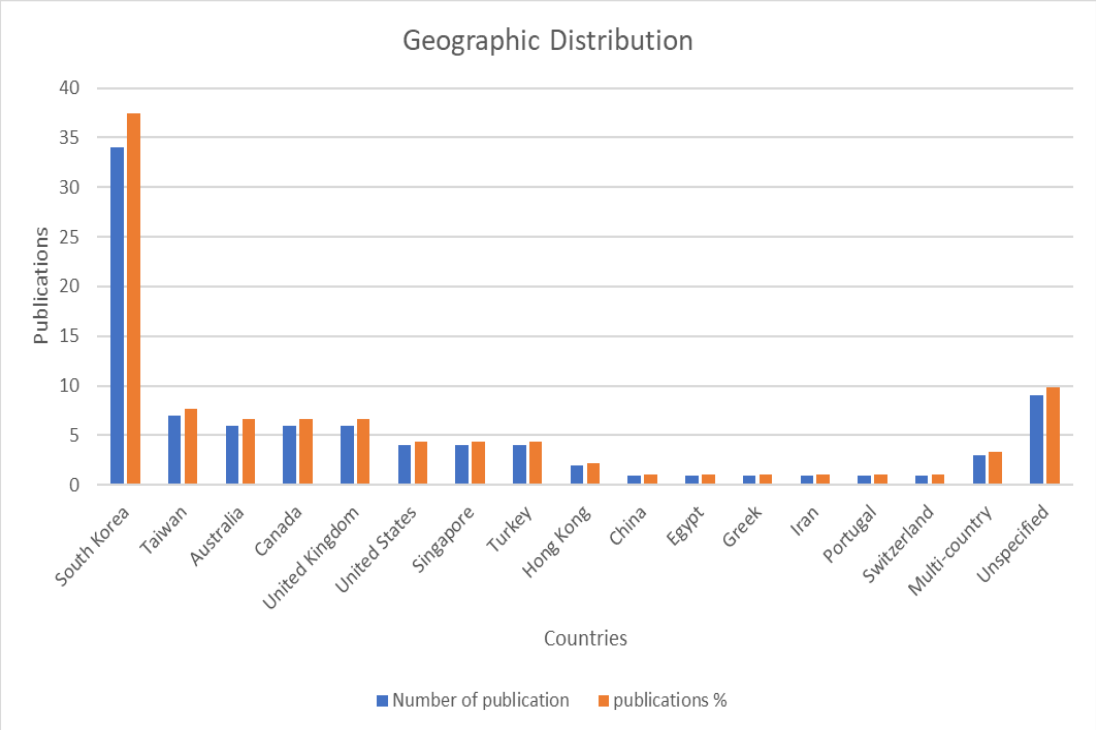

Figure 5. CBR publications based on geographic distribution (Hu et al., 2016).

3.2.5 Four-Phased Case-Based Reasoning (CBR) Cycle Process

The operation cycle of the case-based reasoning (CBR) can be summarized in four Rs (Zima, 2015). That is the CBR technique has four distinct phases; retrieve, reuse, revise, and retain as shown in figure 6 (Jin et al., 2014, Jin et al., 2012, Ahn et al., 2020) and described below.

- **Retrieve:** The most similar previous cases are retrieved from the case base (Jin et al., 2014) . This phase is concerned with retrieving the previous case that is most similar to the current one from the case base (Jin et al., 2012). Ahn et al., (2020) described that retrieved information is vital in predicting the values of target features of a new problem.
- **Reuse:** The information on the retrieved cases is reused to solve the new problem (Jin et al., 2014). Reuse: In this phase, the information and knowledge from the retrieved case are used to solve a problem (Jin et al., 2012).
- **Revise:** If the retrieved cases do not fit into the new problem, the solutions used for the retrieved cases are revised based on the differences between the new problem and the retrieved cases (Jin et al., 2014). If the retrieved case is not suitable for solving the new problem, this phase analyzes the difference(s) between the new problem and the retrieved case and revises the retrieved case accordingly (Jin et al., 2012).
- **Retain:** Retaining the cases and findings for future use (Ahn et al., 2020). This phase stores the solution proposed from the retrieved case in the case base for future problems (Jin et al., 2012).

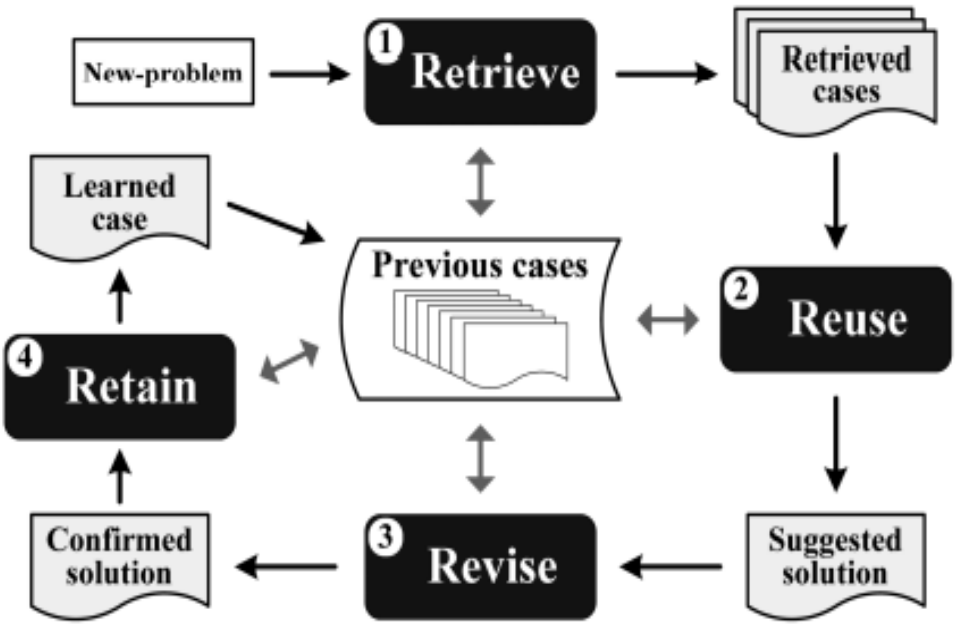

Figure 6. CBR cycle process (Jin et al., 2014).

3.2.6 CBR Cost Estimation Model Development

CBR's cost estimation model has consistently provided strategic and conceptual estimates for construction budgeting (Ji et al., 2012). However, different researchers and experts developed different structures even though the principle is similar and the same. The following steps are the most common process in the model development CBR cost estimation.

Setting a Case Base: CBR models can estimate construction costs by first collecting previous cases. First, determine what attributes (variables) should be stored in each case to retrieve the most similar case from the case base effectively. Similar cases can be extracted by selecting attributes used in previous studies, determining the attributes through expert interviews, or selecting attributes with the most significant frequency used in previous studies (Jin et al., 2014). In this case, four steps are essential to considered when construct a case base:

a. Analysis of related studies to identify attributes available in the early stages of construction projects.
b. Cases are collected based on the collectible attributes identified from previous studies.
c. Select attributes that significantly affect the construction cost estimation using stepwise regression analysis.
d. In the end, used the remaining attributes to create a case base for model development.

Setting the Attribute Weights: Important attributes must be given more weight than unimportant attributes to retrieve the most similar case during the retrieved phase of the CBR cycle. Various methods (RA, NNs, GAs) can be also used in studies to determine attribute weights. Models that use the attribute weights based on RA or GA produce better results than models that use without (Jin et al., 2014).

Calculating the Attribute Similarities: Similar cases can retrieve in three approaches are used: the inductive retrieval method, the knowledge-based retrieval method, and the nearest neighbor algorithm (Jin et al., 2014). The similarity of the attributes can be calculated in different ways.

Calculating the Case Similarities: Case similarities (CSs) are calculated by combining the attribute similarities (ASs) and the attribute weights (AWs). Following the determination of ASs and Aws, can then be used to calculate the overall similarity of a case (Jin et al., 2014).

Selecting a Case with the Highest Case Similarity: the primary purpose of calculating case similarities in the CBR technique is to extract the most similar case from the case base, based on the assumption that the cases with the highest case similarity (HCS) have characteristics that are most related to those of the new (Jin et al., 2014).

Developing the CBR cost model follows a similar procedure, even though researchers use varying steps; some use seven steps, while others use five steps, as shown in figures 7 and 8.

