NTNU
Norwegian University of
Science and Technology

A Comparative Study on Hospital Construction Cost Between Norway and The United States

Based on case studies

Moein Barakchi

Master of Science in Project Management
Submission date: July 2017
Supervisor: Olav Torp, IBM

Norwegian University of Science and Technology
Department of Civil and Environmental Engineering

Moein Barakchi

A Comparative Study on Hospital Construction Cost Between Norway and The United States

Based on case studies

Master's thesis in Project Management (specialization in civil engineering)

Trondheim, July 2017

Supervisor: Olav Torp

Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

NTNU
Norwegian University of Science and Technology

This page intentionally left blank.

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Report Title:	Date: 03.07.2017
A comparative study on hospital construction cost between Norway and the United States based on case studies	Number of pages (incl. appendices): 143 Master Thesis ● Project Work

Name:

Moein Barakchi

Professor in charge/supervisor:

Professor Olav Torp

Other external professional contacts/supervisors:

Dr. Alemu Moges Belay

Abstract:

The purpose of this thesis is to compare construction costs in hospitals between Norway and the US and identify the most important cost factors based on case studies. Primary data from projects, secondary data from online databases, experts' opinion, and previous literature were used to answer the research questions. The reported cost breakdown structures were compared. Pareto chart was applied to rank the cost factors and a questionnaire was conducted to gather the experts' opinion on the importance of factors/stakeholders. Also, a priority checklist was produced based on the questionnaire results. To test the academic with practical perspective the cost factors from literature were compared with the questionnaire's cost factors.
The findings show the Norwegian projects on average have higher construction cost (3822 €/m^2 vs. 2602 €/m^2) and standard deviation (973 €/m^2 vs. 131 €/m^2). The reported American cost breakdown structures were more detailed and there were similarities among the top cost factors in both countries. From overall experts' perspective, number of bed spaces influence the cost the most. Moreover, experts selected consultants and owners as the stakeholders who can affect a larger group of factors than the other stakeholders. Looking at the priority checklist, it seems managers should monitor the building and HVAC cost category more closely.
The results of this research could show the common areas for knowledge sharing programs between the two countries. They help managers identify more important factors that may need more attention. For stakeholders, the results indicate the main stakeholders affecting the projects' cost factors, hence enhancing the efficiency of resource allocation. Finally, for researchers, the results may help them in their future studies by identifying the gap between industry and research.

Keywords:

1. Cost performance
2. Cost factor
3. Hospital construction
4. International comparison

Moein Barakchi

This page intentionally left blank.

Abstract

Within the construction industry, there have been many attempts to identify the cost factors or to compare the building costs. However, it seems the combination of both has not been applied so much especially in healthcare construction. The purpose of this study is to compare cost performance in the hospital construction between Norway and United States and identify the most important cost factors.

A combination of qualitative and quantitative research methods has been used in this study. Case studies, questionnaire, Purchasing Power Parity, and Pareto analysis were the main methods used. The data include both primary and secondary. 3 Norwegian and 3 American hospital cases and questionnaire responses are the primary data. Statistical indices are the secondary data used to gain a holistic perspective on the construction situation.

The results show the reported hospital construction cost in the US is lower than Norway; 2602 €/m^2 vs. 3822 €/m^2, respectively. With 973 €/m^2, the Norwegian projects also had higher standard deviation than the American counterparts with 171 €/m^2. The analysis of the reported cost breakdown structures revealed similarities, such as in HVAC, and differences, such as in special costs category. The Pareto analysis showed there are similarities between top factors in Norway and the US. Therefore, there is a substantial incentive for future knowledge sharing initiatives. The overall experts' opinion was that the number of bed spaces is the most important factor in hospital construction costs. Experts also selected consultants and owners as the stakeholders who can affect a larger group of factors. By the end of study, a priority checklist of the cost factors was created based on the experts' opinion. The checklist shows that the building and HVAC cost categories are better to be monitored more closely.

Unlike previous researches which were mostly focused on building costs, regional comparisons, and operational aspect of hospitals, this thesis draws on the international experience and concentrates on hospital construction costs. Moreover, this research is centered around on quantifiable cost factors and the findings are mainly based on the case studies.

There are different implications regarding this thesis. For industry, it unveils the common cost areas where projects can learn from each other. For managers, it suggests priority checklist of important factors that may need more attention. For project stakeholders in general, the influence of main stakeholders on different cost factor has been presented which can help them to allocating the resources more efficiently. For researchers, it identifies potential factors for future researches.

This page intentionally left blank.

Preface

This thesis is conducted in accordance with Norwegian University of Science and Technology's requirements to grant Master of Science degree in Project Management with a specialization in civil engineering. The main supervisor of this research is Dr. Olav Torp, associated professor at the Department of Civil and Environmental Engineering. Dr. Alemu Moges Belay, postdoctoral fellow at the Department of Civil and Environmental Engineering, also acted as a co-supervisor and spent hours to guide this study.

The initial idea for this thesis comes from discussions regarding a study on conceptual cost estimation, which was initiated by Dr. Glenn Ballard of University of California at Berkeley. The scope of the study was further nourished with the help of supervisors at NTNU.

I have to thank several key individuals who helped in the collection of primary data for this thesis. Ms. Edel Stokholm, head of management and construction in Sykehusbygg for her role in providing the experts' names and contact information in Norway. Mr. Øyvind Ludvigsen, project manager and project support at Sykehusbygg, and Mr. Knut Ola Haug, project manager at Sykehusbygg, for providing the cost data for Norwegian hospital projects.

I thank Mr. Randy Keiser, vice president and national healthcare director of Turner Construction Company, for his helpful and encouraging support and for allowing me to use their data on hospital construction cost in the US. In a similar vein, I thank Mr. Mike J. Pingel, pre-construction services manager of Turner Construction Company, for providing the project data.

Special thanks go to Dr. Alemu Moges Belay for his unwavering support and guidance without whom this thesis would not be possible. My deepest gratitude to my supervisor Dr. Olav Torp who despite his busy schedule helped me in every way he could especially with sharing his contacts and his valuable suggestions. I humbly thank my soon-to-be alma mater, NTNU for the opportunity and platform it gave me to partly satisfy my academic curiosity.

Last but not least, I want to thank my family who although are far away, I still feel their unconditional love and support every day during this journey.

Trondheim, 3 July 2017

Moein Barakchi

Moein Barakchi

This page intentionally left blank.

Table of contents

This page intentionally left blank.

List of figures

List of tables

This page intentionally left blank.

Abbreviations

CEO	Chief Executive Office
Const.	Construction
CPI	Consumer Price Index
CSI	Construction Specifications Institute
DCD	Design Cost Data
GC	General Contractor
GDP	Gross Domestic Product
IMF	International Monetary Fund
LCU	Local Currency Unit
NTNU	Norwegian University of Science and Technology
OECD	Organization for Economic Cooperation and Development
PPP	Purchasing Power Parity
RICS	Royal Institution of Charted Surveyors
SNA	System of National Accounts
UK	United Kingdom
US/ USA	United States of America
USD	United States Dollar
VAT	Value Added Tax

This page intentionally left blank.

1 INTRODUCTION

In this chapter, general background is first presented delineating the issues and importance of cost comparison, cost factors in hospital construction. Afterwards, it is followed by literature study, general aim of the thesis, research gaps, purpose and scope of the study, and the research flowchart.

1.1 Background

The total amount of global foreign direct investment was 1.76 trillion dollars in 2015 (UNCTAD, 2016). However, the data on foreign investments in Norway show a negative figure for the past year (2016) while the USA's economy is apparently following an upward trend in receiving foreign investments (Figure 1) (OECD, 2017b). These large amounts of cross-border investments and financial transactions among different countries, particularly European countries, have highlighted the need for studies on international cost comparison.

On the other hand, construction industry is a major actor in economy of a country (Tse & Ganesan, 1997) and the world (Walsh et al., 2005). For instance, construction sector was one of the main drivers behind GDP growth in Norway and had the highest annual growth rate among all the sectors for the past year (OECD, 2017e). Therefore, it is of interest to study construction sector as a part of studies on international cost comparison.

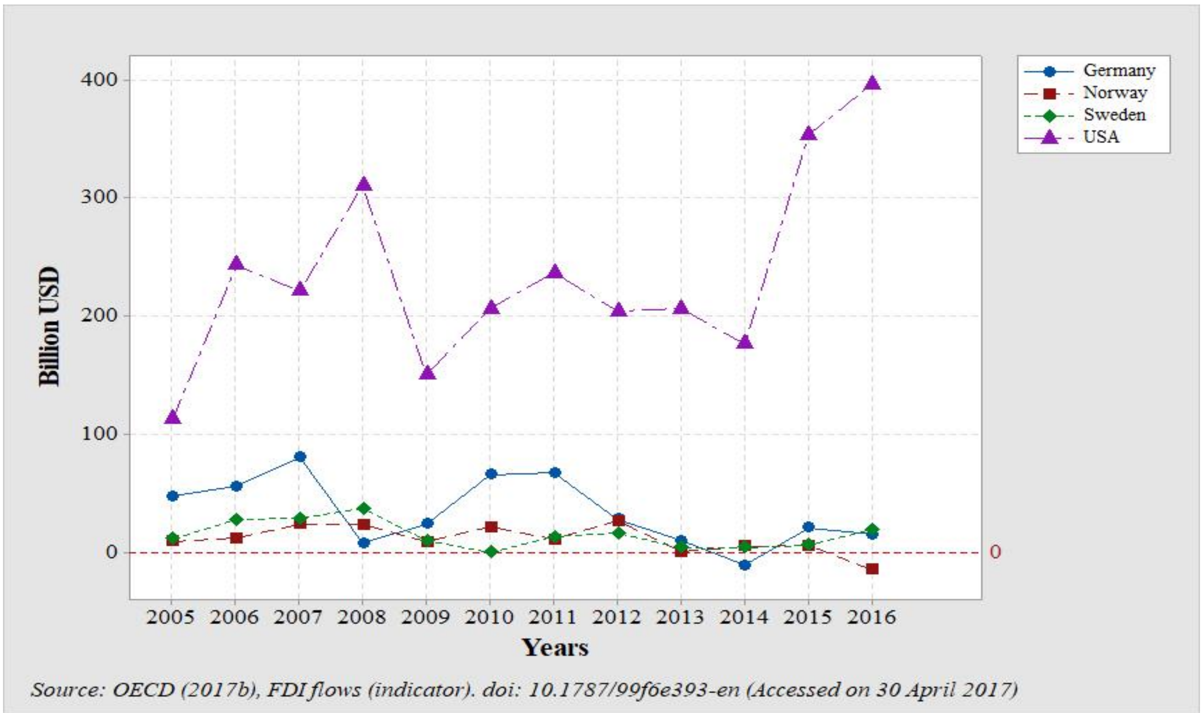


Figure 1. Foreign direct investment trend (inward flow)

However, the construction sector covers a wide span of projects from residential complexes to commercial buildings but hospital projects have a special place in this basket. Meaning, hospital buildings are of importance in every country due to their critical role in healthcare system. According to van der Zwart and van der Voordt (2016), reducing hospital's building costs is among the top priorities for Dutch CEOs and project leaders. Considering Norway, this issue becomes even more important due to the higher-than-average price levels of non-residential construction comparing with the European Union's average which is illustrated in Figure 2 (Eurostat, 2017).

The issue escalates by considering that hospital constructions are often large projects with substantial funding needs (Sherif, 1999). On the other hand, the larger a project is, the more unique its cost factors become (B. Lim et al., 2016). Therefore, investigating the cost factors in hospital construction is essential.

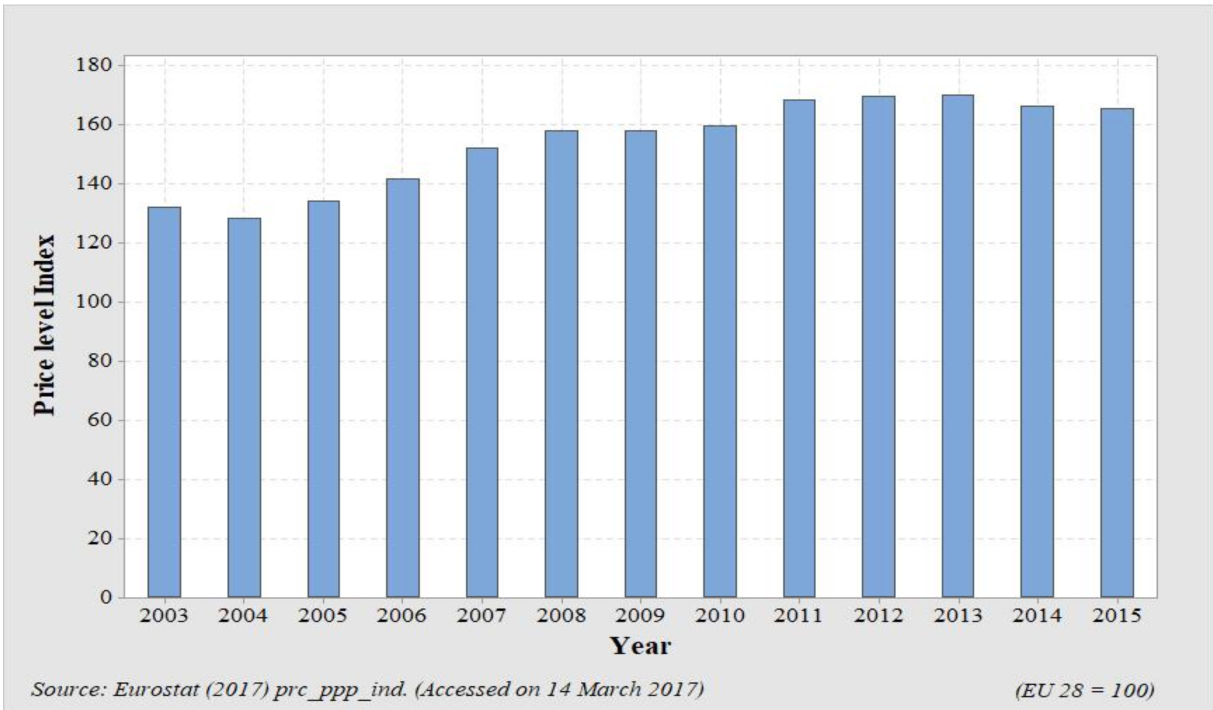


Figure 2. Norway's non-residential buildings price trend

However, cost comparison in construction sector is very challenging. On one hand it is difficult to collect data and define a basis for comparison (Mills, 2013; Walsh et al., 2006) maybe because there is no true consensus on the project costs (Meikle, 1990). On the other hand, there are many qualitative and quantitative factors involved (Elhag et al., 2005) from contract and procurement strategy (Emsley et al., 2002) to median floor height (Stoy & Schalcher, 2007) and CO2 emission costs (Tsai et al., 2014). Furthermore, local conditions also play a role. A study has even gone as far as to say it may not be economic or possible to compare buildings together without considering the local conditions (Meikle, 1990).

To respond to these issues, detailed studies and comparisons are needed. In this regard, NTNU is part of an ongoing cost estimating research which involves academic and industry experts from Norway, the US, and Finland. Moreover, Sykehusbygg, the organization in charge of hospital construction affairs in Norway, has shown its interest to collaboration. This thesis is in line with the aforementioned research.

1.2 Literature study

The literature study helps the thesis in two manners. One is to identify research gaps and applied methods regarding the subject of the thesis. The other is to provide a data pool of the cost factors identified. The latter will be explained in the next chapter.

During the literature study process, several criteria were kept in mind to make the results as relevant as possible. These criteria were developed based on the subject of the study. To elaborate, the literature was selected if it included information about hospital or building construction in the following areas:

- Cost comparison
- Factors affecting the cost and how they are obtained
- Methods to pick the most significant/important factor(s)

Studies investigating building construction cost are also of interest from their methodology point of view. Additionally, it is also possible that some cost factors identified in buildings would also be applicable in hospital construction.

In this study, the literature search was conducted in a step-by-step manner using three scientific databases, namely Scopus, Web of Science, and Google Scholar without any limits on publication date. However, only academic publications such as peer-reviewed papers, scientific books, and book chapters were investigated. Several search terms were selected based on the subject the study and the criteria mentioned. The search terms included: cost, construction, hospital, comparison, countries, driver, factor, and building. Different combinations of the aforementioned terms were used on the databases.

All the searches in Web of Science database were conducted by “topic”, which covers the title, abstract, author keywords, and the database’s additional keywords for the records. Similarly, the searches in Scopus were done in article title, abstract, and keywords. Google scholar has less flexibility in this regards and the only restriction imposed on the process was searching only in articles.

The next step was to filter the results based on their title and abstract. Those with relevant title and abstract were passed to the final step, which was content analysis. The content would be thoroughly examined to confirm the relevancy of the publication to the subject. The search results with relevant content would be included in the thesis. For instance, searching hospital, construction, cost in Web of Science returned 289 results, 11 of which were remained after final filtering or searching hospital, construction, cost, factor, returned 7 results and only one were remained after final filtering.

More than 90 research papers and academic publications were obtained through the literature search process. After the content analysis step, the number were reduced to 64 publications. Out of these 64 publications, a number of them which reflect the research gaps more are selected and presented. These studies are divided into two sections: the studies about cost comparison, and the studies about cost factors which often include methods applied to identify the most important factors.

1.2.1 Cost comparison studies

In a general manner, Meikle (1990) tried analyzing 10 previous studies about international construction cost comparisons of industrial and office buildings. Although the study did not find any pattern regarding different countries or building types, it included key points about the comparison process.

J. L. Kim et al. (2014) also performed cost comparison in construction. The writers wanted to study the role of environmental regulations on construction of residential projects. To do so, they employed comparative cost analysis of between two houses. The research divided the project into smaller parts and compared the costs of each part together. Their conclusion was that the environmental regulations increase the construction cost of the house.

Limited within a country, Mills (2013) performed a comparative cost analysis of building frames in different Australian cities. They utilized the experts' judgements in different cities to find the costs of same building designs. The results were also sent to another group of professionals to be validated.

Zimina et al. (2012) investigated the use of target value design as a management technique on construction cost performance of 12 hospital projects in the US. Apparently, the research noticed this factor's application in other industries and its limited use in construction. In order to inspect the effects of target value design, the authors compared the completed projects using market benchmark cost, target cost, and actual completion cost. Furthermore, the research conducted interview to gather common practices in the American and British construction industry.

1.2.2 Cost factor studies

S. Y. Kim et al. (2017) aimed at identifying the factors causing cost overrun in hospital construction in Vietnam. The study searched previous publications to gather the cost overrun factors. Moreover, the authors used questionnaires and interviews to evaluate the effects of the cost factors. Afterwards, factor analysis was used to assess the reliability of factors and find the major cost factors.

In Indonesia, Kaming et al. (1997) tried to find the factors influencing cost and time in high-rise construction projects. First, the study derived potential variables from previous literature. As for the next step, the authors asked for input of project managers to assess the importance of the factors. Then, the research used the results to rank the factors and find the most important ones.

In a similar study, Stoy and Schalcher (2007) pointed out that German-speaking countries had not identified the cost drivers in building. The authors extracted potential cost drivers from a literature review and improved it by asking the opinion of the professionals. Thereafter, they employed regression analysis on 290 residential properties and found that four drivers are indicator of the project costs.

De Marco and Mangano (2013) tried to find the risk elements which affect the unit costs in healthcare projects in the United Kingdom (UK). The research developed parameters which reflected risk sources found in the previous studies. Thereafter, the research used linear regression on the data from 49 projects to find the major elements.

McKee et al. (2006) used previous literature and case studies from the UK to investigate the role of a specific procurement method in cost of hospital construction and operation. Similarly, Ekeskar and Rudberg (2016) studied the effect of a specific supply chain management method in construction. The research used literature alongside a Swedish hospital construction case to that goal and concluded the method affects costs among other things in the construction of a hospital. Olsson and Hansen (2010) also utilized case studies to inspect the flexibility factor in hospital construction. From one of the case studies, they concluded that late changes would contribute to cost overrun.

Li et al. (2005) used construction price index to make different office building projects in Hong Kong comparable. Moreover, the authors obtained the cost factors directly from the projects' documentations. In addition, the study employed regression analysis to assess the relationship between cost factors and final construction cost.

To develop a model for predicting the total construction cost of buildings in the UK, Emsley et al. (2002) first identified possible cost factors in a pilot study using the previous studies. Then the study removed extra cost factors which had similar definitions but different names in the data collected. Moreover, the research employed different cost indices to compensate for different time and geographical variations in the data. The authors used factor and linear regression analyses to find the major input factors affecting costs based on data from 288 building projects. Apparently, Harding et al. (2000) took a similar approach. The paper examined a model which predicted the costs of different procurement methods in building construction. For identification of the factors, the research only mentioned that the variables were obtained through a pilot study. To find the more significant variables, the authors suggested factor analysis.

Shehu et al. (2014) investigated the subject from another perspective. The authors looked for factors affecting the time overrun in construction which contributes to the cost as well. First, the research assembled a list of major sources affecting time based on literature review. To pinpoint the major factors, they asked for professionals' opinion through a questionnaire survey. An almost similar approach was taken in Shehu et al. (2015). However, the authors also employed statistical analysis to measure the effects of different project characteristics on the duration of the project.

Elhag et al. (2005) gathered 67 factors influencing the construction cost estimation through the previous literature and interviews in the UK. Afterwards, the study categorized the factors in 6 groups and used a survey questionnaire to identify and rank the factors based in the influence on cost estimation. Chung et al. (2009) utilized an expert team to identify the main construction tasks of a hospital as well. Afterwards, they used function analysis to find the most important tasks.

Bilec et al. (2009) studied more sustainable hospital facilities called Green facilities in US using two cases. They pointed out that a survey from professionals has shown that they believe green healthcare facilities have higher costs. In another similar study, Coetzee and Brent (2015) employed case studies and surveys to explore the decision makers' opinion about cost aspect of green building construction.

Investigating cost overruns and delays in large Vietnamese construction projects, Le-Hoai et al. (2008) selected questionnaire survey method to extract the sources affecting cost. The study used different indices in order to examine the impact and rank the factors. In addition, the authors compared the perspectives of different respondents such as contractors, consultants, and owners. In a similar vein, Arditi et al. (1985) analyzed the Turkish public projects to find reasons for cost overrun. The study selected a questionnaire approach and asked to public agencies plus contractors to identify the sources. The authors ranked sources based on the scores they got from the experts.

Elhag and Boussabaine (1998) tried to create an Artificial Neural Network model for forecasting the school buildings' lowest tender price in the UK. The research used a database which contained information about relevant projects and the factors influencing the price. No other explanation was offered regarding how such factors were selected. With respect to identifying more important factors, two models were developed in the study which had different prediction accuracies. The authors associated this phenomenon with the different factors which were used in each models. In other words, they concluded that the factors used in the more accurate model are more significant.

Attalla and Hegazy (2003) tried to build a model for predicting the cost of reconstruction projects. First, the research used field review to determine the factors affecting the cost. Afterwards, a questionnaire survey was created based on the results from the field review to collect the data from construction projects. The study also employed statistical data analysis to screen out less important factors.

In the UK, Lowe et al. (2006) investigated 286 data sets to produce six regression models for building's construction costs forecast. The research performed a literature review to find the cost factors and further filtered them according to their availability of data. Moreover, the study applied relevant indices to dataset to compensate for geographical/time differences and used statistical analysis to limit the number of factors used in each model. To pick the most significant factors, the authors picked the factors which were present in all models.

Sonmez (2008) attempted to develop a model for forecasting the building cost using data from 20 building projects in the US. The paper used cost breakdown and experts' opinion to identify the parameters affecting the cost. Moreover, to determine the significant factors, statistical analysis was used. Likely, Love (2002) used a questionnaire survey to investigate the role of project type and procurement method on rework costs in building projects. Statistical analysis was also applied to test how much variables and rework costs are correlated.

Table 1 summarizes the main points regarding construction field, the data collection method, analysis, and geographical context of the cost factor studies.

Table 1. Summary of cost factor studies

Study	Construction field	Data collection Method			Analysis of data	Country
		Q	L	P		
S. Y. Kim et al. (2017)	Hospital	✓	✓		Quantitative	Vietnam
Kaming et al. (1997)	High rise buildings	✓	✓		Quantitative	Hong Kong
Stoy and Schalcher (2007)	Buildings	✓	✓		Quantitative	Germany
De Marco and Mangano (2013)	Healthcare projects		✓	✓	Quantitative	The UK
McKee et al. (2006)	Hospital		✓	✓	Qualitative	The UK
Ekeskar and Rudberg (2016)	Hospital		✓	✓	Qualitative	Sweden
Olsson and Hansen (2010)	Hospital			✓	Qualitative	Norway
Li et al. (2005)	Buildings			✓	Quantitative	Hong Kong
Emsley et al. (2002)	Buildings		✓	✓	Quantitative	The UK
Shehu et al. (2014)	Construction projects	✓	✓		Quantitative	Malaysia
Shehu et al. (2015)	Construction projects	✓			Quantitative	Malaysia
Elhag et al. (2005)	Buildings	✓	✓		Quantitative	The UK
Chung et al. (2009)	Hospital	✓		✓	Quantitative	South Korea
Bilec et al. (2009)	Hospital			✓	Qualitative	The US
Coetzee and Brent (2015)	Buildings	✓			Quantitative	South Africa
Le-Hoai et al. (2008)	Large construction projects	✓			Quantitative	Vietnam
Arditi et al. (1985)	Public construction projects	✓	✓		Quantitative	Turkey
Elhag and Boussabaine (1998)	Buildings			✓	Quantitative	The UK
Attalla and Hegazy (2003)	Reconstruction projects	✓		✓	Quantitative	Canada
Lowe et al. (2006)	Building		✓	✓	Quantitative	The UK
Sonmez (2008)	Building	✓		✓	Quantitative	The US
Love (2002)	Building	✓			Quantitative	Australia

Note: Q is for questionnaires/interviews/field surveys/surveys, L is for previous literature, and P is for project data. Quantitative analysis includes analyzing quantifiable data including factor analysis, function analysis, regression analysis etc. Qualitative studies are indicative of descriptive analyses.

1.2.3 Ambiguities

An issue observed in the literature was structuring the cost factors. Emsley et al. (2002) classified the data into four groups: numerical such as duration, categorical with apparent order such as site access, categorical with cost such as wall finishes, and categorical without apparent order or cost such as frame type.

Lowe et al. (2006)'s representation of the data was different. In this regard, the factors had three possible formats: nominal, ordinal, and scale. Apparently, in nominal category, there was only a choice involved for the factor such as piling or no piling. An ordinal factor had an order to its possible states such as shape complexity which was low, medium, or high. It seems scale factors were those which could be represented by numbers or cost such as internal doors (£) or number of lifts (number).

Harding et al. (2000) applied a somewhat similar way of grouping. The authors arranged the factors in 4 groups: continuous variables such as area, single-input variables such as type of location, binary-input variables such as tendering strategy, and variables which have uncertain cost differences between the choices such as type of substructure.

Elhag et al. (2005) approached the issue from another perspective. The research categorized the factors with a special attention to attributes of the main stakeholders involved: client, consultant and contractors. The authors had three more categories for characteristics of project, contract and procurement procedures, and external factors such as market conditions.

Another ambiguity was about the use of the words questionnaire, survey, questionnaire survey and survey questionnaire in the literature. Although the authors may have used these terms interchangeably, there is a slight difference between these concepts. To elaborate, according to Oxford English Dictionary, a survey is "a systematic collection and analysis of data relating to the attitudes, living conditions, opinions, etc. of a population, usually taken from a representative sample of the latter" (OxfordEnglishDictionary, 2017b) while questionnaire is "a formulated series of questions by which information is sought from a selected group, usually for statistical analysis" (OxfordEnglishDictionary, 2017a). In other words, the survey seems to be more general than a questionnaire.

1.3 Research gap

The literature review shows that there are some gaps in studying hospital construction cost. The obtained research publications were mostly focused on regional issues of costs. Therefore, approaching this issue from an international perspective may lead to new findings. Furthermore, only a limited number of studies was in respect with hospital construction. During the literature search, it was noticed that operation aspect of the hospital seemingly has received more attention than the construction aspect.

Regarding the cost factor sources, it seems the cost factors are primarily obtained through investigating the past publications, questionnaires/surveys, and project data. The obtained literature results usually employed one or two of the aforementioned sources in order to identify the cost factors (see Table 1). It would be interesting to use all three and see the results.

Some studies mostly emphasized on analyzing one or two cost factors in construction cost. Furthermore, it seems more attention has been directed towards cost overrun in the field. In studies about finding buildings' cost factors, expert's opinion, statistical analysis and modelling were among the mostly used methods to find the significant factors. However, maybe such methods can be used in studies about hospital construction as well.

Another issue is that different studies from different countries have pointed out relatively similar cost factors but with small differences in detail. For instance, height (Cunningham, 2013; Emsley et al., 2002; Latief et al., 2013; Picken & Ilozor, 2003), and average story height (Li et al., 2005; Stoy & Schalcher, 2007). Apparently, the researchers are trying to find the underlying factors affecting the costs.

Finally, the literature study shows that the same factor is not viewed the same by different authors. To illustrate, Lowe et al. (2006) considered tendering strategy as an ordinal variable which apparently means there is an order to different tendering strategies with respect to cost; some costs more than the others. On the other hand, Harding et al. (2000) treated the same factor as a binary variable which means the effect of it differs in each project and no order can be identified for that variable. This means that there is no general consensus on the nature of some cost factors which should be taken into consideration while studying this subject.

1.4 Purpose and scope of the study

This thesis aims at comparing the costs and identifying the cost factors in hospital construction of Norway and the US. Studying such topic would contribute to the stakeholders' understanding of the issue and promote sharing the constructive experience between the countries in this field. As a result, the research questions are expressed as follows:

1. How is the hospital construction cost performance in Norway and the US?
2. What are the quantifiable cost factors behind hospital construction cost?
3. What are the major cost factors in reported hospital construction cost?