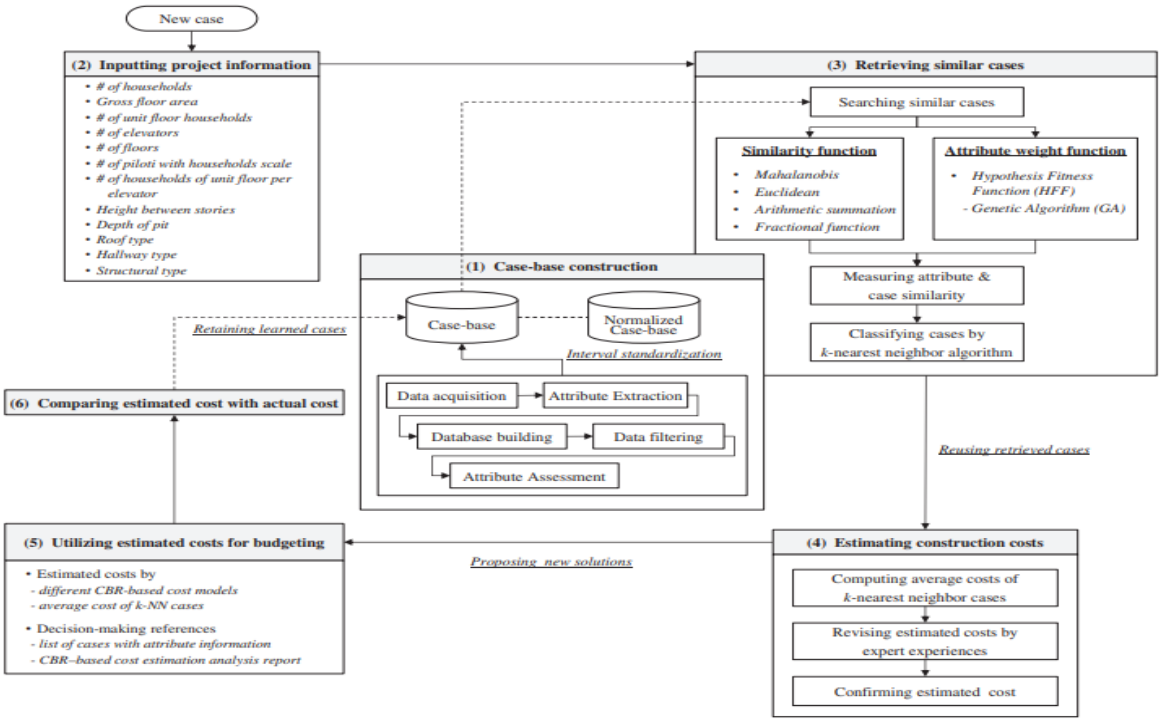

Figure 7. CBR development cost model (Ahn et al., 2017)

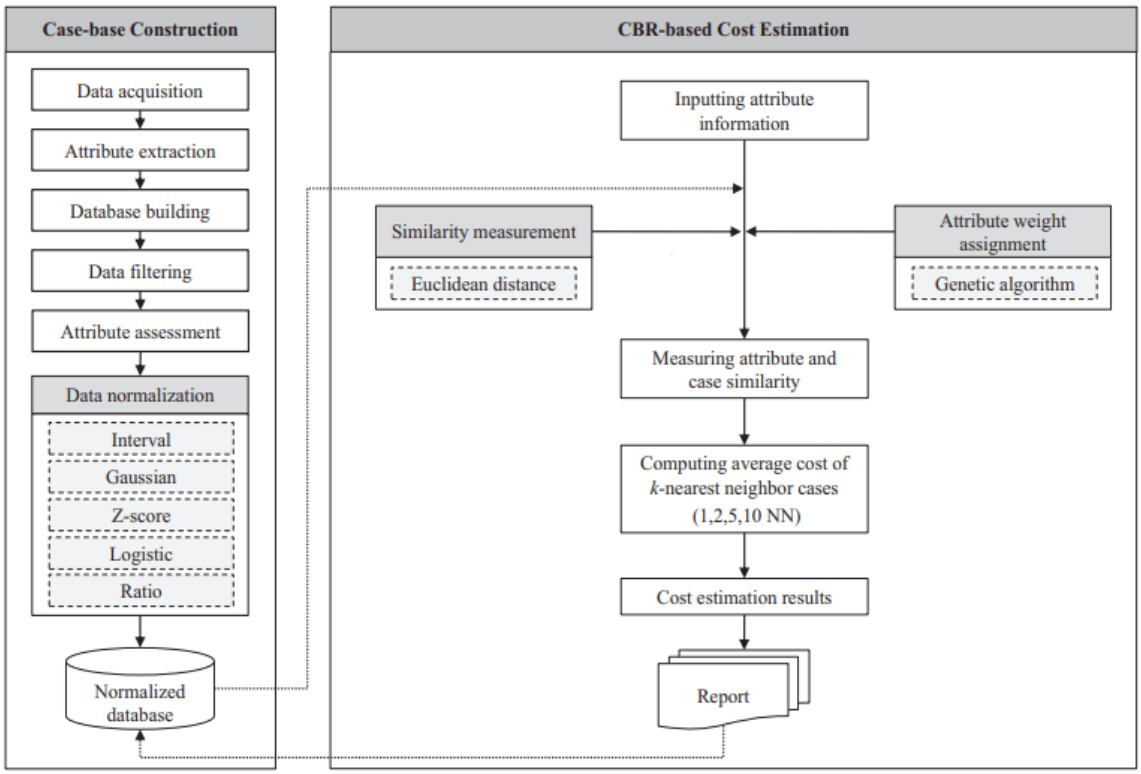

Figure 8. CBR cost model (Ahn et al., 2020)

Attributes and similarity are two important terms in CBR model development. Identifying the main attributes that significantly affect construction costs is necessary before developing a

CBR-based cost estimating model (Kim et al., 2012). Thus, the attributes can act as inputs into the model. The similarity is usually a fundamental concept in CBR. This concept of similarity always depends on the underlying context of a particular application, and it does not convey a fixed characteristic that can apply to any comparative context (Ji et al., 2011a). According to Ji et al., (2011a), CBR has two major retrieval approaches. One approach is measuring case similarity by computing the distance between the cases. The other approach focuses more on the representative or indexing structures of the case, which is intended to be applied to text-based applications. A similarity assessment compares the test case characteristics with those of the cases in the case base systematically (Jin et al., 2012).

3.2.7 CBR Application in Construction Sector

Planning a new construction project (such as scheduling, budgeting, and resource allocation) requires extensive knowledge and experience from previous projects. This suggests that CBR is an appropriate application for construction. A CBR technique is widely used in numerous construction management fields, including landscape design, architectural design, bid decision making, international market selection, safety hazard identification, and construction litigation (Jin et al., 2014). Moreover, CBR is also applicable in other construction management areas than just cost estimation. For instance, Yau and Yang (1998) found that CBR is potentially appropriate to various phases of a typical construction project's life cycle, as shown in figure 9 and summarized in table 7.

Life-cycle phase	**Potential application areas**
Feasibility study	Risk analysis and feasibility analysis.
Conceptual planning	Project requirements in design, cost, and duration.
Preliminary design	Design system selection, conceptual time and cost estimates, selection of construction methods.
Detail design	Architecture design, design review criteria, time, and cost predictions.
Procurement and contracting	Selection of contractors, bidding price prediction, preparation of bidding documents.
Construction	Site layout, schedule generation and control, budgeting and cost control, quality control, safety inspection, resource management.
Operation and maintenance	Operation problems resolutions

Dismantle and rebuild	Construction product assessments

Table 7. Construction project Cycle Process (Yau and Yang, 1998).