This thesis focuses on the hospital construction of Norway and the US. Many cost factors were identified during this study yet the study considers quantifiable factors for further analysis. In addition, the results rely on reported cost data from case studies and experts' opinion. In a case that an online database is used, the access date has been mentioned thus the data indexed after the access date is not included in the study.

1.5 Research flowchart

The following flowchart illustrates the main components of this thesis and their relationships together. Components belonging to the same chapter have similar patterns. The oval shape enveloping the flowchart means the components within the oval contribute to the last chapter, "Future works", to some extent. More information about each component is presented in its respective chapter.

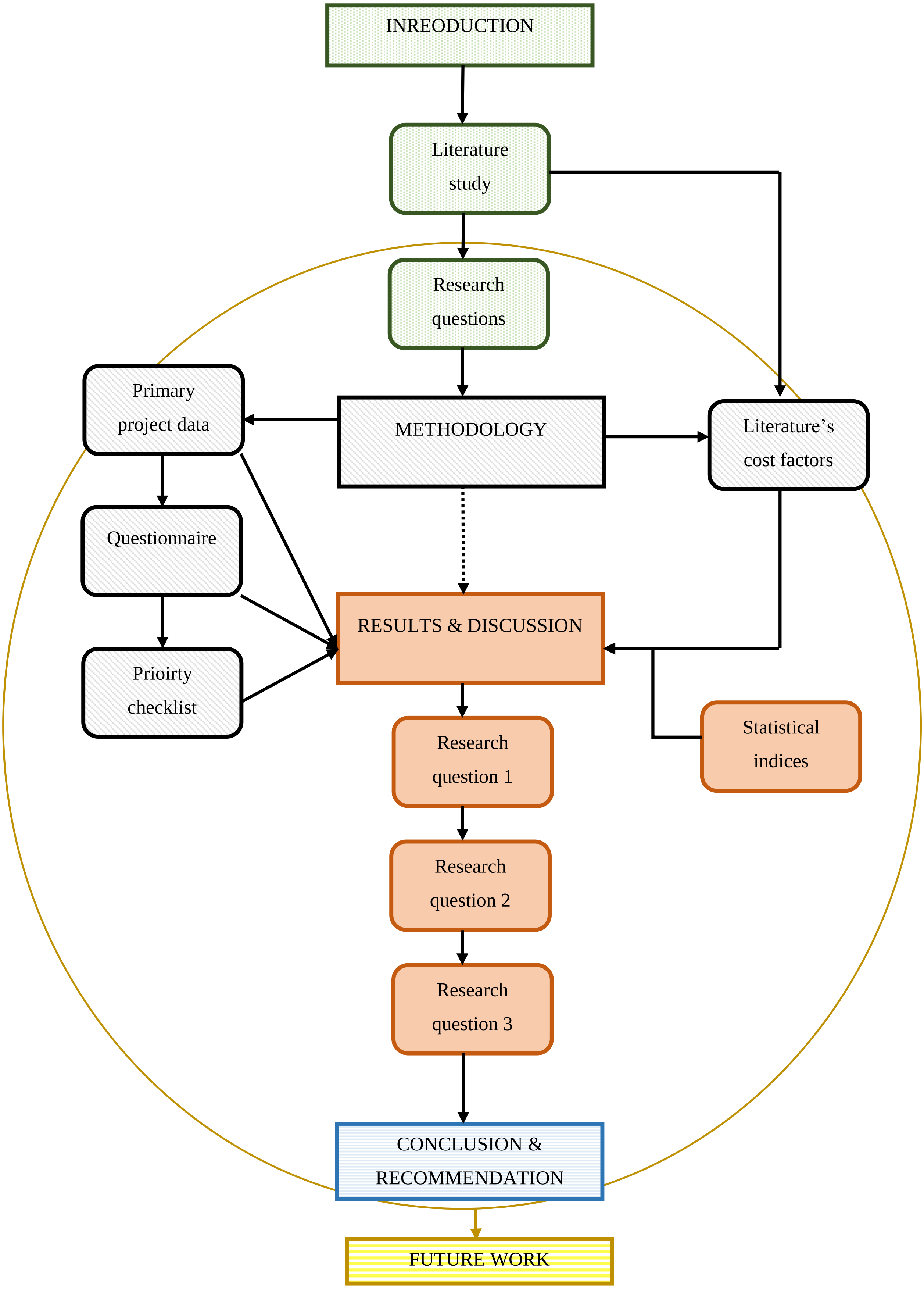


Figure 3. Research flowchart

This page intentionally left blank.

2 METHODOLOGY

First, the possible research methods are explained in this chapter. Then the selected method is going to be explained in details.

2.1 Methods of research

According to Kothari (2004), there are two basic types of research:

I. Qualitative
II. Quantitative

Kothari (2004) continues explaining that the methods above are employed based on the objectives of the research. The quantitative research approach is defined as a study which results in production of data in a quantitative way. Such data have the possibility of going through detailed quantitative analysis. The quantitative method has 3 sub-methods, namely inferential, experimental, and simulation.

The author adds, the inferential approach is usually when a sample of a population is investigated to find certain characteristics. Afterwards, it is inferred that the population also possesses the characteristics. On the other hand, the experimental approach has control over specific variables which are manipulated to see their effects on the subject of interest. Finally, simulation approach is building a model which simulates a dynamic state with certain parameters. This model helps investigating the behavior of the state over time.

The qualitative method involves a subjective evaluation of “attitudes, opinions, and behavior”. In most cases, different interview and projective techniques are utilized in this approach (Kothari, 2004).

2.2 Method of the thesis

To address the research questions, this thesis has taken out both quantitative and qualitative approaches to some extent. To elaborate, Table 2 shows the sources and methods used to answer each research question.

Table 2. Research methods and data sources

Research Question	Data source	Method
How is the hospital construction cost performance in Norway and the US?	Primary data from projects in Norway and US	Quantitative
What are the quantifiable cost factors behind hospital construction cost?	Primary data from projects Secondary data (statistical indices), literature factors	Qualitative
What are the major cost factors in reported hospital construction cost?	Primary data from projects and questionnaire (expert's judgment)	Qualitative - Quantitative

It is worthy of noting that the literature study show that studies usually use one or two sources in order to obtain data. In this research, cost factors are obtained using the following three main sources:

1. Previous studies
2. Primary data obtained from companies
3. Experts opinion

Moreover, Secondary statistical data from databases such as The Organization for Economic Cooperation and Development (OECD) database were also reviewed to understand the construction situation better. In order to answer the first research question, primary data from different construction projects from Norway and the US are obtained and compared quantitatively. As for the second research question, the Norwegian and American projects' reported cost breakdown structure is compared qualitatively. In addition, literature cost factors were also studied for the second research question; this process was also qualitative. For the final question, a Pareto analysis was performed on the projects' data which ranks the factors in a quantitative manner. Additionally, a questionnaire was distributed among the experts to find out what major cost factors are from their opinion. The questionnaire process is considered qualitative; however, the results were analyzed in a quantitative manner.

Furthermore, the concept of triangulation has been used to improve the validity of the research. This concept refers to using more than one approach in the research process in order to get holistic and more comprehensive data/results (Wilson, 2014). According to Flick (2002), there are four types of triangulation, namely data, investigator, theory and methodological.

Flick (2002) explained that data triangulation indicates different sources are used to collect data. Investigator triangulation means different individuals are sought out in data collection and analysis process. Theory triangulation refers to investigating the subject from the perspective of different theories. Methodological triangulation is about utilizing more than one method to capture data. With the exception of theory triangulation, this study has used the rest of the triangulations.

For instance, in order to identify the potential cost factors, three sources were used: literature, project data, and expert's opinion. To find the major cost components, the investigator triangulation was applied and more than one individual have weighed in to identify the factors. Lastly, other than using the experts' judgment to find the major cost factors, Pareto method was employed to pick the major cost components in projects; this procedure reflects the methodological triangulation.

In the following sections, the methods taken in each step of the thesis are going to be completely explained.

2.3 Primary data from companies

When it comes to comparing construction cost on an international level, there are two issues that are more important than the others. Firstly, the costs should represent their context and secondly, they should be comparable.

2.3.1 Comparability vs. representability

In a study, Meikle (1990) stated three main procedures for international building cost comparison. The first method is asking experts in different countries to produce costs for one identical building, such as the study conducted by Mills (2013). The second method is to ask experts to calculate the cost of similar buildings but with local modifications. The third and final approach is to ask experts to provide the costs of the typical buildings of that category in their countries.

However, there is an issue regarding these three procedures as the author has pointed out. The issue is that with each method, the comparability decreases and the representivity increases. In other words, the first method holds the highest comparability among the buildings but is the least representable of the ongoing situation in the countries. Similarly, the third method is the least comparable but represent the situation the best.

This study selects the third method in order to achieve the maximum representivity of the projects' context. Meaning, the data consist of different hospital projects finished in different countries.

2.3.2 Primary data collection

A list of the top 25 American construction firms in healthcare sector was obtained through literature search (Cassidy, 2012). All of these firms plus several personal contacts from the US were contacted in order to obtain primary data regarding their previous hospital construction projects. Furthermore, a framework for cost breakdown structure of a hospital in Norway was also translated into English and sent to the companies in order to form a common understanding about the data needed. In Norway, personal contacts in Sykehusbygg were reached out to in order to obtain the data for Norwegian cases. The result was 8 healthcare projects; 5 from the US and 3 from Norway.

2.3.3 Cost comparison methodology

Choosing the right comparison method is important in a way that the method has the potential to affect the results greatly (Meikle, 1990). However, there were several steps taken to ensure that the data become as comparable as possible.

2.3.3.1 Area unit and time

The first issue was that the projects' data were expressed in two manners. One was local unit currency (LCU) per gross area (m^2 or ft^2) for each cost factor. The other was representing the cost factors in terms of total cost without considering the gross area. So one needed to be picked.

In this thesis, cost per area unit is selected as the basis for comparison because it allows comparing the construction costs irrespective of the building size (Emsley et al., 2002). However, it could be argued that the increase in size may affect the costs disproportionately. In this regard, Wibowo (2015) investigated 1050 construction projects. The study concluded that hospital construction costs increase with size at a constant rate which further justifies a comparison by cost per m^2.

After picking the results represented in LCU per m^2 in Norwegian cases (or ft^2 in American case), the area units were converted to one single unit. In other words, all of the American cost figures were converted to United States Dollar (USD) per m^2.

The next issue was that the projects' costs were reported in different years. In this regard, Meikle (1990) pointed out that in order to truly compare the costs, they should be considered at the same date. This date defines both exchange rate and market conditions. To bring the total construction cost to the same base year the following formula was used:

$$C_j = C_i \frac{(Cost\ index)_j}{(Cost\ index)_i}$$

Where:

C_j is the cost at year j

C_i is the cost at year i

The next question would be what “cost index” should be used in this formula. According to Walsh et al. (2006), the united nations system of national accounts (SNA) has divided “construction” into three categories: residential, non-residential, and civil engineering with hospital construction listed under non-residential buildings. Therefore, Wibowo (2015) suggests that a construction cost index which is the closest representative of changes in construction industry should be used.

However, in this study consumer price index (CPI) was used. To elaborate, CPI shows the “average price of goods and services in an economy relative to a base year” (Suranovic, 2010). The reason for choosing CPI concerns databases. A database covering both countries must be selected to avoid methodological differences in production of the price index. In addition, that database should contain data regarding the construction price index, or non-residential price index to be exact. Needless to say, the study did not find a database which could satisfy both conditions. On the other hand, OECD’s CPI database satisfied both conditions (OECD, 2017c), hence it was selected. The prices were all converted to the base year 2014. The reason why 2014 was chosen as the base year would be explained in the next section.

2.3.3.2 Currency

At this point, the costs were in the same year but in different currencies. Therefore, a common currency platform is needed to compare the costs. With respect to this issue, studies had put forward several methods for comparing construction costs between different countries:

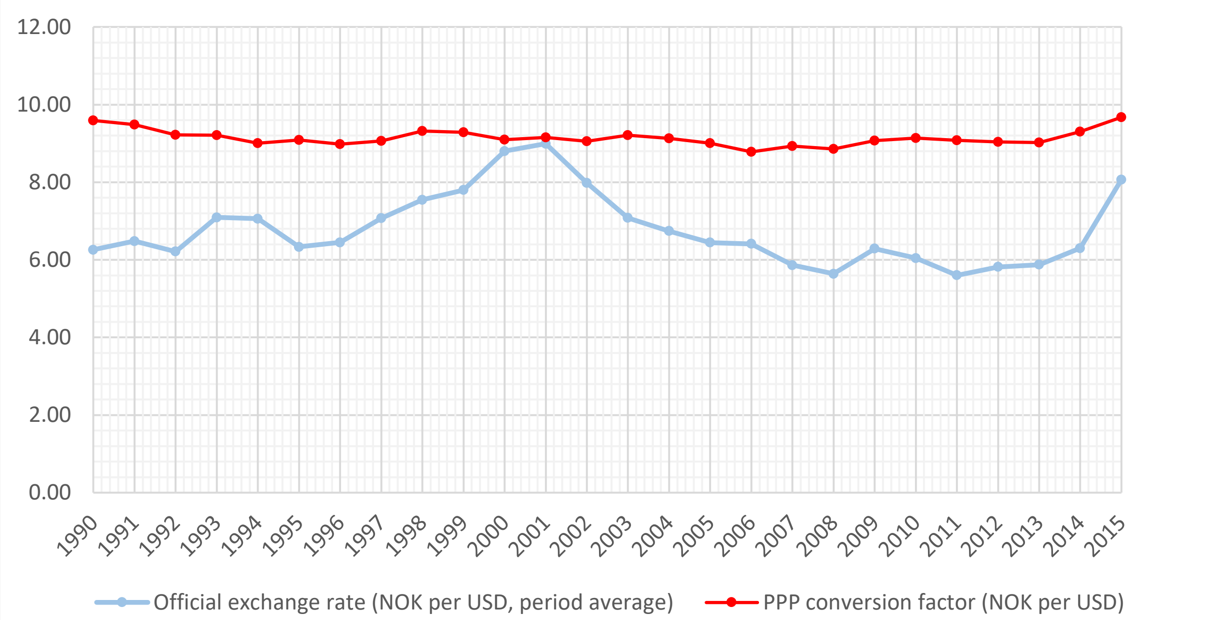
1. Currency conversion: In this method, different currencies are converted to a single one using markets’ exchange rates (Meikle, 1990; Turner & Townsend, 2016).
2. Atlas conversion method: It is used by World Bank. This method considers the average yearly exchange rates plus inflation rates in different countries (Walsh et al., 2006).

3. Purchasing Power Parity (PPP): It is a relative measure of showing costs compared with the cost of living in one's country (Turner & Townsend, 2016).
4. Location factor: It is an extension of the previous method by considering more factors such as labor, productivity etc. (Turner & Townsend, 2016).