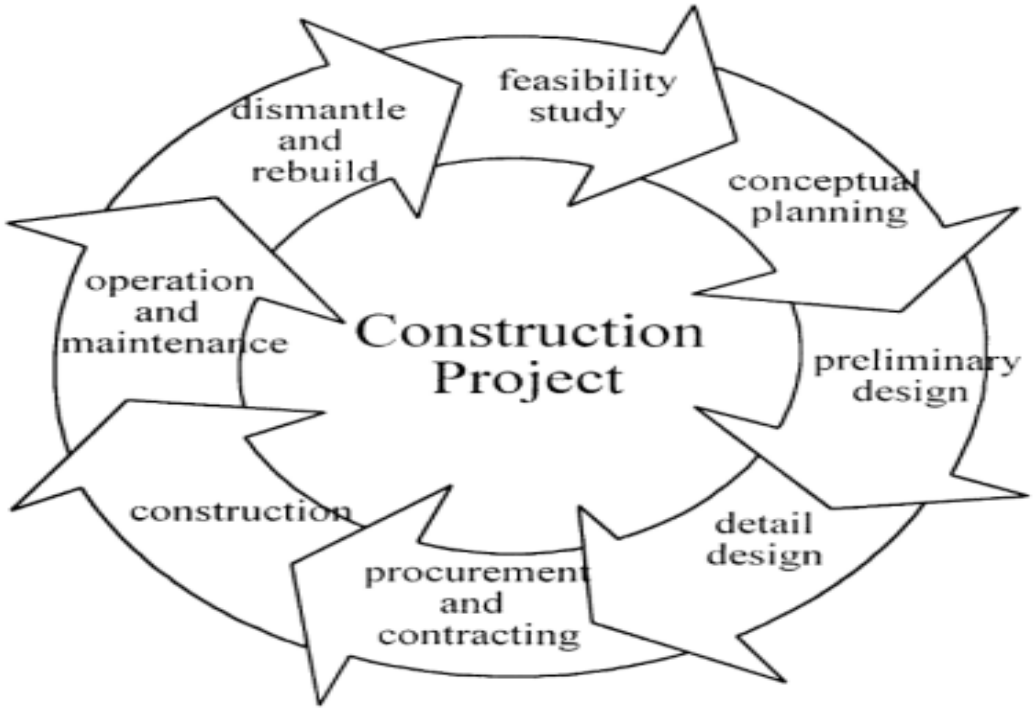

Figure 9. Application of CBR and Life cycle of construction (Yau and Yang, 1998).

3.2.8 Database in Case-Based Reasoning (CBR)

CBR-based construction cost prediction models require the collection of existing cases and creating a case base. When the model attempts to predict the cost, each case base contains collectible information (attributes). There are several methods to select attributes to retrieve similar cases in CBR cost model process. for example, Jin et al., (2012) explains that collecting the data base to retrieve similar case and create CBR cost model by:

- Use attributes from previous studies.
- Derive attributes from expert interviews.
- Select attributes based on the highest frequency in previous studies.

Each collected case data base must come from the same building type and branch, such as contractor-contractor, client-client, or consultant-consultant. Projects are divided into parts

and elements. for example, dataset/attributes from a bridge does not match dataset/attributes from the school building.

For example, figure 10 presents project that includes construction works consisting in removal of the hummus layer, making the sub-base and paving the area around the field with setts as well as installation of the field surface.

Main group	Index	Subgroup
Construction works	R1010	Removal of hummus
	R1020	Excavation and Fill
	R2010	Subbase Layer
...	...	...
Elements	E3010	Pavement surfaces
	E4010	Pedestrian Pavement Curbs
...	...	...
	E5010	Sports fields surfaces
...	...	...
	E7010	Sports Equipment
	E8010	Protective/safety nets
...	...	...

Figure 10. Breaking down into construction elements of database (Zima, 2015).

Table 8, presents an example of weights of attributes

Attributes	Equal weight	Gradient descent method	AHP
Gross floor area (m^2)	0.1111	0.2157	0.2200
Number of storeys	0.1111	0.1168	0.0490
Total unit	0.1111	0.1798	0.1010
Unit area (m^2)	0.1111	0.1447	0.1840
Location	0.1111	0.1052	0.1230
Roof types	0.1111	0.0225	0.0480
Foundation types	0.1111	0.0690	0.1090
Usage of basement	0.1111	0.0226	0.0340
Finishing grades	0.1111	0.1237	0.1340
Total	1.0000	1.0000	1.0000

Table 8. weights of attributes (An et al., 2007).

3.2.9 Application Case-Based Reasoning (CBR) in Construction Cost Estimation

Several studies have demonstrated that CBR can effectively estimate construction costs in the early phase. Jin et al., (2014) proved that CBR is applicable and effective in estimating construction cost. Similarly, Ahn et al., (2017) mentioned that CBR is an early cost estimation method that retrieves and reuses either historical cost values or data used for cost estimation, for example, quantities of representative items. Jin et al., (2012) also demonstrated how CBR could be used to predict construction duration and costs during the preliminary design stage of a construction project. Furthermore, An et al., (2007) proved that the CBR construction cost estimation model is an effective method that reuses the experience of experts from previous cases to obtain the cost of a new project.

3.2.10 Comparison CBR with other methods

Compared CBRs' cost estimation accuracy with that of NNs and RA. Despite higher prediction performances for the ANN model, the CBR model was superior to the two other models (NNs and RA) regarding long-term use, remaining knowledge from the data, and time versus accuracy tradeoffs. As such, the CBR technique is highly applicable to construction cost estimation. Comparing case-based reasoning to other artificial intelligence techniques, it uses a concrete history of past cases to solve new problems, and it stores these solved new problems as case-based historical cases that can be used in the future(Jung et al., 2020).

Despite both CBR and ANN being artificial intelligence, CBR is the most widely used technique in cost estimation for construction projects. The concept of the two models, however, is quite different, as well as one method is preferable to the other. The processes and phases are also different in each model as shown in the Table 9.

Artificial neural networks (ANN)	**Case base reasoning (CBR)**
is based on the concept of generalized knowledge.	is based on the concept of specialized knowledge.
data patterns used in developing the model are disregarded afterwards and the model is used independently.	data used in model development are an indispensable component of the model,

is highly dependent on the quality of training patterns and on how close user inputs to these patterns are.	does not produce any answers for very low similarities when the case library does not cover the user input.
inconsistency of some patterns significantly affects the overall performance of the model, which sometimes leads to undetectable errors that cannot be tracked.	model specifies exactly the case(s) that are retrieved and allows the user to track these cases, their circumstances, and solutions.
provide less percentage correct predictions when a high level of accuracy was required with an error of only 0.1 was allowed, while it was able to provide 100% correct prediction when an error of 1.0 is allowed.	provide high percentage correct predictions with an error of 0.1 or less, while it could not provide any prediction for 7% of the cases even when an error of 1.0 is allowed.

Table 9. Comparison between CBR and ANN

4 Established practices in Cost Estimation in Construction

4.1 Available guidelines and experience from the web, companies, etc.

Today different companies use cost estimation software combined with spreadsheets to do the cost estimation of construction projects. Moreover, the spreadsheet method is more prevalent among companies worldwide because most construction and remodeling companies use simple spreadsheets over complex and costly estimating software. This simple tool indicates the areas where estimates are high and low, which is essential to accurate estimations. For example, BuildingAdvisor.com use estimating and budgeting spreadsheet to track and calculate; labor and material cost estimates, estimate actual variance, the amount paid/due to vendors and subs, and the percent complete of each work item (BuildingAdvisor.com, 2022). The spreadsheet is easy to customize for any building project, as shown in the figure 10.

	A	B	C	D	E	F	G	H	I	J	K
1	BuildingAdvisor.com	ESTIMATING & BUDGETING WORKSHEET V3.3.1									
2	BEST CONSTRUCTION CO.		SMITH JOB								
3	DESCRIPTION	VENDOR OR SUBCONTRACTOR	LABOR	MATERIALS	TOTAL	ACTUAL COST	VARIANCE	% Complete	CURRENT PAID	AMOUNT DUE	NOTES
178	Exterior Foam Sheathing	ABC Lumber	$550.00	$950.00	$ 1,500.00	$1,400.00	$100.00		$1,400.00	$ -	2 in. Styro
179	Weather Barrier (Tyvek, etc.)	ABC Lumber	$1,100.00	$320.00	$ 1,420.00	$1,420.00	$0.00		$1,420.00	$ -	
180	Metal Flashing	Tin Knockers	$400.00	$350.00	$ 750.00	$725.00	$25.00		$725.00	$ -	
181	Membrane Flashing	ABC Lumber	$200.00	$225.00	$ 425.00	$425.00	$0.00		$425.00	$ -	Ice & Water
182	Vinyl or Composite Siding				$ -					$ -	
183	Wood Siding	Cedar Ltd	$3,780.00	$6,350.00	$ 10,130.00	$11,300.00	($1,170.00)		$5,000.00	$ 6,300.00	KD red cedar
184	Brick Veneer				$ -					$ -	
185	Stone Veneer				$ -					$ -	
186	Stucco				$ -					$ -	
187	Fascia, Soffit, Frieze, Corner Boards, Water Table	ABC Lumber	$2,400.00	$4,000.00	$ 6,400.00	$6,600.00	($200.00)		$3,000.00	$ 3,600.00	Select pine
188	Soffit/Gable Vents	ABC Lumber	$100.00	$250.00	$ 350.00	$2,300.00	($1,950.00)		$0.00	$ 2,300.00	white alum
189	Window/Door Trim	ABC Lumber	$700.00	$900.00	$ 1,600.00					$ -	Azel brickmold
190	Other Exterior Trim	ABC Lumber			$ -					$ -	
191	Exterior Stairs, Landing				$ -					$ -	
192	Exterior Paint, Stain, Caulk	JJ Paint & Glass	$2,800.00	$1,500.00	$ 4,300.00	$5,000.00	($700.00)		$0.00	$ 5,000.00	2 coats oil stain
193	Exterior, Labor-Only				$ -					$ -	
194	Enter Additional Items				$ -					$ -	
195					$ -					$ -	
196					$ -					$ -	
197					$ -					$ -	
198					$ -					$ -	
199	Subtotal		$12,030.00	$14,845.00	$ 26,875.00	$29,170.00	($3,895.00)		$11,970.00	$ 17,200.00	
200	WINDOWS/EXTERIOR DOORS				$ -					$ -	
201	Exterior Doors, Prehung				$ -					$ -	
202	Exterior Door Slabs				$ -					$ -	
203	Exterior Door Frames, Sills				$ -					$ -	
204	Sidelights, Transoms				$ -					$ -	
205	Patio Doors: Sliding, Hinged				$ -					$ -	