The study checked the availability of the needed indices for each comparison method by searching in online databases such as OECD, International Monetary Fund (IMF), the World Bank etc.; it seems a choice has to be made between PPP or exchange rates. The thesis selects PPP over exchange rate to convert the different currencies into one. The idea behind this approach is to reflect the purchasing power of a currency within its border (Walsh et al., 2005). As a result, a PPP is commonly defined as the amount of currency that is needed to purchase a basket of goods and services over the amount of currency needed to purchase the same basket in another country. It is worthy of noting that PPP is primary designed for dealing with GDP but they can also be used in comparing other spatial economic data if the results are interpreted with care (EuropeanCommission, 2012). The following paragraphs explain the justifications for this choice of method.

Firstly, although straightforward, the exchange rates are influenced by different factors such as international confidence in the economy of a particular country, economic situation of the country at time and so on (Walsh et al., 2005) which may not necessarily be related to construction. Furthermore, these factors make the exchange rates unstable and it cannot fully reflect the volume or value of construction (Best, 2008; Meikle, 1990).

Secondly, PPP is less prone to have significant changes than exchange rates (Walsh et al., 2006). Figure 4 shows the time trend of PPP and exchange rates for Norwegian Krone to USD (IMF, 2017; WorldBank, 2017). Clearly, PPP trend has less fluctuations and is more stable over time. To support this visual conclusion by statistical analysis, '2 variances test' was carried out on the data illustrated in the time trend using Minitab 17. The procedure tests the hypothesis to find out if variances of two populations are significantly different or not.



Sources: The World Bank (2017), World development indicators. (Accessed on 30 March 2017)
IMF (2017), Financial sector: exchange rate & prices. (Accessed on 30 March 2017)

Figure 4. PPP and exchange rate trend

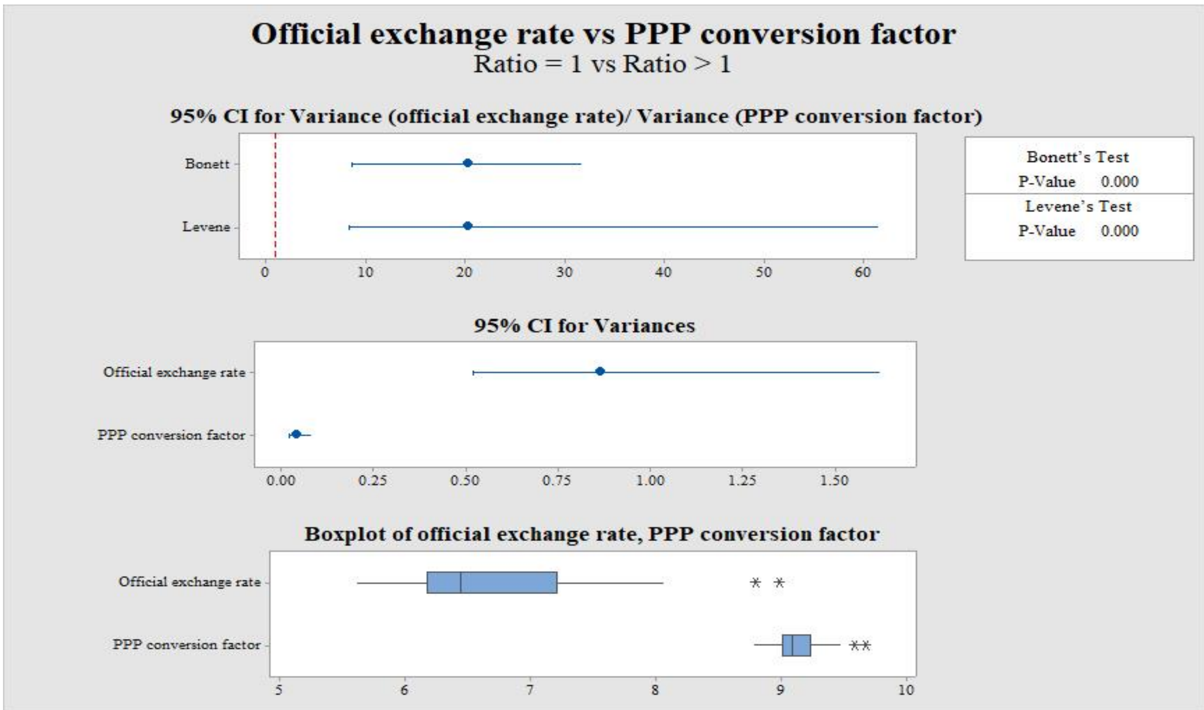


Figure 5. Two variances test

The null hypothesis of this test is that the two population variances are equal. In other words, the ratio of σ^2 (official exchange rate) / σ^2 (PPP conversion factor) is one. The alternative hypothesis is that PPP conversion factor has less variations, hence the ratio is more than one.

The results of this test are available in the Figure 5. With a significance level commonly set at 0.05, the p-value for both Levene's and Bonett's test show that the test rejects the null hypothesis. In addition, the 95% confidence interval (CI) for PPP variance is also substantially smaller than official exchange rate; the boxplot also shows PPP is more stable. Therefore, it can be concluded that the PPP conversion factor has smaller variance than the exchange rates and is more stable.

Thirdly, Walsh et al. (2005) argued that domestic price indices could be regarded as temporal indices used in cost comparisons within a country while PPP could be considered as spatial indices which can be used to compare construction costs in different countries. This point justifies using PPP in this thesis more.

As a result, the primary data on projects' costs, which are now in the same year, will be converted to one single currency by applying PPP method. Van Biesebroeck (2004) has discussed that it is possible for PPP to change significantly in different sections of economy. Therefore, the aforementioned PPP is available for different product's categorizations on different databases. This means it is needed to identify the category which is closest to hospital construction.

OECD has provided a database on PPP indices which follow SNA's classification (EuropeanCommission, 2012). Meaning, OECD database includes PPP for construction section. On the other hand, latest publication of this index is for the year 2014 (OECD & Eurostat, 2017) which is why 2014 was selected as the base year for converting the costs before. Finally, using the figures from OECD's PPP dataset, the projects' prices would be converted in one single currency (Euro) per m^2.

2.3.4 Cost item analysis

The reported cost breakdown structure of Norwegian and American projects are compared to identify the different construction practices between the countries. In order to compare the cost items, the projects data from other databases such as Design Cost Data (DCD) (DC&D Technologies, 2014) and American standards such as Construction Specifications Institute's MasterFormat (C.S.I., 2016) were also employed; MasterFormat is a standard adopted by federal agencies in the US (Miller & Newitt, 2005). The Holte's handbook on construction costs, which is according to the Norwegian standard NS 3453, provided the details needed for Norwegian cases.

In order to find the important cost factors, a systematic way should be applied. In this regard, Pareto principle has been applied extensively as a quality control tool in order to screen critical elements in a process (Wilkinson, 2006). According to Pareto principle, the vital few govern the trivial many (Lipovetsky, 2009). Therefore, a Pareto chart was selected to filter the important cost items of the primary data. Not only may Pareto analysis provide a good basis to discover the important cost items in each country but also its results would later be used in analyzing the experts' opinion and literature results.

2.4 Cost factors from literature's perspective

In order to examine the academic and practical perspectives, the literature cost factors were extracted to be later compared with the questionnaire cost factors. In this regard, the previous experience in literature search process helped the study immensely. To elaborate, the author carried out a project concerning cost estimation in transportation infrastructure by utilizing a systematic literature review. The results of the project have been published in the form of a conference paper available in Appendix F. The cost factors were extracted from the 64 selected publications mentioned in the section 1.2. However, further filtering in factors were required based on two reasons:

1. The number of obtained factors were high.
2. There were repetitions in some factors.

Three rounds of filtering were applied. In the first round, the repetitions were removed. Instead, the frequency that each factor was mentioned was computed to give a general idea about the focus in the research community. It was observed that the remaining cost factors are either quantifiable, such as number of stories, floor area, and building height, or qualitative such as availability of contractors or bidding process. Similar category definitions have already been observed in Emsley et al. (2002); Harding et al. (2000); Lowe et al. (2006). The qualitative data are somewhat intangible and difficult to define. Therefore, with the help of two academic experts the second filtering was performed to divide the factors into two categories:

- Direct cost component (quantifiable)
- Indirect cost component (qualitative)

At this stage, the quantifiable cost factors were collected from the factor pool.

The third and final filtering was to categorize the factors in the Norwegian standard's framework for hospital construction, NS 3453. This framework divides the construction costs into different subsets and all of the Norwegian hospital cases followed the same structure to a large degree. The result of this step would show us the factors found by previous researches in a Norwegian context thus making the comparison more straightforward.

2.5 Questionnaire

Through questionnaire, information can be gathered from a large amount of experts scattered geographically (Ackroyd & Hughes, 1981). As a result, the questionnaire was selected to gather experts' opinion on the cost factors in hospital construction. The methodological details of this process is systematically divided into three parts: design, questionnaire's indices, distribution.

2.5.1 Design

A preliminary questionnaire was first drafted based on the final filtering results from the literature (available in the section 3.2.2). This questionnaire, which is attached in Appendix B, was later presented to two academic experts who were experienced in performing academic surveys and industry.

The feedback showed that the possible respondents may have trouble comprehending literature factors plus the questionnaire was deemed too long; it had to be concise to encourage the respondents to answer it quickly. The two experts believed that practitioners in the industry would be more familiar with the reported projects' cost factors. Therefore, a second set of questions were drafted based on the cost breakdown structure from all of the 6 hospital projects seen in Table 3 plus one other American project obtained from Design for Cost magazine database (DC&D Technologies, 2014). The challenge was to combine the American and Norwegian cost breakdown structures together in one set of questions in order to provide the same base for judgement and create consensus. The second questionnaire is included in Appendix C.

This questionnaire was also presented to the experts for feedback. Their feedback revealed that the number of factors are too high for a questionnaire whose main target audience is professional managers. Based on their suggestion, insignificant cost factors were removed and a number of factors were grouped together. The results were once again reviewed by the two experts.

Their evaluation showed the third questionnaire seemed practical and appealing to the respondents. This final questionnaire is attached in Appendix D.

This questionnaire included three main sections:

1. Project cost factor selection: In this part, the respondents would be asked to give scores to the cost factors attained from the American and Norwegian projects. Moreover, there was another column in which the respondents could pick multiple stakeholders who can affect the corresponding factor the most.
2. Suggestion box: The respondents could suggest important factors which they believed should have been included on the questionnaire.
3. Information about the respondent: It consists of questions about the position of the respondents in the industry, years of experience, field of construction.

Two scoring systems were found in the literature, namely those of Elhag et al. (2005) and Le-Hoai et al. (2008). In both of them an index would be calculated based on the scores given by the experts in order to rank the cost factors. Elhag et al. (2005) employed only one measure to assess the degree of influence for each cost factor and used the frequency of the respondents as another measure to come up with the ranking index.

The second approach, which was used by Le-Hoai et al. (2008), relies more on the expert's experience by asking the frequency of the cost factors directly from the experts. To illustrate, the experts would be asked to score the cost factors in two categories: frequency and severity. A third index would be used to calculate "the importance" of the cost factors based on the multiplication of severity and frequency.

To make the questionnaire shorter and more appealing, the first type was selected. A five-point Likert scale was chosen to reflect each cost factor's degree of influence on the total cost. The scale and the corresponding weight with which the experts present their judgment are as follows: 'not at all=1; slightly=2; moderately=3; very=4; extremely=5'.

Furthermore, in order to find the stakeholders who can potentially affect the cost factors, the major stakeholders in hospital construction were also listed alongside each cost factor. Answers to this index could result in better focus on resource allocation to the source of the cost factors. With the help of thesis' supervisors the major stakeholders were divided into owner, consultant, contractor, and government. The stakeholders were selected in a way to be clear for participants plus similar classifications were already seen in other studies (Assaf & Al-Hejji, 2006; de Melo et al., 2016; Le-Hoai et al., 2008). Unlike the assessment for degree of influence, the respondents were given the opportunity to select multiple choices in the stakeholder section.

2.5.2 Questionnaire's indices

The expert's opinion is processed by two types of indices:

Importance index: The aforementioned index evaluates the degree of influence each cost factor has on the total construction cost. For each factor, it is calculated by this formula:

$$Importance\ Index = \sum_{i=1}^{5} a_i n_i \Big/ N$$

Where:

a_i is the constant weight assigned to each response option (see the section 2.5.1) e.g. 1,2, etc.

n_i is the number of responses that each option has received.

N is the total number of responses.

The formula is a weighted average of the data. Its product is a number from 1 to 5. The higher the number is, the more important the factor would be. For example, if the cost factor "Gross floor area" receives 3 responses out of which 1 is answered moderately, 1 very, and 1 extremely, its importance index will be:

$$= \frac{(3 * 1) + (4 * 1) + (5 * 1)}{3} = 4$$

Which on average shows that the "Gross floor area" is "very" affecting the cost.

Stakeholder index: Respondents use this indicator to pinpoint the stakeholder(s) who can affect the cost factor the most. In each cost factor, it is calculated for each stakeholder separately.

$$Stakeholder\ index = \frac{n_i}{N} * 100$$

Where:

n_i is the number of respondents selecting the ith stakeholder e.g. owner, consultant, etc.

N is the total number of responses.

Each stakeholder in each cost factor would receive a percentage showing the rate of the experts who believe that stakeholder can affect the cost factor. For each factor the stakeholder with highest percentage would be selected as the stakeholder who has the potential to affect the cost factor the most (see under the "who" column in Table 7. Experts' opinion results). In the case that stakeholders have the same amount of percentages, all of them are listed. For instance, the cost factor "elevator" would receive four percentages for the four stakeholders, 16.67% has chosen owner, 66.67% consultant, 66.67% contractor, 16.67% government. Therefore, consultant and contractor would be selected as the main stakeholders than can affect the aforementioned cost factor.

For each stakeholder, the number of the factors they can affect was counted to find out which stakeholder has the widest range of influencing the cost factors. The results can be seen in the section 3.3.2.3.

2.5.3 Distribution

Although face-to-face delivery of the questionnaire promotes the response rate (Le-Hoai et al., 2008), an online distribution platform was chosen due the geographical diversity of the target audience. Authorities at Sykehusbygg in Norway and professional contacts in the US were contracted to help form a list of possible respondents.

To increase the response rate, the following measures was taken:

1. The study made sure to include the data providers' names such as Sykehusbygg itself, the short amount of time that is needed to answer, and the potential positive outcomes of the study in the invitation emails.
2. A link to the online questionnaire was also generated to be distributed among professionals and expand the target audience in an easy manner. This link was also included in the 'thank you' message after the respondents submitted their answers.
3. The experts were particularly encouraged to pass the invitation email to their colleagues.
4. A reminder schedule was set to remind the respondents who have not answered the questionnaires every 5 days.
5. Following the recommendation of Attalla and Hegazy (2003), the main section of questionnaire, which was part 1 and 2, was projected in one page in order to encourage more respondents to reply.

2.6 Priority checklist of cost factors

In order to bridge the questionnaire results with practice, a checklist was created. This checklist prioritizes the factors into three classes based on the scores given by the experts. The Pareto principle were applied to assign the factors to each class. To elaborate, four rounds of Pareto analysis were applied to the factor list. The first two rounds determined the factor with top priority. The second two rounds revealed the moderate priority and the rest of the factors are considered as low priority.

In each round approximately the top 20% of the factors were selected and moved to the checklist priority list. The subsequent rounds were performed over the remaining factors until the four rounds were completed and the factors are divided into three priority classes. The final checklist is included in Chapter 3.

3 RESULTS & DISCUSSION

This chapter is structured according to research questions to enhance coherence and readability. For each research question, first the results are presented and then they are discussed.

3.1 How is the cost performance in Norway and the US?

Turner Corporation, one of the largest companies in healthcare sector in the US, provided the study with a set of data covering 5 projects. According to Cassidy (2012), Turner company is the top healthcare construction firm in terms of revenue in the US. Two of the projects were not in the scope of the project. The rest of them, which were all hospital projects, are presented here.

From Norway, Sykehusbygg is the organization responsible for hospital planning and construction. There are four health regions in Norway and all of them are covered by Sykehusbygg. In addition, this organization oversees all major hospital projects worth more than 500 million Norwegian Kroner (SykehusbyggHF, 2014).

The results were data covering two projects; one for a hospital in Østfold and another for a hospital in Østmarka. A third set of data was also available from Holte company’s handbook. Holte is a Norwegian software company specialized in construction and real state with over 40 years of experience. Their hand book provided costs based on assumptions about a hospital construction project.

Table 3 shows the total construction cost per m^2 for the six projects.

Table 3. The projects’ cost comparison

Country	Project Name	Total Cost in the base year 2014 (LCU*/m^2)	Total Cost (€/m^2)
Norway	Holte	40129	2950.66
Norway	Østfold Hospital	66258.03	4871.91
Norway	Østmarka Hospital	49536.00	3642.35
US	Ohio State Wexner Medical Center	4554.91	2558.94
US	Children's Hospital of Buffalo	4446.41	2497.98
US	University of Princeton Medical Center	4893.60	2749.22

*LCU= Local Currency Unit

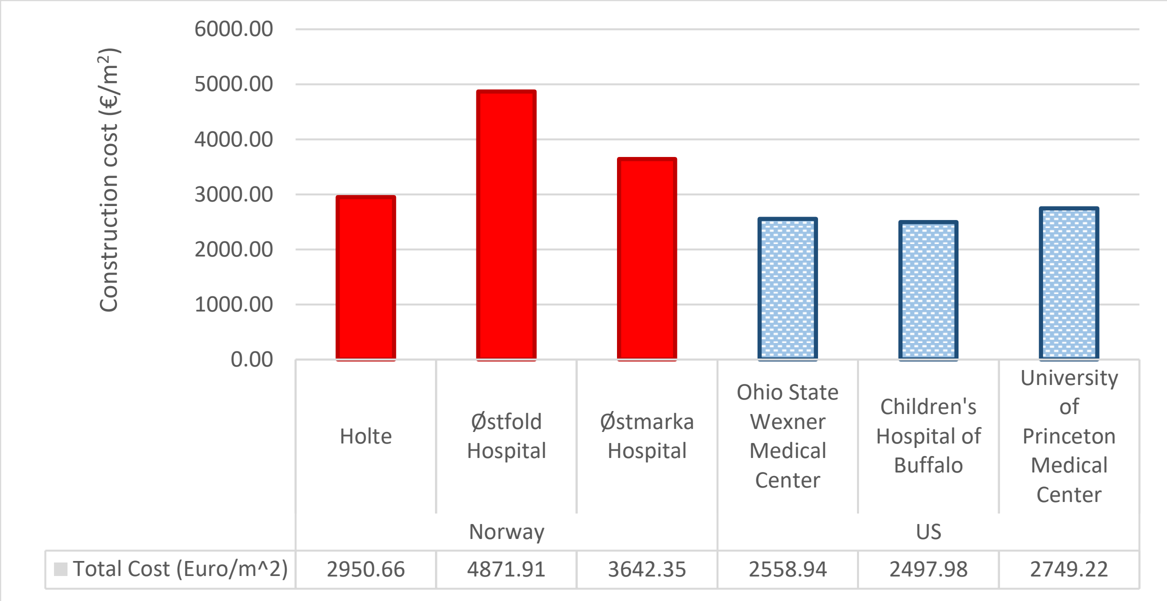


Figure 6. Cost of hospital construction in Norway and US

Figure 6 shows clearly that there are cost differences between the Norwegian and American projects. As a matter of fact, the lowest Norwegian cost figure, which is Holte's 2950 €/m^2, is still higher than the University of Princeton Medical Center which is the highest figure with 2749 €/m^2 in the US. Although analyzing the descriptive statistics would not be of much significance due the limited number of projects, it would still provide a tangible platform to compare the projects. The following table (Table 4) shows the mean, variance and standard deviation for the projects.

Table 4. Descriptive statistics for the projects

Country	Mean (€/m^2)	Variance (€^{2}/m^4)	Standard deviation (€/m^2)
Norway	3822	946,911	973
US	2602	17,173.4	131

Based on Table 4, on average, the Norwegian projects have higher costs. The standard deviation shows there are more cost differences within the Norwegian than the American projects. This difference in cost performance could be attributed to the process of making the projects' cost comparable. According to Meikle (1990), no international cost comparison is perfect and this includes the conversion process performed in this thesis. The thesis also believes there is no wrong way of making the different currencies comparable, per se. Each method has some advantages and disadvantages. However, it might be of interest to see the difference in methods' application in future studies.

Moreover, it might be argued that the projects are not completely comparable thus there is a difference which may be true. However, it should be noted that instead these projects are representable of the situation. Moreover, it is very difficult to find two project with exact same definitions of cost items on an international scale; even inside Norway, the data show the projects do not completely follow the same structure in presenting their construction costs. Furthermore, if taken from an investment point of view, the price per square meter for hospital may be more important than the differences among the hospitals.

These differences in costs can also have other reasons which are explained in the next section.

3.2 What are the quantifiable cost factors behind hospital construction?

With respect to the causes for these cost differences, studying the previous researches has provided many reasons. In this regard, Chan et al. (2004) has proposed 5 classes for factors affecting construction success. Given that cost is one criterion for project success (Pinto, 2013), these classes could also be deemed as reasons for cost differences.

Therefore, the difference in costs could be attributed to the following reasons (Chan et al., 2004):

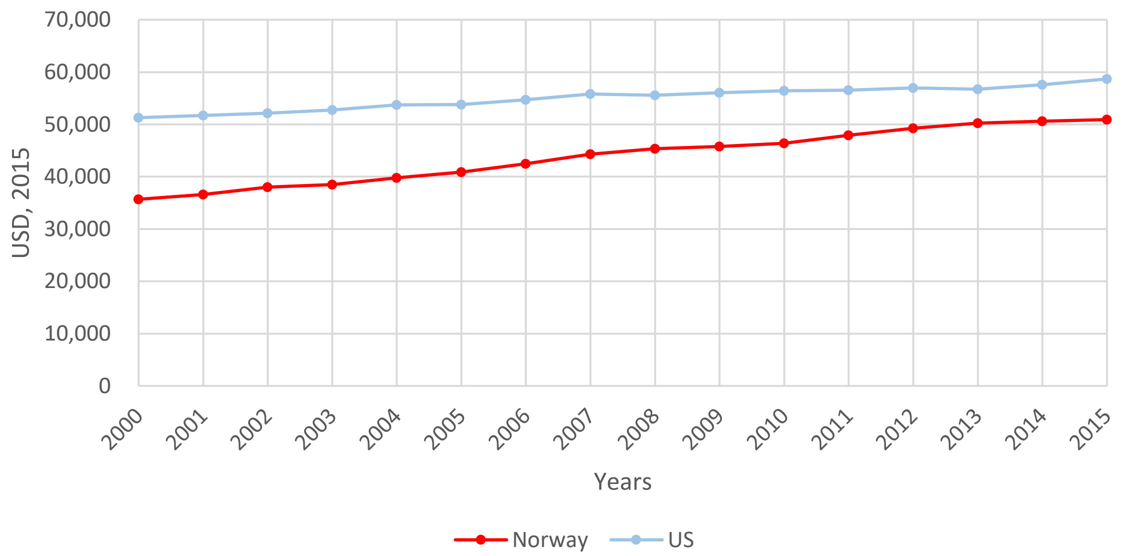
I. Human-related factors such as planning, coordination, decision-making skills of project participants etc.
II. Project procedures such as procurement/tendering method.
III. Project management actions such as organization structure, control mechanism, quality assurance system etc.
IV. External environment such as economic, social, political, etc.
V. Project-related factors such as size, number of floors, type of project etc.

The project data which were obtained does not cover details about the first three reasons neither are those in the scope of the thesis, therefore they will not be investigated here. However, those factors have been mentioned as influencers on cost in other studies as well (Cunningham, 2013; De Marco & Mangano, 2013; Erdis, 2013; Hong et al., 2010; Rosenbaum et al., 2014; Rybkowski et al., 2012; Shehu et al., 2015).

Although the external environment is not in the scope of thesis either, it certainly affects the costs. To elaborate, Construction industry in each country is different than the other countries.

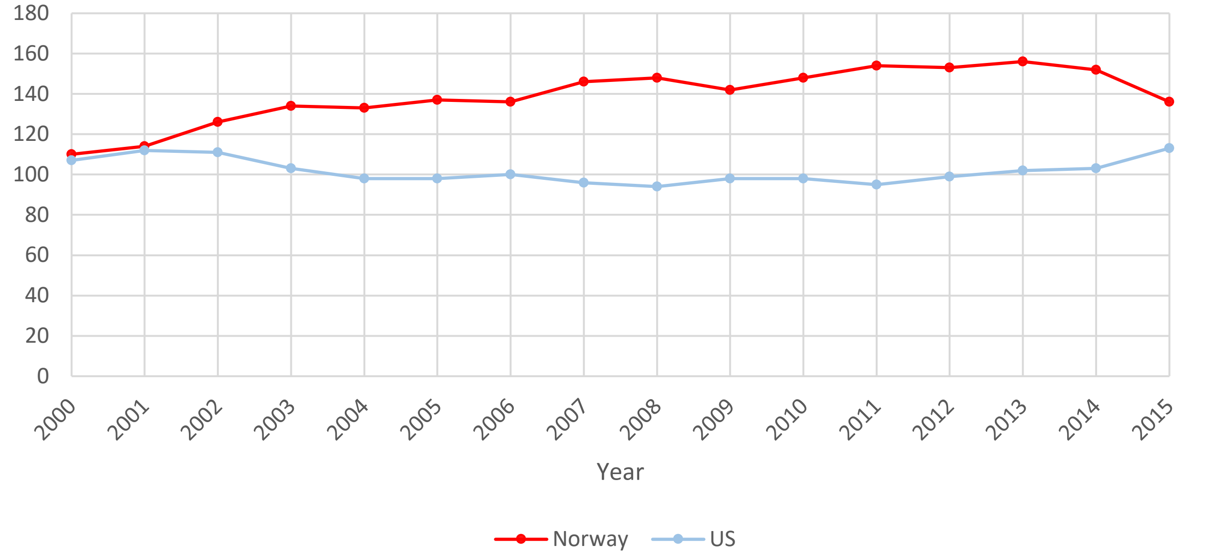
Factors reflective of the construction situation could be market conditions (de Carvalho et al., 2015; B. Lim et al., 2016; Sonmez, 2008), regulation (J. L. Kim et al., 2014; Le-Hoai et al., 2008; Pennanen et al., 2011), climate (Cunningham, 2013; S. Y. Kim et al., 2017; Trost & Oberlender, 2003), and labor cost (Gurcanli et al., 2015; Wasmi & Castro-Lacouture, 2016). For instance, analyzing a 15-year period of average annual wages (Figure 7) shows that there is difference in labor cost between Norway and US (OECD, 2017a). However, the figures show for that duration, the Norwegian average annual wage is actually less than the American counterpart.

In a similar vein, investigating the comparative price level indices for the same duration (OECD, 2017d) shows Norway has higher price levels (Figure 8) which may indicate that the material cost is higher in Norway than the US in general. Nevertheless, detailed researches are required to measure the exact impacts of such factors. The project data obtained from the companies already include the material, labor, and machinery costs inside each cost category.



Source: OECD (2017a), average annual wages. (Accessed on 25 May 2017)

Figure 7. Average annual wage comparison



Source: OECD (2017d), Price level indices (indicator), doi: 10.1787/c0266784-en (Accessed on 15 June 2017) (OECD=100)

Figure 8. Price level indices

The results of this thesis mainly concerns the last class of factors; project-related factors. In the following sections, those results are going to be discussed in detail. These factors are divided based on the source they were obtained from.

3.2.1 Projects' reported cost factors (cost breakdown structure)

Figure 9 and Figure 10 show the cost comparison of the items within each country. The bars with the same patterns represent the cost for a project case. Looking at the aforementioned figures, it is obvious that the two countries do not follow the same construction practices. It seems there is a difference in breaking down the costs for healthcare construction projects.