Table 10. Estimating and budgeting Worksheet adapted by (BuildingAdvisor.com, 2022)

Many construction and engineering companies in Norway also use calculation software and a spreadsheet to estimate the cost of a construction project. These includes the clients, contractors, consultants, and architected companies. Most the companies use ISY Calcus from the Byggoffice program and excel spreadsheet. ISY Calcus is developed by Bygganalyse together with Norconsult. Based on the respondents from Bygganalyse, Norconsult and Betonmast Innlandet AS, all these three companies used the ISY Calcus program and excel spreadsheet to calculate the cost estimation of their construction projects.

This shows that most of the companies I Norway use ISY Calcus program and excel spreadsheet techniques to calculate the cost estimation of their construction projects.

In general, most organizations/companies require their projects to be budgeted according to specific procedures (Tim, 2019). For example, some organizations may give the responsibility up to the project manager. Others may work off preliminary estimates in the earliest project planning phase compared to later stages where more exact estimates are needed. Tim (2019) presents four of the most common cost estimation methods: analogous estimating, parametric estimating, bottom-up estimating and three-point estimating.

a. **Analogous Estimating:** a project manager estimates the expected costs of a project using known costs associated with a similar project that's been completed in the past. This estimation method builds upon a combination of historical data and the project manager's knowledge. Analogous estimating does have its limitations since no two projects are the same. Because of this, it is usually used at the earliest stages of project planning, when a rough estimate is sufficient. It is also possible to use analogous estimating when there is not much information about the current project.
b. **Parametric estimating:** historical data and statistical models are used to assign a monetary value to certain project costs. Based on this approach, the underlying unit cost for a particular project component is determined and provided. The method is much more accurate than analogous estimating but requires more data to estimate costs accurately. Many construction companies use parametric estimating. A construction manager might calculate, for example, the cost of a typical new home based on its square footage.
c. **Bottom-up estimating:** an approach that breaks down a larger project into smaller elements. Once these smaller work packages are broken down, the project manager estimates each separately. For example, if a project involves work divided among multiple departments, the costs might be organized by department. Each cost estimate is combined into a single estimate for the entire project. Bottom-up estimating allows the project manager to look at individual tasks within a project, allowing for a more accurate estimation process.
d. **Three-point estimating:** identifies three separate estimates of a project's costs by the project manager. According to this estimate, the first point represents an optimistic estimate in which the most work is done, and the funds are spent efficiently, the second point represents a pessimistic estimate in which the least work is done, and the

least funds are spent effectively; and the third point represents a most likely estimate in which the middle ground is occupied. Three-point estimating builds on several layered formulas and originates from the Program Analysis and Review Technique (PERT) as shown in figure 11.

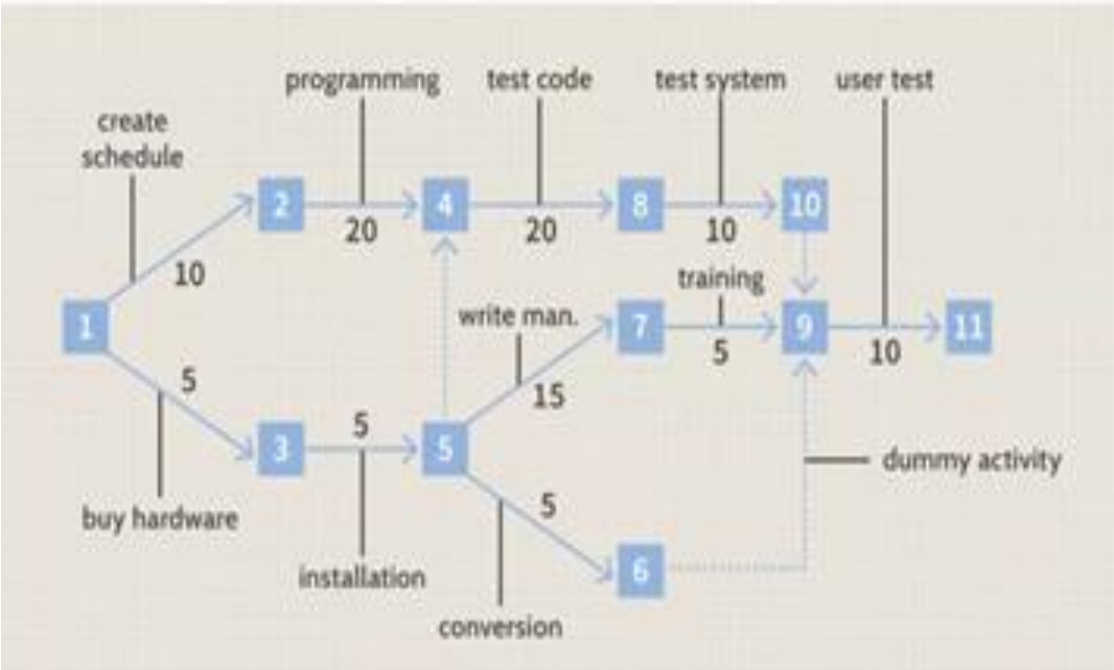

Figure 11. Program Analysis and Review Technique (PERT) chart(Tim, 2019).

Furthermore, different research and resources also show that several organizations/companies use the unit rate method to estimate construction costs. Top-Down and Historical Data-based techniques are also a common choice as cost estimation techniques by some organizations. For example, Alzebdeh et al., (2019) conducted a survey to gather information on techniques used for project cost estimation in Oman and found that unit rate method was among the first-choice technique in a project cost estimation as shown in figure 12. It is justified that the Unit Rate Method is the most common because unit rate method is the most accurate. In addition, it is the safest method to employ when the scope of work is unclear (Alzebdeh et al., 2019).

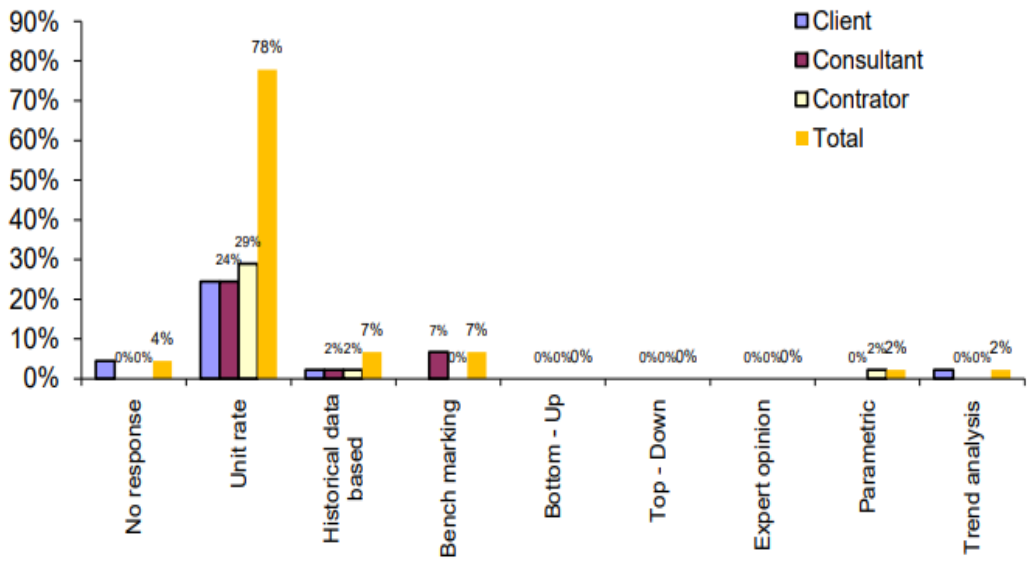

Figure 12. Cost estimation methods in construction projects (Alzebdeh et al., 2019).

4.2 Cost Estimation System in Norwegian Construction Projects.

A realistic cost estimate is essential to all project proposals so the client can determine the size of the investment, and whether to make it. In the same way, every project manager needs realistic cost estimates to manage costs effectively. The budgeting process and cost control are vital, but they are also challenging because of the uncertainty of projects.

As mentioned in section 1.2 above, all Norwegian public projects with an initial estimate of over 750 MNOK have to go through the quality assurance scheme as illustrated in figure 13. The model is intended to ensure the quality of the project concept and the positive contribution that the project will have on Norwegian society (Danielsen et al., 2017). Two control points are present in the model. One is to assess whether the project concept is of sufficient quality, and the other is to examine whether the project can be completed within the estimated steering goal. First, quality assurance will be applied to the choice of concept before a cabinet decision is made to start a pre-project (QA1). A second control point is the quality assessment of the management base and cost estimates before the project is submitted to the Parliament for approval and funding (QA2).

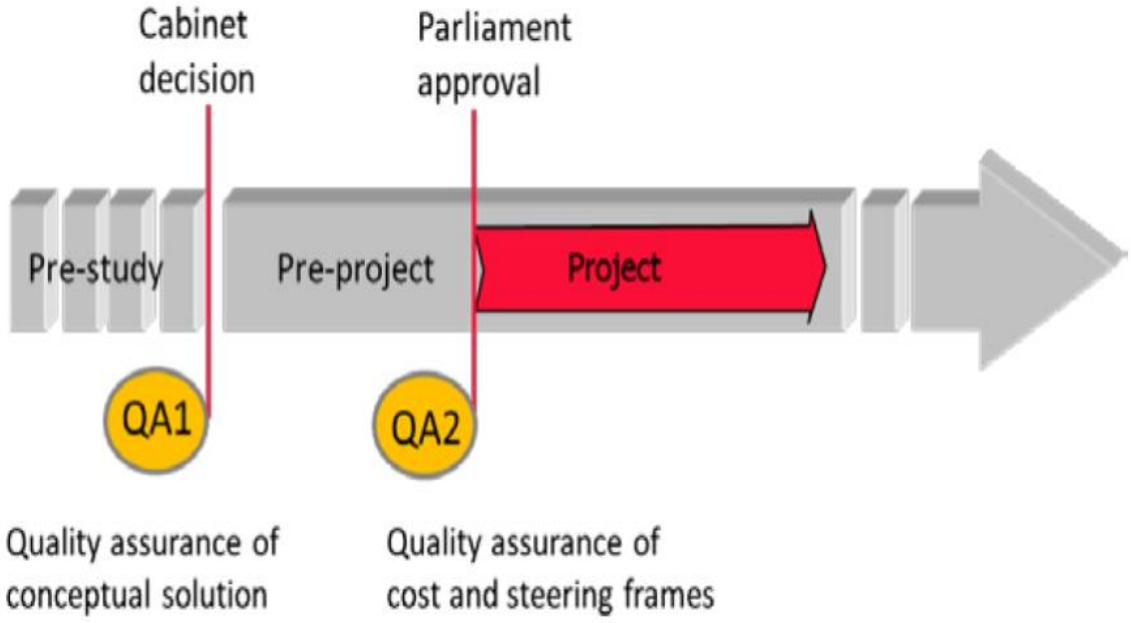

Figure 13. The Norwegian QA scheme involves two overarching decision points (Samset and Volden, 2014).

To improve the QA regime continuously, the Ministry of Finance has launched a research program to study the effects of the QA scheme. Data was collected on the first 40 projects enrolled in QA2 (Samset and Volden, 2013), for which the final settlement of contracts was completed or progressed to the point where the final investment cost was known. Of these, about half were road projects (21). Others included building construction (7), railway (6), and defense (6). Overall, the sectoral distribution of investment projects under the QA scheme is representative.

Figure 14 shows the final cost relative to approved cost frame. The data displays, that among the 40 completed projects, 32 were completed within or below the budget. There were some significant savings (mostly related to road projects). There were eight projects, however, that exceeded their budgets. Almost half of this was due to one railway project. Total net savings for the portfolio of projects was more than US$500 million, or roughly 7% of the total investment (Samset and Volden, 2014). This is an incredibly good result compared to experience and studies conducted in other countries.

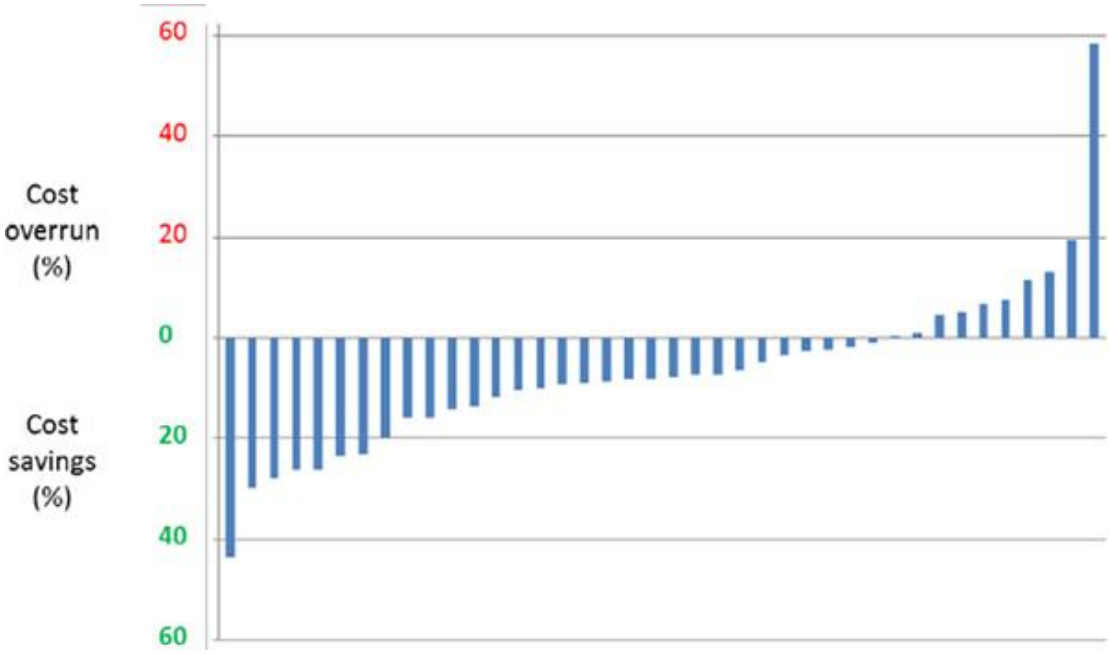

Figure 14. Deviation between the final cost and the cost frame approved by Parliament (N=40) (Samset and Volden, 2014).

Figure 5 shows the over-and undershoot of the 40 projects in absolute terms, sorted according to the project size. It demonstrates that all eight projects with cost overruns are smaller. In the sample, the majority of the projects are of this size, including those within the budget. However, all the major projects were completed with cost savings, deviating positively from the cost frame.