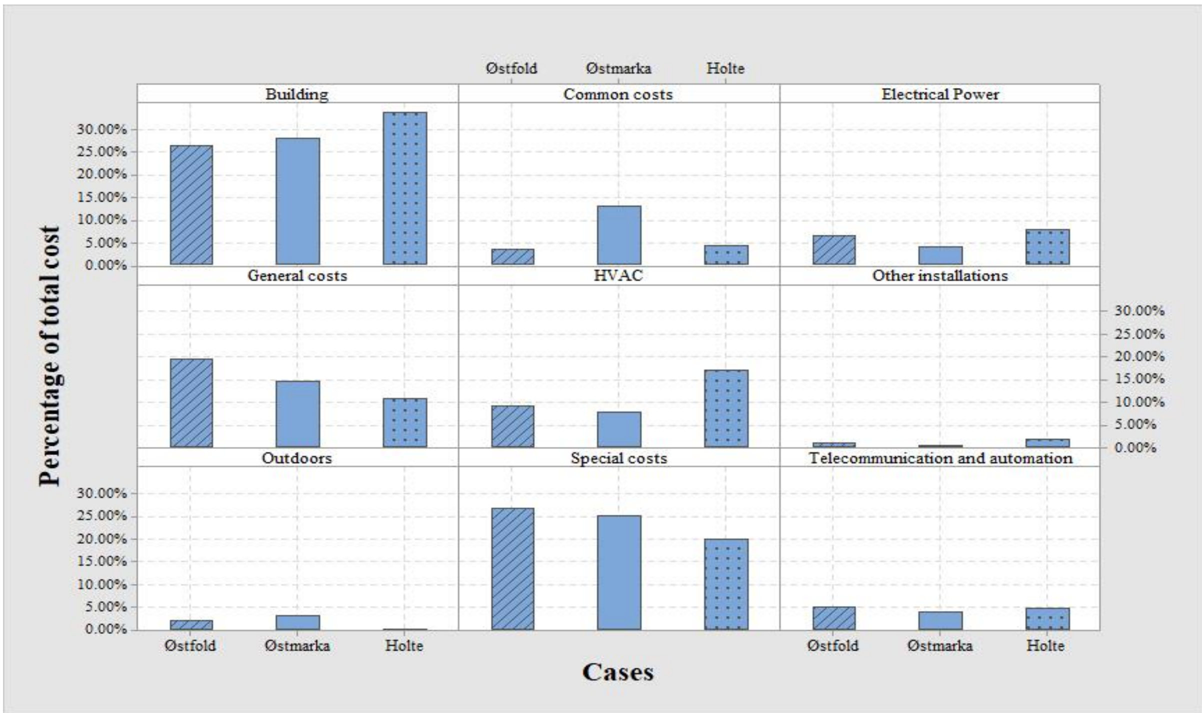


Figure 9. Cost breakdown comparison within the Norwegian projects

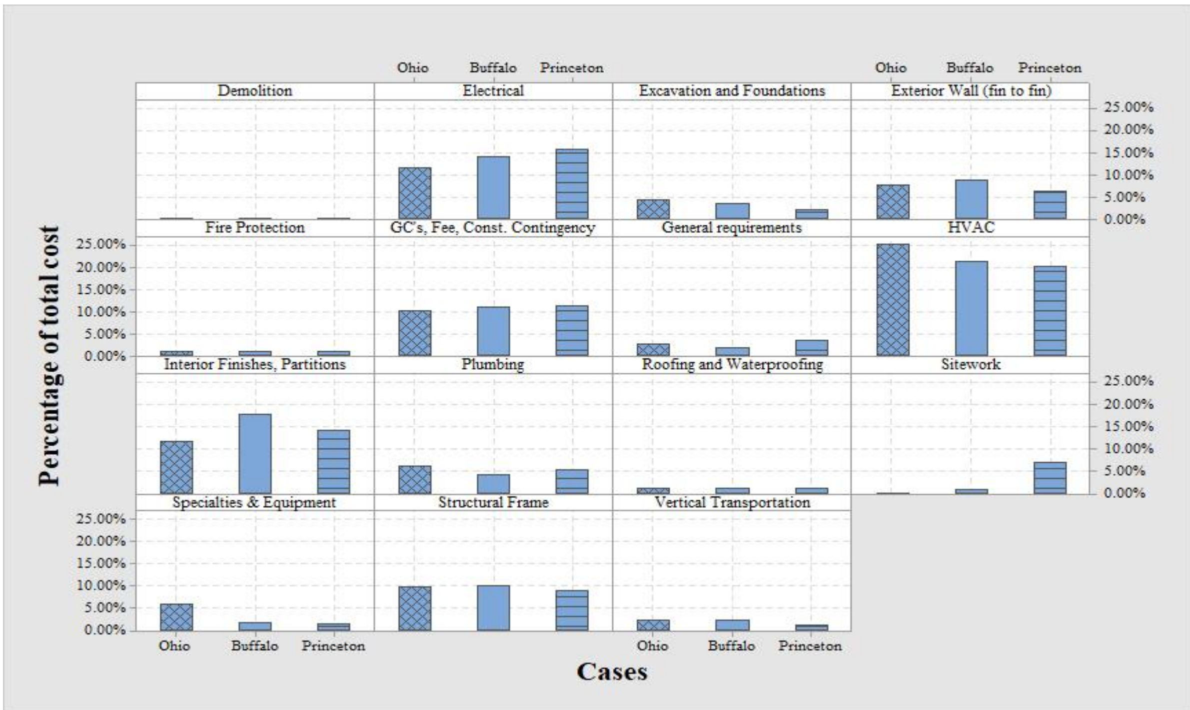


Figure 10. Cost breakdown comparison within the US projects

Apparently, one of the main differences is the “building” cost category in the Norwegian cases. This single category in the Norwegian cases seemingly is the equivalent of summing up 5 categories in the American cases. To elaborate, the main categories of “Excavation and Foundation”, “Exterior wall”, “Interior Finishes, Partitions”, “Roofing and Waterproofing”, and “Structural Frame” in the American cases are seemingly all sub-items of “building” category in the Norwegian cost breakdown structure. In order to test and see if the sum of these 5 categories make up the same amount of total costs as the Norwegian "building" category, a simple average was taken between projects. On average, "building" was 31.7% of the total cost in the Norwegian cases and the sum of those five categories was responsible for 36.39% of the total cost in the American cases. Apparently, building costs carry almost the same share of the total cost in the cases from each country.

Another difference was the "finishes" category. Finishes are all the surface material which are observable in the inspection other than furnishings (Shields et al., 1986). In the Norwegian projects, the exception of flooring finishes, the rest of the finishes such as internal and external were combined with other factors with. For instance, the "interior wall" cost item description in Holte's project data included the cost of plasterboard finish as well. "Flooring" which referred to floor finishes had its separate cost item in the Norwegian projects. On the other hand, the American projects' had a separate cost category named "interior finishes". Furthermore, project data from the other American cases were also checked to see if such categorization is also followed elsewhere. In this regard, data from Design Cost Data database also had "finishes" as separate categories (DC&D Technologies, 2014).

Comparing Norwegian with American projects, it could be assumed that 'flooring finishes' needs more attention or is costlier than internal/external wall finishes in Norway. This assumption explains putting this item as an independent cost factor. For the US, it seems "finishes" category in general is more important than Norway because the American cases had it as an independent cost item. Moreover, it seems external finishes are not that important in the reported American projects because they did not have their own cost category as opposed to internal finishes.

It was also difficult to find an equivalent American category for the Norwegian "special costs". This category covers the mainly Value Added Tax (VAT), aesthetic decoration, and portable equipment in Norwegian cases. In the US, these sub-items are covered by more than one cost category. To elaborate, taxes are listed under "procurement and contracting" category in the MasterFormat standard (C.S.I., 2016) and sometimes they are not even expressed in the cost estimation stage (Butcher & Demmers, 2003). Aesthetic decoration is put under "furnishings" in the MasterFormat standard, however, the American projects did not include furnishings separately or maybe they have listed it under other items. Portable equipment is classified mainly under two other categories in the MasterFormat standard which are "specialties" and "equipment". In other words, the one category of special costs in the Norwegian cost breakdown structure seemingly equals five categories in the American standard.

The two categories of equipment and specialties, which are separate in the MasterFormat standard, are combined together in the American project data into one single class. This marks a discrepancy between the standard and the reported project data from the US. Furthermore, a discrepancy was also discovered while investigating the Norwegian projects in this regard. One project did not include the VAT under "special cost" but provided two set of figures one including taxes and the other without; maybe the standards and project data have compatibility issues. This subject could be investigated more in future studies.

The American projects also had different views about the pluming works of hospital. In all of the American projects, pluming had its own category while in the Norwegian projects such factor was not independently presented. The Norwegian Holte's cost breakdown, shows that pluming cost is included in the factors under HVAC; sanitary installation to be specific. It seems pluming costs are more considerable in the American projects thus the independent categorization would be justified.

There were similarities in the projects as well. The cases from both countries took somehow similar approaches toward "preparation of the construction site" cost factor. The Norway's cases classified those works under the "common costs" which is about building the offices, setting up the cranes and preparation works. The closest category in the US cases is "demolition" which is about clearing the site, grading the ground and putting up the temporary walls for safety purposes (Butcher & Demmers, 2003).

Another common point was the "Electrical" category. In Norway, this category covered the costs of basic installation, cabling, illumination, and low/high voltage equipment. Apparently, in the US this category also covers "lighting", medium/low-voltage distribution, and "common work results for electrical" (C.S.I., 2016).

Other similarities could include the American "site work" and Norwegian "Outdoors". No cost item with the exact name "site work" was found in the MasterFormat standard. However, the closest cost item was "site improvements" in the MasterFormat and "Site paving, structure, and landscaping" in Butcher and Demmers (2003), which included work packages such as paving, site furniture, fencing etc. The "outdoors" cost category also covers outdoor infrastructure, roads, parks, gardens, etc.

In projects' from the US, there is another factor named "GC's, fee, const. contingency" which is not considered a direct cost. Apparently, it is about the general contractor's fee and administration costs and construction contingency (Butcher & Demmers, 2003). However, in the American standard the contingency is under "general requirements" category. Therefore, it seems there is another discrepancy between the standard categorization and the practical project categorization. In the Norwegian projects, such costs are mainly covered by the "general costs" category. In addition, the aforementioned category also lists designing and project planning tasks.

To conclude, there are some similarities to categorization of the hospital construction cost in the countries. However, the differences seem to be outnumbering the cost, for instance, the "special cost" category. There are also almost-similar categories such as HVAC and electrical for example. Apparently, the American cases present a more detailed cost categorization in their reports; maybe this is the reason for the cost differences. To elaborate, detailed categorization could mean more information should be gathered to calculate the costs thus more accurate costs are produced. Furthermore, within the projects in the same country there are differences between the standard categorization and the project. Maybe on the professional level, it is impractical to strictly follow the standards. However, this may be a suitable subject for future studies.

3.2.2 Literature cost factors

More than 440 cost factors were derived out of the 64 academic works attained in literature search; all of which are available in Appendix A. After the first round of filtering 236 cost factors were left. The second round of filtering left 92 cost factors. The following table (Table 5) shows those 92 cost factors filtered and classified according to Norwegian cost breakdown structure.

Table 5. Filtered cost factors from literature

Categorization	Cost factors obtained from literature
Common costs	• Excavation conditions • Site facilities • Workspace in site • Energy consumption of the materials
Building	• External walls • Finishing grades • Fittings • Floor finishes • Floor type of the building • Structural frame type • Internal doors • External doors • Internal wall finishes • Internal walls • Masonry structure • Piling • Roof construction • Roof finishes • Roof profile • Roof types • Stairs • Stair types • Structural units • Substructure • Type of exterior finishes • Type of foundation • Windows
HVAC	• Air conditioning • Protective installations • Sanitary appliances • Plumbing system • Mechanical system • Mechanical installations
Electrical	• Electrical installations • Electrical system
Telecommunication and automation	• IT installation
Other installations	• Disposal installation • Number of elevator stops • Number of lifts • Special installations
Outdoors	• Transportation
General costs	• Inspection by operator, maintenance and end user • Project administration cost increase • Safety costs • Site overheads • Resumption/accommodation works • Time of construction (duration) • Productivity • Additional works in project
Special costs	• Cash allowances • Location value • Quantity increased measure

	• Tax policies • Type of the location
Project-specific cost components	• Percentage area of commons and nursing facilities in total building • Average floor area • Average story height • Building area • Degree of circulation space • Floor area • Fully enclosed covered area • Height • Inpatient nursing units • Internal perimeter length • Labor cost • Material cost • Material (what is bought from supplier) • Number of stories • Number of stories above the ground • Number of stories below ground • Number of units • Number of units per number of stories • Outpatient clinics and operating theater suite • Ratio of floor area to total area of the building • Ratio of ground floor area to total area of the building • Site area in m^2 • Size • The compactness of the building (external wall area/gross external floor area) • The share of ancillary area for services (ancillary area for services/gross external floor area) • Total building height • Total gross building area per residential unit • Unenclosed covered area • Unit prices • Upper floors • Wall area • Wall-to-floor ratio • Outdated hospital equipment • Contingency allowance

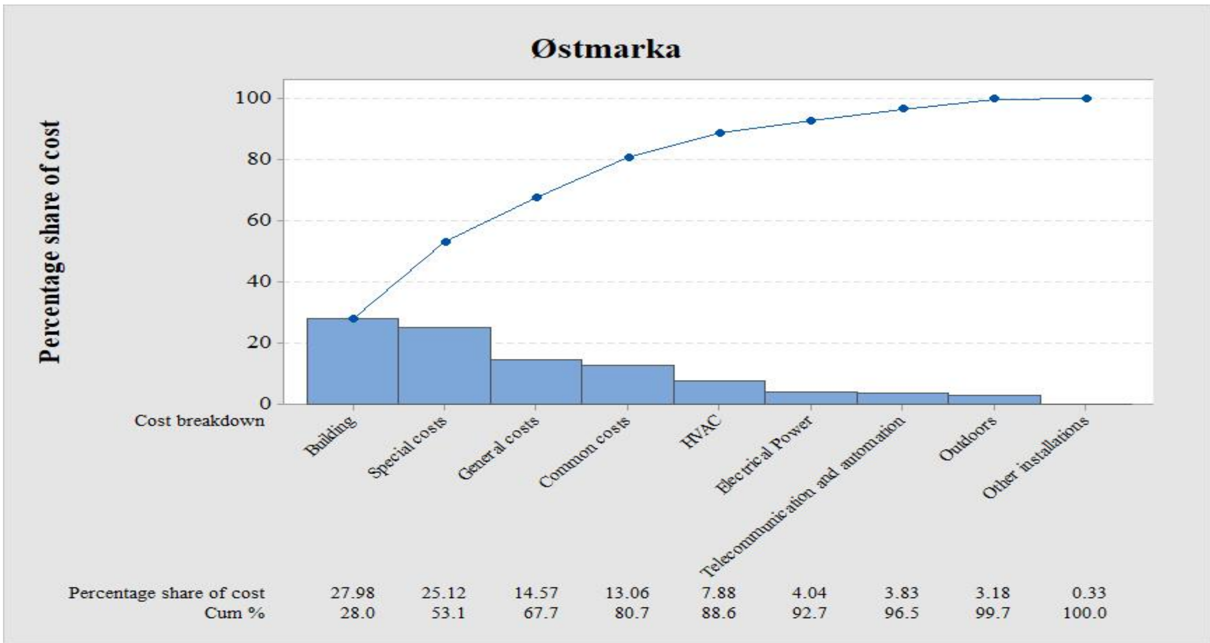
These factors are going to be later compared with the cost factors obtained from case studies.

3.3 What are the major cost factors in reported hospital construction cost?

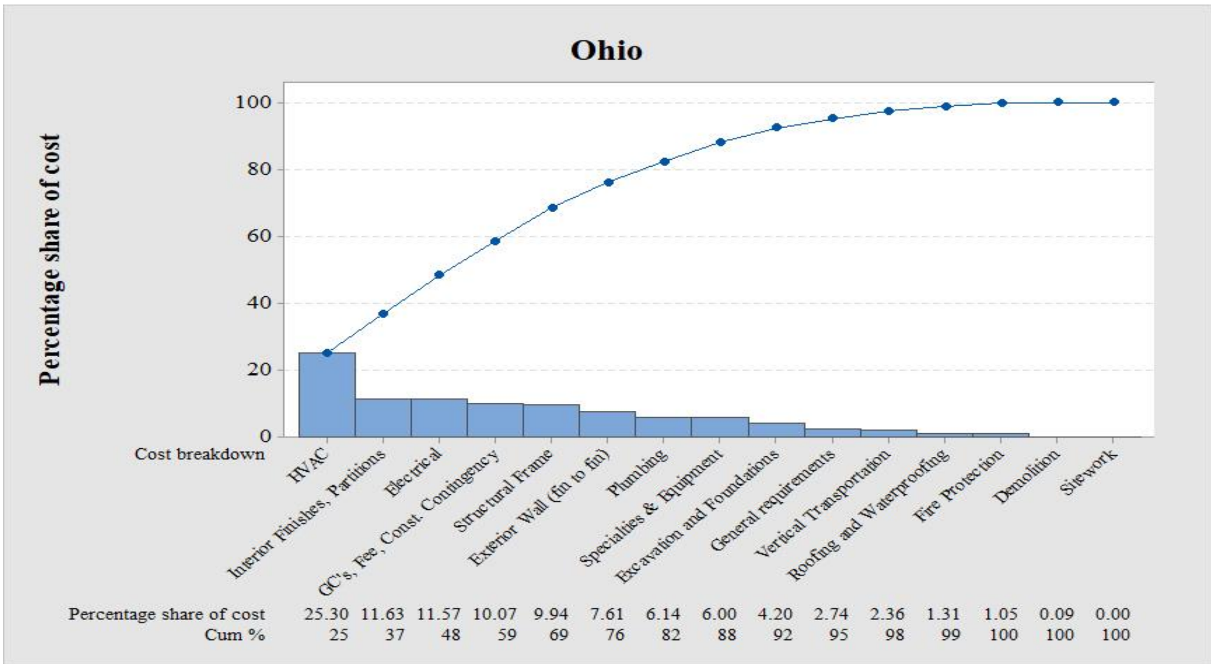
The results of this section is mainly based on the project data and opinion of the experts which was revealed through the questionnaire.

3.3.1 Pareto analysis on the project data

There are so many cost factors involved in each of these categories as mentioned by the literature study. In Pareto analysis, the cost factors are organized based on their total cost share:



(a)



(b)

Figure 11. Pareto chart analysis examples (a), (b)

Figure 11 represents the important of each cost factors in the projects according to Pareto principle with two examples; the same measure was taken to find the most important costs in other projects. It is observed that there are similarities between top three factors in Norway and top four factors in the US. Table 6 clearly shows this phenomenon. These similarities are observed within each country and also between them. Therefore, first the similarities within each country are explained and then the similarities between the countries.

Table 6. Major cost items in projects

Project	Holte	Østfold	Østmarka	OSWMC[1]	CHB[2]	UoPMC[3]
1	Building	Special costs	Building	HVAC	HVAC	HVAC
2	Special costs	Building	Special costs	Interior finishes, partitions	Interior finishes, partitions	Electrical
3	HVAC	General costs	General costs	Electrical	Electrical	Interior finishes, partitions
				GC's, Fees, Const. Contingency	GC's, Fees, Const. Contingency	GC's, Fees, Const. Contingency.

Note: General contractor (GC) and Construction (Const.)

In the Norway's cases, building costs was the highest cost category in two out of three projects and came second in the third one. Among the projects, the category carried between 26.5% to 34% of the total cost with an average of 31.7%. On the US side, "interior finishes, partitions" are among the highest cost factors. Since "building" category also covers the costs of finishes, it is possible there are close similarities between the cost factors in both countries. However, this phenomenon is going to be observed again and again later.

The "special costs" was among the top two in all three Norwegian projects. The share of this category out of the total cost varied from 20% to 26.9% with an average of 24%. It seems that "special costs" category is more dependent on project conditions because of two reasons. First, in the Norwegian projects, there is 25% taxes on the cost items, therefore it can greatly affect the projects with higher costs as higher costs mean more taxes. Second, this category covers the costs of equipment and equipment needs specially varies if a hospital performs special types of healthcare services. As a result, this study believes that the special cost category a volatile cost group the amount of which is largely dependent on the project properties.

[1] Ohio State Wexner Medical Center
[2] Children's Hospital of Buffalo
[3] University of Princeton Medical Center

To estimate the VAT effect on total cost, its cost item was removed from the Norwegian projects and each cost category's percentage share of total cost share was recalculated. The result shows that "special costs" is not on the top anymore. Building, general costs, HVAC, and common costs became the top cost categories in that scenario. Therefore, tax policies have the potential to impact the cost of healthcare projects drastically and should be implemented very carefully.

In the Norwegian's projects, "General costs" was the third highest cost factor in 2 of the projects. It covered 10.7% to 19.4% of the costs with an average of 14.9%. Apparently, designing and planning the project is the main contributor to this cost factor. In this respect Ulrich et al. (2008) has stated that hospital design affects its key operational attributes such as patients' safety. Therefore, it is logical to assume that such a sensitive issue requires special planning and designs which would increase the costs in return. Moreover, as it was explained in the cost breakdown structure section, the closest cost group for "general cost" in the US is "GC's, fee, const. contingency" which is among the top cost categories as well. This can be considered another similarity between the countries.

HVAC was also the third highest cost factor in one of the projects in Norway. This cost category varied between 7.9% to 16.9% of the total projects' costs with an average of 11.34%. It seems air conditioning and sanitary installations are the main items under this category. Maybe it is because room temperature in certain areas of the hospital should be in a certain range to prevent slow the bacteria growth, humidity from damaging the equipment, and ensure the comfort of the personnel; this issue largely affects the design of HVAC systems (Murphy, 2006). In a similar vein, sanitary installation is one of the potential sources of causing infections in a hospital (Kannan, 2016). As a result, the designing of this item should be done with extra care which could explain the high costs. Not only was HVAC costly in the Norwegian's project but also it was the highest cost item in all of the US projects. This marks yet another similarity between the countries.

From the top American cost items, almost every one of them was covered by the top Norwegian cost items with the exception of one item. Electrical cost category was the only cost items in American projects which was not ranked as high on their Norwegian counterparts. On American projects the electrical category was on average 13.8% of the total cost; for Norwegian projects this figure is almost 6%. Maybe there are more electrical sub-items under the American projects. It is also possible that Norwegians have more efficient electrical practices which means there is a potential for learning on the American side. However, more study should be done in this regard.

In conclusion, it seems there are a lot of similarities between the top cost factors in projects from both countries. This potentially creates a significant incentive to study these factors more. To elaborate, by studying these factors and identifying the major cost items within each one, a project manager can monitor those factors carefully in the similar projects and prevent further cost overruns.

3.3.2 Questionnaire

43 invitation emails were sent to a number of selected professionals within the construction industry. All of the selected individuals have experience in construction industry or in hospital construction either as managers or researchers.

After skimming the questionnaire, two of the professionals announced they cannot answer the questionnaire because they have limited knowledge in that area. Twelve experts responded which makes the response rate 27.91%. However, one of the responses were removed from further analysis due to the respondent being unfamiliar with a number of cost factors.

3.3.2.1 Characteristics of respondents

The answers show 36.36% experts were working in the US, 54.54% was in Norway, and 9.09% in Finland. Their years of experience in construction industry varied between 17 to 40 with an average of 27.18. The number of projects the respondents had been involved in was between 6 to 300 projects with an average of 50.09. 18.18% of the respondents identified themselves as consultants, 27.27% as contractors, 9.09% as financing party (owner), and 45.45% marked "other" as their job position. The "other" category would allow the respondents to explain more about their positions. For instance, the answers included "project management" and "academic".

3.3.2.2 Ranking of the cost factors

Table 7 summarizes the expert's opinion regarding importance of cost factors and the corresponding stakeholder(s). The factors and their respective stakeholders are ranked and presented based on the overall opinion of the respondents. Furthermore, in order to compare different experts' views with the project data, the answers of those professionals working in different countries were derived and analyzed separately.

Table 7. Experts' opinion results

Factors	Overall		Norwegian			American		
	Score	Rank	Score	Rank	Who	Score	Rank	Who
Number of bed spaces	3.91	1	3.67	2	OW	4.00	2	OW
Gross floor area	3.64	2	3.33	7	CS	3.75	4	CS
Air conditioning (ventilation)	3.55	3	3.17	13	CS	3.75	3	CS
Heating installation	3.36	4	3.17	12	CS	3.50	6	CS
Wall area (interior/exterior)	3.36	5	3.17	16	CS	3.25	17	CS
Walls (interior/exterior)	3.36	6	3.33	5	CS	3.25	10	OW, CS
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	3.36	7	3.50	3	CS, CT	3.00	19	OW, CS
Foundation and base (excavation, laying foundation)	3.18	8	3.17	11	CS	3.25	8	CS
Sanitary installation (including plumbing, ducts, equipment etc.)	3.18	9	2.83	24	CS	3.50	5	OW, CS, CT
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	3.18	10	3.33	4	CS	3.25	9	CS
Equipment and furnishes (chattels)	3.09	11	3.17	8	OW	3.00	32	OW
Basic installations for electrical power	3.09	12	3.00	20	CS, CT	3.25	13	CT
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	3.09	13	3.00	19	CS	3.25	11	OW, CS, CT
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	3.09	14	3.17	15	OW, CS	3.00	30	CS
Integrated communication (cabling for phone and data)	3.09	15	3.33	6	OW, CS	3.00	21	CS
Number of stories	3.09	16	2.50	37	OW, CS	3.50	7	CS
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	3.09	17	3.17	14	CS	3.00	20	OW

Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	3.09	18	2.83	25	OW, CS	3.25	12	OW, CS, CT
Automation (switchboards, control centers, control equipment etc.)	3.00	19	3.00	21	CS	3.00	22	CS
Construction of road's infrastructure	3.00	20	3.17	17	CS, GO	3.00	29	CT
Illumination (lighting)	3.00	21	2.83	27	CS, CT	3.25	15	OW
Low-voltage equipment	3.00	22	2.83	26	OW, CS, CT	3.25	14	OW, CS
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	3.00	23	2.83	28	OW	3.00	27	OW, CS
VAT	3.00	24	3.83	1	GO	2.00	42	GO
Contractor's administration costs	2.91	25	3.17	10	CT	2.75	35	CT
Fire alarm and patient call systems	2.91	26	2.50	31	CS	3.25	16	OW, CS
Number of parking spaces	2.91	27	2.67	30	OW	3.25	18	OW, CS
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	2.91	28	3.17	9	CT	2.50	37	CT
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	2.91	29	3.00	22	CS	3.00	28	OW
Project owner's administration including user equipment (insurance and fees etc.)	2.91	30	3.00	23	OW	3.00	31	OW
Operation of construction site	2.82	31	3.00	18	CT	2.50	38	CT
Other equipment (telephony, nurse call, visual and auditory, etc.)	2.82	32	2.67	29	OW	3.00	23	CS
Transportation of personnel and goods	2.73	33	2.50	34	OW	3.00	25	OW, CS
Elevator	2.64	34	2.50	32	CS, CT	3.00	24	OW, CS

Land-related costs and aesthetic decoration	2.64	35	2.00	41	OW	4.00	1	OW
Park and garden construction	2.64	36	2.50	36	CS	2.75	36	OW
Waste and vacuuming	2.64	37	2.50	35	OW	3.00	26	OW, CS
Reserves	2.45	38	2.17	39	OW	3.00	33	OW
AGV (Automated Guided Vehicle)	2.36	39	2.50	33	CS	2.25	41	OW, CS
Cost contingency (uncertainty analysis, fixed etc.)	2.36	40	2.00	42	OW	3.00	34	CT
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	2.36	41	2.17	38	CS	2.50	39	OW
Other costs (copying, travels, communication, art, electricity etc.)	2.18	42	2.00	40	OW	2.50	40	OW

Note: Stakeholder classifications are owner (OW), consultant (CS), contractor (CT), and government (GO).

Table 7 results could be compared based on two manners. The first could be comparing the experts' opinion between the two countries. The second could be comparing the opinion of experts from each country with their respective project results; American experts' opinion with American projects' results for example. This comparison would reveal the gaps between projects and the perspective that experts have of the project.

Figure 12 compares the scores that experts from each country have assigned to the factors in the questionnaire. The numbers on the "Factors" axis represent the factors according to their overall ranking in Table 7. For instance, number one on that axis shows the factor "number of bed spaces".

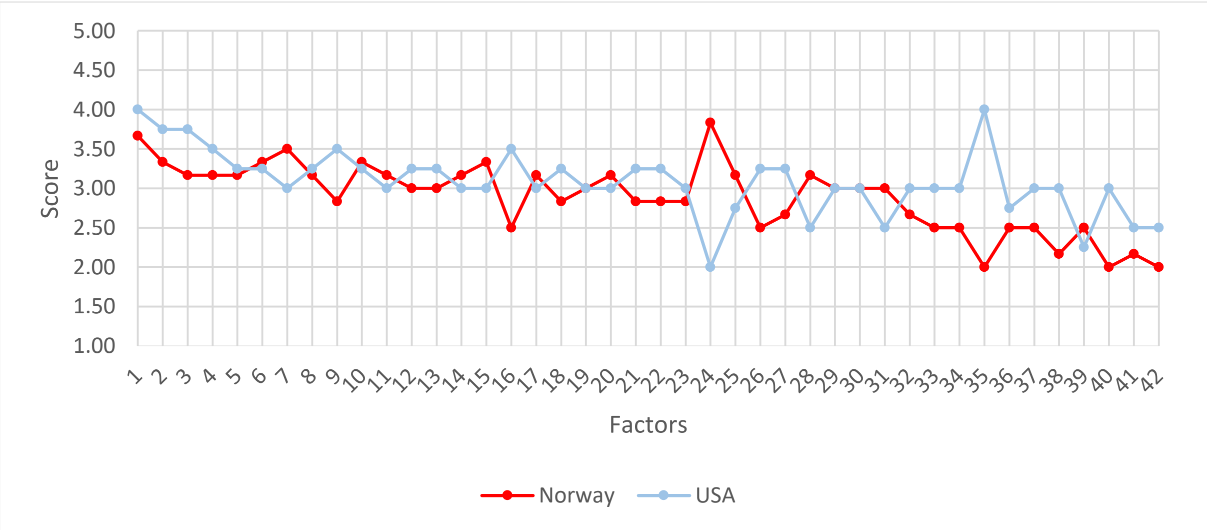


Figure 12. Experts' score comparison

Here, some observations are described based on the Figure 12 and Table 7:

On an overall scale, the results show that the number of bed spaces has the highest degree of influence over the total cost. This may be due to the fact that this cost factor implies both building size and equipment as well. To elaborate, each bed needs a certain area and the beds as equipment have also costs, therefore this item becomes very influential in total costs. This also explains why gross floor area is in the second place. There are also factors such as “number of stories” and “wall area (interior/exterior)” which refer to the size but are on lower rankings. This shows that within the project size’s cost factors, there are sub-factors which experts believe are more important.

Regarding the most important factor within each country, the local experts had different opinions. Norwegian experts believed VAT was the most important factor. This corroborates with the Norwegian projects’ cost performance in which the “special costs” category, which covered VAT, was among the top factors. The aforementioned factor was not deemed so important from the American professional’s perspective; probably because VAT in the US does not affect the construction costs as much. As a matter of fact, the American experts gave VAT the lowest score among all of the factors.