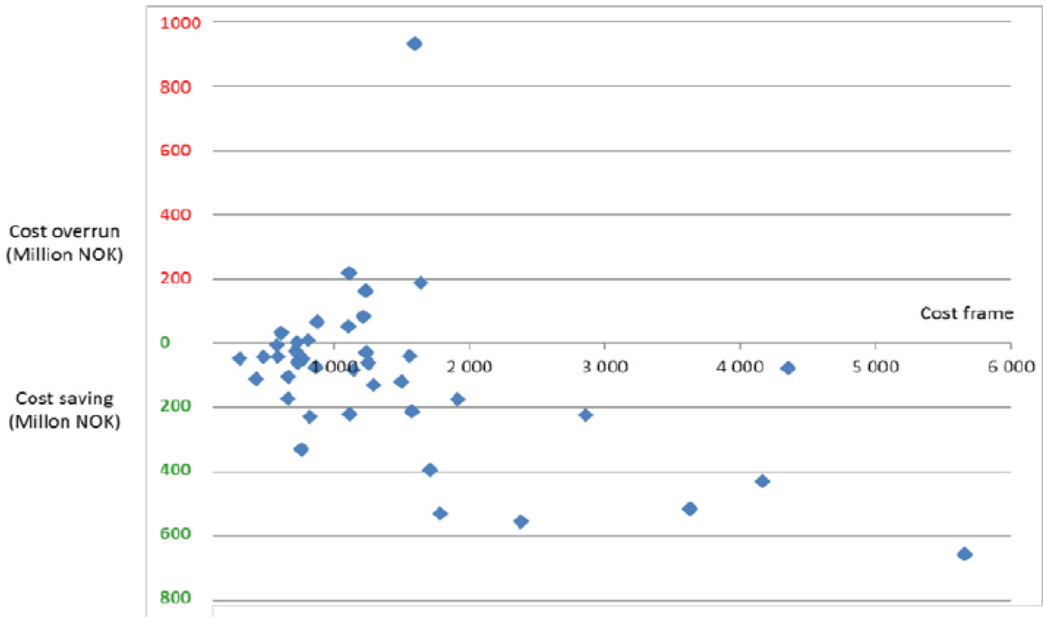

Figure 15. Difference between the final cost and the approved cost frame, by the size of projects. Only the smaller projects had cost overruns (Samset and Volden, 2014).

Welde et al., (2019) have examined the cost estimation in large government projects as to how good are the estimates and uncertainty analyses in the QA2 reports? Projector from two major public companies, the Statsbygg and the defense department. In general, the cost control in the largest campanies is good. The goal of completing half of the projects within the management framework has not been achieved, but the average deviation, which matters at the portfolio level, is low - only +1.9% as shown in figure 16 (Welde, 2016).

over the cost framework

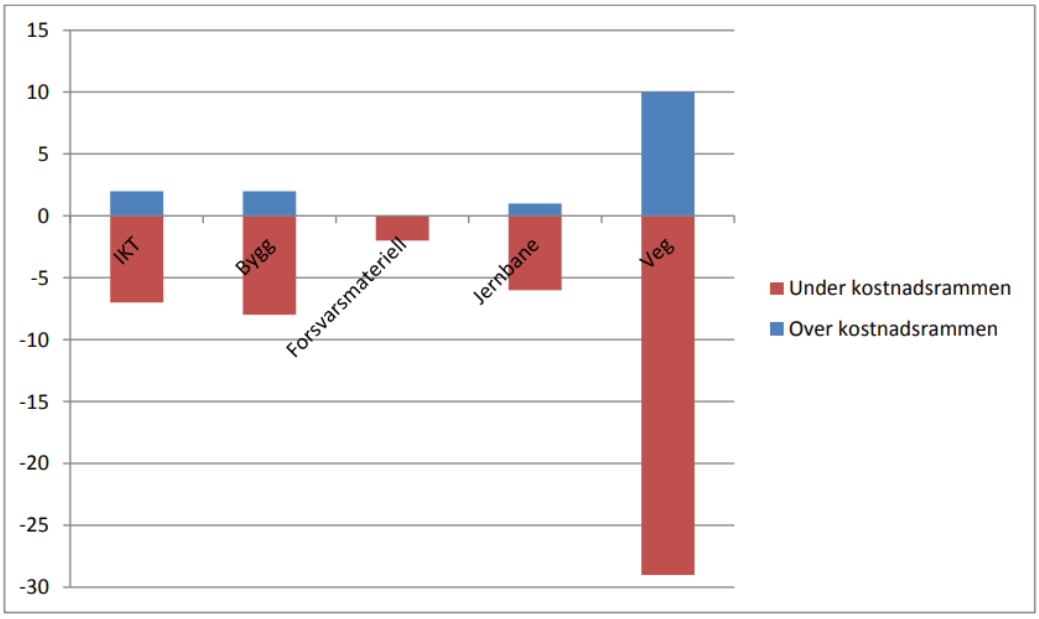

Figure 16. cost control after project types (Welde et al., 2019)

The results are good, but there is room for improvement. Some projects have had large overruns or underruns. Norwegian Public Roads Administration may seem to have a slightly better result than the portfolio level, as the road projects, on average, deviate less from the management framework, but the other agencies have so few projects that the difference must be interpreted with caution (Welde, 2016).

4.3 Existing practice Cost Estimation in Norway Based on Interview from Respondents

In this thesis, three respondents conducted a semi-structured interview regarding existing construction cost estimation practices, and the results are presented below.

a. The importance of cost estimation during the early phases of a project:

According to the respondents, cost estimation in the early phase is very important as all clients demand Cost estimation in the early stages of a project. An uncertainty is significant at the start of a project due to limited information, and the more precise the cost estimation results, the more to know later in the project. So cost estimation in the early phase is crucial to avoid uncertainty. Cost estimation in the early phase is also essential, especially for public projects, because politicians give funds based on the cost estimation at the early stage. When the project's cost increases later, it may become difficult to fund. In addition, cost estimation in the early phase is vital in decision making for a project.

b. Cost estimation methods and professionalism:

Respondents mentioned that the cost estimation is performed using the ISY Calcus program and Excel spreadsheet. Experts and professionals in cost estimation work for organizations. For example, Bygganalyse has 30 highly skilled cost estimator professionals for Construction Cost estimation. The ISY calcus program is precise and effective, but it depends on the project's size, location, and function. Accurate information on the project's size, location, and function gives a precision range between -10% to 10%. Bygganayse has done around 10000 cost estimation work with this method. Cost estimation by Norconsult is 90% accurate, meaning a cost estimation error is very unlikely to occur during the early phases. Another advantage that the ISY calcus program makes good is that it is possible to export a database to an Excel spreadsheet, which makes the cost estimation process easy. Furthermore, the respondents described the current system they use as very reliable in estimating construction costs, with correct references and databases. Nevertheless, expert knowledge and experience are still necessary.

c. Factors that affect the accuracy of construction cost estimates at early phase:

According to the respondents, many factors affect the accuracy of construction cost estimates in the early stages. One factor is incorrect information on the assumed gross area in square meters. Construction cost estimation is calculated as a unit price per square meter (parametric cost method). Therefore, the lack of correct data relating to a project's gross area affects the

results of cost estimation at a later stage. For example, if the gross area of a project at early stage is 10000 square meters, but later, the gross area becomes 12000 square meters, the cost estimation is affected compared with the original cost estimate. Another factor is changes in the market. The cost of a project will be affected by any changes in the market due to different reasons. For example, change in the market of material or other items due to political and inflation through further project development. Furthermore, if the project's scope changes during the project development, the cost will also change.

d. Cost overrun, uncertainty and risk:

Based on the respondents' experience, it is very rare that cost overruns occur in their organizations because of the solid set of methods for Cost estimation in the early phases. However, there are some concerns about uncertainty and risk. There is always uncertainty and risk in the case of geotechnical relations. It is not easy to update the Cost estimate when the project is further developed when the ground conditions change.

e. Difference between traditional and existing modern practice and impact of new technology cost estimation:

Skilled professionals have the same precision today as before. A qualified estimator will have equivalent accuracy regardless of method and technology. In the traditional method, the paper manual used to define the cost of the parameter has a limited dimension. It is not able to admit all the variants of the construction industry. However, new technology and cost estimation methods are effective in terms of time and helpful when upgrading documents.

f. Experience and Knowledge about CBR:

The respondents clarify that they are not familiar with CBR. However, during cost estimation of the contraction projects at an early stage, they use the previous experience and database from older projects.

4.4 When Where and How is Existing Practice a Good Choice

As described in the theory section, the existing practice provides detailed cost estimating and budgeting of construction projects for project managers. As a result, existing practice cost estimating gives the following advantages and why it is a good choice. For example, the use of software for project cost estimation gives a variety of advantages. It provides estimators with tools that allow them to save time and assists estimators in calculating the project's total net cost. Moreover, it is helpful for those who make decisions based on the estimation report. Additionally, it helps standardize company procedures.

- It helps to have a project structure plan that includes phases, work packages, milestones, etc., and determine the responsible parties.
- Determine the labels and categories for resources, cost elements, and units.
- Identify the individuals and organizations involved (departments, suppliers, distributors, customers, experts, etc.) and the resources they bring (plants, machines, tools, products, appraisals, trades, travel to meetings, rooms, catering).
- Calculate the cost rates for labor, material, equipment, travel, etc. This helps determine the cost rates for the project. A change in the cost rates, for example, caused by price increases or salary increases, will also be recorded.
- Provide a detailed resource plan for all resources used during the project, like personnel, equipment, products, services, and travel. This makes it possible to assign work packages to the work plan and determine when resources are used in each scope.
- It compiles and calculates the total project costs. Using a cost report, these can be further differentiated and represented individually. It contains information on individual project costs, such as work packages, partners' costs, and period.

Existing practice technology improves efficiency, accuracy, and responsibility to cost estimating. New technology such as BIM allows all actors to share documents and update the documents. In addition, new technology makes Existing practice cost estimating easy to work with, especially since some changes are made later in the project.

5 Discussion (Comparison of practice cost estimation and CBR)

5.1 Comparison on Basis for Cost Estimation (access to data, definition of scope, timeline, other prerequisites)

Case-Base Reasoning (CBR)

CBR solves problems by using the knowledge already stored and captures new knowledge immediately to solve the next problem. This conceptual model needs to be implemented in a computerized system based on methods from statistics, pattern recognition, artificial intelligence, machine learning, database research, and other fields. Combining all these methods will give us a system that can efficiently solve practical problems. Thus, CBR has demonstrated success in various application areas, including medical and technical diagnosis, image interpretation, geographic information systems, construction and engineering fields, user-support systems, etc.

CBR cost estimation method is a very dependent case database. CBR cost models are demonstrated and developed by gathering case data from many projects. Many of the case databases come from previous years' projects. Thus, access to the collection case data set is relatively difficult. In addition to obtaining the case dataset, public projects are the only option. Moreover, the process and procedure using the data in weight attributes and similarity retrieving is complex and lengthy.

Practice cost estimation

Generally, the case data in existing practice cost estimation depends on the project's database itself. From the database, the program imports, for example, drawings and takeoff sheets of the project and estimates/calculations made by the estimator. As a result, accessing the data for a project in practice cost estimating is simple and non-time consuming.

5.2 Methodology (stepwise and guiding principles, need for resources, tools)

Case-Base Reasoning (CBR)

Methodically CBR needs to include adequate expert definitions of case base features to provide meaningful results. Preliminary estimates of costs and duration, for example, are based on several prominent features such as the number of floors and the type of structural system, which experts should provide. However, similar cases in the case base can still be retrieved even when incomplete information is provided (for example, lack of one or more key features).

Cost estimators follow the previous experience and documents in existing cost estimation practices. As a result, it is based on the same principle, and utilizes computer-aided/artificial intelligence to resolve issues. The CBR cost estimating process is more complex and lengthier than the practice cost estimate. The procedures from attribute selection attribute weighting, similar case retrieving, Collecting the case database collection, developing the cost CBR model to validating the is very much time-consuming process.

Existing Practice Cost Estimation

Mythologically, estimating practice costs is relatively simple, fast, and takes a short amount of time. Because most of the cost estimation work is done by the programs and excel spreadsheet. For the cost estimation program for the project, experts will be needed. Practice cost estimation also requires limited resources to complete the job. In addition, the project uses its own documents to achieve the cost estimation, despite the estimator taking references from previous documents. Therefore, there is no need for a collection case database. Practice cost estimating is estimating the cost of a project in detail. Detail cost estimating have an advantage to identify the factors that affects the accuracy of cost estimating.

5.3 Under what circumstances will CBR be a better choice?

As mentioned in the theory section, Case-based reasoning (CBR) is an experience-based technique for solving new problems by drawing upon prior successful solutions to similar problems. Thus, CBR applies the specific knowledge of previously experienced and tangible problem situations. CBR also provides continuous and sustained learning in that each time a problem is solved, a new experience is retained and can be adapted for future problems.

CBRs are more suitable for construction cost estimation and other construction areas and other departments. Because CBR remembers past mistakes, the reasoner can identify the significant features of a problem and focus on them. In addition, CBR reflects how people think and work. The development of rules and methods is more manageable because no knowledge is required. In addition, systems can learn from new cases, making maintenance easier. In addition, CBR enables the reasoner to provide fast solutions to problems. The reasoner will be able to offer solutions in areas they do not fully understand, evaluate solutions when no algorithm is available, and interpret ill-defined or open-ended concepts.

CBR critics point out that CBR is based primarily on anecdotal evidence and that adapting the elements of one case to another may be complex and lead to errors. In recent years, CBR

has been improved by utilizing a statistical framework, making it possible to produce case-based predictions with a higher confidence level.

CBR can combine with multi-regression analysis (MRA) and genetic algorithm (GA) in developing the cost model, which increases accuracy in the cost estimation of a project. CBR is advantageous for long-term use, and there is no empirical study illustrating this advantage and how the performance of the CBR model changes with the increase in the number of cases in the case base. Thus, CBR has an advantage in terms of long-term use.

5.4 Limitations and challenges with CBR in theory and practice

It has also been observed that CBR methods can increase the accuracy of construction cost estimates. However, there are challenges related to the retrieval process that still need to be addressed. One issue is the computation of similarity, which is particularly important during the retrieval process. It is challenging to retrieve similar cases in a CBR system because it is based on the favored choice of a software project similarity measure. There is no doubt that this is critical because it will determine what similar cases are taken from the data set. For example, the similarity of two software projects described and characterized by a set of attributes is often evaluated by comparing the distance between their attributes. Consequently, two projects are considered dissimilar if the differences between their respective attributes are apparent.

It is also evident that the CBR model has limitations when the retrieved cases are not very similar to the new case. Therefore, if appropriate attribute weights are not utilized, the CBR model may fail to provide a reliable solution. For example, if one estimates the construction costs of a new office building of 1,000 m2 gross floor area with reinforced concrete (RC) structure. In such a case, if the gross floor area of the retrieved case (i.e., the most similar case to the new office building) is 500 m2 and its structure type is steel reinforced concrete (SRC), it would be difficult to directly use the construction cost of the retrieved case to estimate the construction cost of the new case because of the differences in the attributes between the two cases as listed below as an example.

- If the case presented from the retrieved phase is less similar, this will result in a higher estimation error rate of the construction cost.
- The less similar the case presented in the retrieval phase is, the greater the revision effects in the revising phase.

- When an attribute value is located on the edge of the case base, greater attention must be given to the case's revision.
- In the retrieval phase, the attributes were not effective in the complete revision of the revision phase, so it needs to verify for appropriateness before using them in the revision phase.

Another challenge is how to assign the attribute weight values that enable the most similar case to be identified by an index of corresponding features. The CBR method is a technique that reuses expert experience from previous cases to determine the cost of a new project. However, it has been difficult to include experience in all processes of cost estimating, especially in determining how to weight attributes in a CBR model. As a result, CBR model uses GA and MRA, which gathers knowledge of the entire cost estimation process from industry experts and uses that knowledge to determine the weights of the attributes. Furthermore, it is difficult to determine the weights of attributes that affect construction costs, thereby minimizing the cost estimation error. Moreover, the conventional linear planning method has limitations in estimating weight due to the nonlinear relationship between the error rate and the similarity scores of attributes, which require the use of GA and MRA.

CBR is well-suited for computer application system in the experience-based industry if the information from previous construction projects is available. Such an application system must carefully consider the appropriate features for representing a construction project before it can be implemented. It may not be possible to find a correct solution if the cases are not defined correctly.

6 Conclusion

This section presets the conclusion by answering the research questions.

6.1 Answer to the Research Questions 1

1. Is case-based reasoning (CBR) a precise cost estimation method to use in construction projects at an early stage based on theoretical literature study?

Based on the literature study CBR is an effective method of cost estimating for construction method. The studied research shows that the case-based reasoning method is accurate cost estimation. However, measuring the cost estimation's accuracy is not easy. Similarly, some studies shows that CBR is an early cost estimation method that retrieves and reuses either historical cost values or data used for cost estimation, for example, quantities of representative items. The results from the literature study also show that when CBR is integrated with multi-regression analysis (MRA) and artificial neural networks (ANN), it improves the cost estimation accuracy in construction projects. Some studies also demonstrated how CBR could be used to predict construction duration and costs during the preliminary design stage of a construction project. In addition, some studies, proved that the CBR construction cost estimation model is an effective method that reuses the experience of experts from previous cases to obtain the cost of a new project.

Moreover, CBR has the potential to use in other construction areas. Experts and researchers have also found the potential use of CBR for other areas of construction management, including risk analysis, schedule planning, site layout, method selection, resource management, and time cost predictions.

6.2 Answer to the Research Questions 2

2. Comparing case-based reasoning (CBR) to existing practices for cost estimation in construction projects, what are the advantages and disadvantages?

CBR have both advantages and disadvantages as construction cost estimating methos.

Advantages of the CBR technique:

a. problem-solving does not require a transparent model; rather, collecting cases is important.
b. since the model can be established by specifying key attributes that represent the cases, this technique makes it easy to build a model.
c. it allows a vast amount of information control using a database technique.
d. information in the case base can be updated and maintained easily.

e. CBR offers advantages over other artificial intelligence techniques in terms of knowledge acquisition, knowledge representation, reuse, updating, and justification.

Disadvantages of CBR:

a. CBR model has limitations when the retrieved cases are not very similar to the new case.
b. If CBR does not integrate with MRA and GA results in less cost estimation accuracy.
c. It is a complex and time-consuming process.
d. Data access is very limiting due to the need for a huge number of databases.
e. Hard to determine weight attributes and similarity in retrieving.

6.3 Answer to the Research Questions 3

3. What is the potential of using case-based reasoning (CBR) in Norway?

Geographically, the application CBR is distributed differently. It is more dominant in the far East part of the world. The CBR cost estimating method is used dominantly in south Korea. Some the publications shows that the system is more used in the years from 2006 to 2014. The CBR cost estimating method is not used and known in Norway. Due to the limited data access, time consuming, complex procedure in developing the CBR cost model, and limited professionals/specialist on CBR system, the potential to use CBR is very limited.

6.2 Further research

Similarity measurement and attributes weight assignment developing cost model in the CBR cost Estimating system is still challenging despite combing with MRA and GA makes better. Therefore, addressing these issues to enhance the reliability of CBR models is still needed. Further research is required to develop an improved CBR model that reflects experience in all estimating processes without MRA and GA.

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8 Appendix

8.1 Interview questions

1. Introduction to Interviewer

I am Teame Zerazghi Tekeste, a current master student at NTNU Trondheim, studying Project management in civil engineering specialization. As for my academic background, I have a bachelor's in civil/building engineering and a master's degree in digital building service at NTNU Gjøvik. This interview is regarding my master thesis and specialization project at the Department of Civil and Environment Engineering. The study is supervised by Ole Jonny Klakegg (Professor at the Department of Civil and Environmental Engineering). I chose a topic ¨Early cost estimation of construction projects using case-based reasoning (CBR). I will review the potential of the CBR in construction cost estimation and will answers the following research questions.

I. Is case-based reasoning (CBR) a precise method for estimating the cost of construction projects?
II. What are the advantages and disadvantages of case-based reasoning (CBR) method using as cost estimation in construction projects?
III. What is the potential to use case-based reasoning (CBR) in Norway?

2. About case-based reasoning (CBR)

Case-based reasoning (CBR) is a method/technique based on a similarity concept that solves a new problem/case by deriving previous similar situations and reusing the information and knowledge obtained in solving these situations. Solutions are generated by retrieving the most pertinent cases from the memory, and they are adapted to fit the new situations. CBR has been used in construction areas such as early-stage cost estimation and duration. The CBR technique has been also widely utilized as an important decision-making tool in various construction management areas including landscape design, architectural design, bid decision making, international market selection, safety hazard identification, and construction litigation.

3. General information

- This interview will be sent to the respondents before the interview to give them an insight into the questionnaire.
- This interview is meant to be audio recorded. In case of any conflict of interest in this regard, please notify the interviewer.
- A summarized report of the interview will be written and sent to the respondent to confirm and prevent any misunderstanding.
- Reported data from the respondents will be anonymous, and the interviewer will only mention their roles and positions in case of need.
- In case of need for further information or clarification, the interviewer will contact the respondent.

4. Introduction to opening questions

4.1 Respondent 1

Please introduce yourself, and your organization including:

- The main activity area of organization
- Your position and role in the organization
- The construction cost method that your organization is currently using.
- Your experiences in construction cost estimation and the method you use this construction Cost estimation.

5. Interview questions- early phase cost estimation of a construction project

5.1 Respondent 1

This is an interview about cost estimation analysis of construction projects at early phase. The aim of the interview is to acquire knowledge about cost estimation as it takes place in Norway.

1. How important is cost estimation at early phase of a project (for example, in decision making and feasibility study)?
2. Who is involved in the process of cost estimation at your company?
3. How is cost estimation practiced in your company (Bygganalyse)?
4. What kind of method/software is used in the cost estimation process at your company today?

4.1 How precise/accurate is the method/software you are using today?

4.2 How efficient is the current method used in your company/Bygganalyse compared to other cost estimation types?

5. How reliable do you consider the current cost estimation method based on your experience?
6. Can you name some factors that can affect the accuracy of construction cost estimation at early phase of a project?
7. What is your experience with construction cost estimation, and how do you see the cost estimation methods in Norway (by considering cost overrun, uncertainty, and risk)?
8. From your experience and comparing the old traditional and modern cost estimation methods, which method do you think more precise/accurate?
9. From your experience, what can you say comparing the estimated and actual cost of a project? (Do you experience cost overrun for example)?
10. Do you think cost estimation is improving due to the new technology (for example, new software for calculating)?
11. What do you think is the impact of new technology on cost estimation in the future?
12. Have you used Case-based reasoning (CBR) as a cost estimation method before? If yes, how do you evaluate it as a construction cost estimating method?

6. Introduction to opening questions

6.1 Respondent 2

Please introduce yourself, and your organization including:

- The main activity area of organization
- Your position and role in the organization
- The construction cost method that your organization is currently using.
- Your experiences in construction cost estimation and the method you use this construction Cost estimation.

7. Interview questions- early phase cost estimation of a construction project

7.1 Respondent 2

This is an interview about cost estimation analysis of construction projects at early phase. The aim of the interview is to acquire knowledge about cost estimation as it takes place in Norway.

13. How important is cost estimation at early phase of a project (for example, in decision making and feasibility study)?
14. Who is involved in the process of cost estimation at your company?
15. How is cost estimation practiced in your company (Bygganalyse)?
16. What kind of method/software is used in the cost estimation process at your company today?
    - 16.1 How precise/accurate is the method/software you are using today?
    - 16.2 How efficient is the current method used in your company/Bygganalyse compared to other cost estimation types?
17. How reliable do you consider the current cost estimation method based on your experience?
18. Can you name some factors that can affect the accuracy of construction cost estimation at early phase of a project?
19. What is your experience with construction cost estimation, and how do you see the cost estimation methods in Norway (by considering cost overrun, uncertainty, and risk)?
20. From your experience and comparing the old traditional and modern cost estimation methods, which method do you think more precise/accurate?

21. From your experience, what can you say comparing the estimated and actual cost of a project? (Do you experience cost overrun for example)?
22. Do you think cost estimation is improving due to the new technology (for example, new software for calculating)?
23. What do you think is the impact of new technology on cost estimation in the future?
24. Have you used Case-based reasoning (CBR) as a cost estimation method before? If yes, how do you evaluate it as a construction cost estimating method?

8. Introduction to opening questions

8.1 Respondent 3

Please introduce yourself, and your organization including:

- The main activity area of organization
- Your position and role in the organization
- The construction cost method that your organization is currently using.
- Your experiences in construction cost estimation and the method you use this construction Cost estimation.

9. Interview questions- early phase cost estimation of a construction project

9.1 Respondent 3

This is an interview about cost estimation analysis of construction projects at early phase. The aim of the interview is to acquire knowledge about cost estimation as it takes place in Norway.

25. How important is cost estimation at early phase of a project (for example, in decision making and feasibility study)?
26. Who is involved in the process of cost estimation at your company?
27. How is cost estimation practiced in your company (Bygganalyse)?
28. What kind of method/software is used in the cost estimation process at your company today?
    - 28.1 How precise/accurate is the method/software you are using today?
    - 28.2 How efficient is the current method used in your company/Bygganalyse compared to other cost estimation types?
29. How reliable do you consider the current cost estimation method based on your experience?
30. Can you name some factors that can affect the accuracy of construction cost estimation at early phase of a project?
31. What is your experience with construction cost estimation, and how do you see the cost estimation methods in Norway (by considering cost overrun, uncertainty, and risk)?
32. From your experience and comparing the old traditional and modern cost estimation methods, which method do you think more precise/accurate?

33. From your experience, what can you say comparing the estimated and actual cost of a project? (Do you experience cost overrun for example)?
34. Do you think cost estimation is improving due to the new technology (for example, new software for calculating)?
35. What do you think is the impact of new technology on cost estimation in the future?
36. Have you used Case-based reasoning (CBR) as a cost estimation method before? If yes, how do you evaluate it as a construction cost estimating method?