On the other side, the American experts picked “land-related costs and aesthetic decoration” as the top factor. This factor could include land value, right-of-way, visual enhancement of the project. The aesthetics part may be the main contributor to this phenomenon Given that the Norwegian experts ranked this factor very low, it is possible that the cultural aspect plays a role in this regard; maybe the aesthetic demands in the US projects are high. It is also possible that the land-related costs are the main reason for this selection. Maybe in Norway the land-related costs are lower than the US. There is also a chance that a gap exists between the American managers and the practice. Meaning, the land-related costs are addressed by general requirements cost category and this category is not ranked high in the American projects, hence a gap between management body and the project could explain the experts’ choice for this factor. Nevertheless, this seems as a good point of departure for future researches.

Two of the HVAC factors, air conditioning and heating installation, have emerged in the overall top factors (factor 3 and 4 in Figure 12). It shows the experts in both countries agree on the importance of HVAC in construction cost. This observation is also in accordance with the projects’ cost performance in which HVAC was among the top cost factors in both countries.

Therefore, studying the HVAC in both countries and sharing the experience would be beneficial to both countries.

3.3.2.3 Stakeholder analysis

Figure 13 illustrates the number that each stakeholder was mentioned as a top influencer among the cost factors.

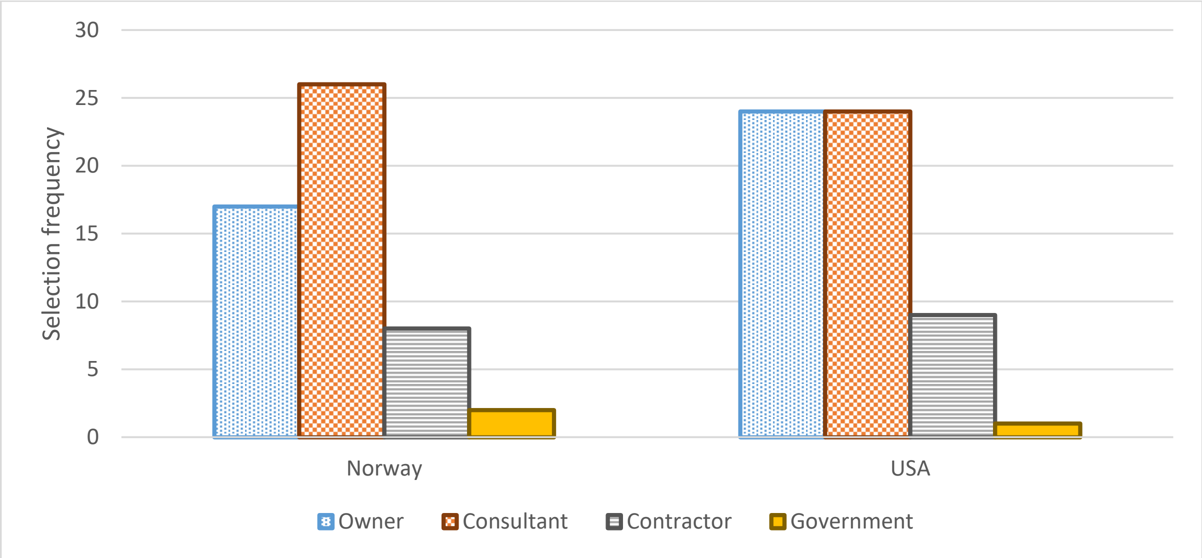


Figure 13. Stakeholder analysis results

The common issue among both countries is that experts believe government and contractor influence a limited number of factors. In the US, the government's influence was deemed to only impact VAT in projects. Of course it is logical to assume such thing because tax policies are commonly a tool controlled by the government. Moreover, the Norwegians experts had the same opinion about government's role in projects plus they believed that the government also can impact the construction of road's infrastructure in hospital. The specific role of government in that area can be investigated in future studies. It is worthy of noting that although government can influence few factors, the impact on the project could be very high. To elaborate, VAT in the Norwegians projects is considered the most significant factor affecting the costs and only government can affect it according to experts' opinion.

On the other hand, consultant and owner have the potential to affect a wider range of factors in both countries. Norwegian experts believed that consultant was considered to be affecting more cost factors than the owner. As a result, according to experts, the efforts of to control the costs should be mostly dedicated to these two stakeholders.

The study believes that the focus should first identify the factor to be monitored. Then focus on the stakeholder who can affect it. For instance, although consultants seem to have more potential to affect the cost factors in general, experts indicated that it is the owner that can affect number of bed spaces. Therefore, it is better to identify the factor that we want to reduce first. Then target the stakeholder who can affect the factor.

3.3.3 Priority checklist

The following checklist has divided the questionnaire’s results into three priority classes by performing Pareto analysis on their corresponding scores. The category column shows the corresponding category that each factor belonged to on the questionnaire.

Table 8. Cost factor's checklist

Factor	Priority	Category
Number of bed spaces	High	Project-specific aspect
Gross floor area	High	Project-specific aspect
Air conditioning (ventilation)	High	HVAC
Heating installation	High	HVAC
Wall area (interior/exterior)	High	Project-specific aspect
Walls (interior/exterior)	High	Building costs
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	High	Building costs
Foundation and base (excavation, laying foundation)	High	Building costs
Sanitary installation (including plumbing, ducts, equipment etc.)	High	HVAC
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	High	Building costs
Equipment and furnishes (chattels)	High	Special costs
Basic installations for electrical power	High	Electrical
Comfort & process cooling (refrigerator & freezer rooms, cold water circuit for cooling coil)	High	HVAC
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	High	General costs
Integrated communication (cabling for phone and data)	High	Telecomm. & automation
Number of stories	Moderate	Project-specific aspect
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	Moderate	Electrical
Other HVAC installations (fire suppression system, medical gas equipment, etc.)	Moderate	HVAC
Automation (switchboards, control centers, control equipment etc.)	Moderate	Telecomm. & automation
Construction of road's infrastructure	Moderate	Outdoors
Illumination (lighting)	Moderate	Electrical
Low-voltage equipment	Moderate	Electrical
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	Moderate	Other installations
VAT	Moderate	Special costs
Contractor's administration costs	Moderate	Common costs
Fire alarm and patient call systems	Low	Telecomm. & automation
Number of parking spaces	Low	Project-specific aspect
Preparation of construction site (e.g. building offices, temporary construction works etc.)	Low	Common costs
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	Low	Outdoors
Project owner's administration including user equipment (insurance and fees etc.)	Low	General costs
Operation of construction site	Low	Common costs
Other equipment (telephony, nurse call, visual and auditory, etc.)	Low	Telecomm. & automation
Transportation of personnel and goods	Low	Other installations
Elevator	Low	Other installations
Land-related costs and aesthetic decoration	Low	Special costs
Park and garden construction	Low	Outdoors
Waste and vacuuming	Low	Other installations
Reserves	Low	Special costs
AGV (Automated Guided Vehicle)	Low	Other installations
Cost contingency (uncertainty analysis, fixed etc.)	Low	Project-specific aspect
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	Low	Outdoors
Other costs (copying, travels, communication, art, electricity etc.)	Low	General costs

This checklist could help the construction practitioners to have better resource management by allocating the resources to the factors which are deemed important by the experts. To elaborate, the building cost category apparently should receive more attention because all of its factors are in high priority group. Similarly, only one factor from HVAC is in moderate priority and the rest are all in high priority thus it can be advised that managers monitor HVAC carefully. On the other hand, the majority factors belonging to “other installation” cost category are among the low priority. Therefore, managers can focus on the more important factors.

This page intentionally left blank.

4 CONCLUSION & RECOMMENDATION

The purpose of this thesis was to perform a comparative study regarding the hospital construction costs and identify the factors affecting the costs in Norway and the United States. The literature review showed there is gap in comparing the construction costs of hospitals and identifying its cost factors on the grounds that most of the works were focused on buildings such as residential and office buildings. In addition, there were also lack of research in comparative construction costs between countries. As a result, the research questions were defined as the following:

1. How is hospital construction cost performance in Norway and the US?
2. What are the quantifiable cost factors behind hospital construction cost?
3. What are the major cost factors in reported hospital construction cost?

In order to answer the research questions, the primary project data were collected from the Norwegian and American companies. The results were three Norwegian and three American hospital construction projects. After converting the units and the project years to the same baseline, purchasing power parity method was employed to convert the currencies into one comparable currency. The results showed the Norwegian projects require more funding than American projects; the average cost for the Norwegian and American projects were 3822 €/m^2 and 2602 €/m^2, respectively. The standard deviation in the Norwegian projects were 973 €/m^2 which was higher than the American projects' 131 €/m^2. The difference in project funding can have various reasons. However, the thesis focused on the cost factors available in reported cost breakdown structure.

In the next step, the project data from each country were compared together from two perspectives; the breakdown structure and total cost share of each category. Comparison of the cost breakdown structure is seemingly a good way to learn more about the countries' perspective on costs. To elaborate, there were some similarities between the countries for example in electrical and HVAC categories. However, the American projects were more detailed in representing the construction costs. For instance, the pluming, interior finishes, excavation and foundation were considered a cost category while in the Norwegian counterparts these were parts of larger cost categories. Maybe detailed cost categorization in US encourages the project to gather more information and details which subsequently monitors the costs better. In addition, some discrepancies with the standards were observed regarding the representation of costs within the Norwegian and American projects. This may indicate that the standards and cost breakdown structure are incompatible with the obtained projects on some levels.

As for the next step, a Pareto analysis was performed to rank the cost items and compare the share of cost items in the countries. For the Norway's cases, building, special costs, general costs, and HVAC cost categories were on top, on average carrying almost 80% of the reported total cost share. For the American cases, HVAC, "interior finishes, partitions", electrical, and "GC's, fee, const. contingency" were the among the top high cost categories, on average carrying almost 60% of the reported total cost. A closer look at these factor reveals that there are many similarities between American and Norwegian top cost categories. This creates a considerable opportunity for future knowledge sharing programs between the countries. To elaborate, if one country could identify a measure to control the cost of a top category, there is chance that the other country could use the measure as well.

Using two academic experts' input, an online questionnaire was designed based on the cost factors of the Norwegian and American projects. The factors from the Norwegian and American projects were collected, combined, and listed in a questionnaire; four major stakeholders in projects were also put down for each factor. This part could contribute to making future efforts of cost management more focused and efficient based on the experts' opinion. Forty-three experts primarily from Norway and US were contacted to fill the online questionnaire. The response rate was 27.91%. The expert's answers revealed that two factors, namely gross floor area and number of beds, were very influential on the costs.

One of the major differences between the experts from the US and Norway was their response toward VAT cost factor. The Norwegian experts selected VAT as the factor with the highest influence on cost while the American experts ranked it in the bottom three. In addition, the project data from Norway also showed that VAT affects the cost to large extent. Both experts group claimed government as the sole stakeholder affecting this factor. As a result, the tax policies of the government over the healthcare facilities should be executed cautiously because it can have substantial effects on the costs.

Another issue observed in the responses from the American experts was regarding their choice of top factor, 'land-related costs and aesthetic decoration'. This factor was ranked high by the American experts and low by the Norwegians. The reason may be attributed to cultural differences. It is possible that there is higher aesthetics demand in the American projects than in the Norwegians.

Moreover, the responses showed that consultants and owners in both countries can affect a larger number of cost factors which potentially means they are more prone to affect the construction costs in general. However, it does not mean that government and contractor are powerless to affect the cost. On the contrary, government controls the highest ranked factor, VAT, based on the Norwegian experts' perspective. Therefore, instead of always targeting owner/consultant for managing the cost factors, it is recommended to first consider the cost factor we want to manage and then find the stakeholder responsible for it.

Moreover, using Pareto analysis on the questionnaire's results, the cost factors were divided into three priorities which may be helpful for the practitioners. The priority checklist shows that building and HVAC cost category are better to receive more attention.

With literature as one source, more than 440 cost factors from 64 academic publications were derived. These factors were filtered down to 92 factors which were then categorized according to Norwegian cost breakdown structure. A comparison between literature cost factors and cost factors derived from the projects was later made to reveal the gap between academic and practical perspectives. The results of this comparison are presented in the next chapter.

4.1 Implications of the study

The results of this study could improve the cost performance issues on the following levels:

On industry level, it shines more light on similarities and differences between construction practices in each country. Therefore, revealing the spots where countries can learn more efficient methods from each other and reduce the construction cost. For instance, if two cost items are relatively similar in content but have different cost performance, the country with lower cost performance can investigate and learn from the country with better cost performance. On the other hand, the difference in cost performance can also be a result of difference in cost structure which may be another potential area for learning and improving the cost structure.

Managers can also follow the priority checklist presented here to better divide their attention. For stakeholders, it would identify the main stakeholder(s) who can influence each cost factor. Therefore, the results could enhance the efficiency of the efforts when the projects need to control one specific cost factor through its stakeholder.

On academic level, it identifies the areas which there is gap between the industry and the academic research.

4.2 Challenges

One challenge was to make sure that projects are as similar as they possibly can be. Therefore, to avoid the problem of different project sizes the cost per unit area was selected, and the projects' contents were also checked.

Understanding the cost breakdown structure, cost factors in the literature and what they contain were also challenging. To understand the Norwegian cost breakdown structure, Holte company's handbook included useful information plus the Norwegian projects also included some details for each cost category. Whereas, in American projects, there were little details on the cost breakdown structure provided by the company. Therefore, American standards, instructions, and similar albeit more detailed projects were reviewed to understand the attributes of the projects provided. Literature details were sometimes unclear as well. As a result, an educated guess based on the context of the paper was the solution on such occasions.

Another difficult task was combining the two cost breakdown structures of Norway and US to create consensus while trying to be as clear as possible so that both parties understand the terms. Despite all of the efforts, a few more emails had to be sent to clarify the cost factors more.

Finally, the last challenge was making incentives for the people to respond. Several measures were taken in this regard. The invitation email was crafted in association with experts who have already had experience in performing questionnaires. The cost factor list was kept short and factors were combined together wherever possible. Moreover, the questionnaire was performed using an online database to promote accessibility and increase the feedback speed. Reminder emails were sent regularly to increase the number of responses to encourage experts to respond.

4.3 Limitations of the study

The results of this study is limited to the projects' data provided. Therefore, this thesis considers quantifiable and the reported projects' cost factors. However, all of the possible factors derived from literature, regardless of being quantifiable or not, are included in Appendix A.

The questionnaire answers are dependent upon the expertise of the respondents. However, their answers were cross-checked with the project results, where possible. Moreover, the findings are within the geographical context of two countries.

Furthermore, the time limitations placed on the Master's thesis meant there was a limit on the number of case studies that could be investigated, the questionnaire responses that could be collected, and the amount of literature that could be reviewed.

5 FUTURE WORK

During the course of the thesis, several potential areas have been discovered for future studies:

This study has identified the similarities of the hospital construction practices between two countries. As the next step, studying the knowledge management and knowledge sharing methods are recommended in order to exchange constructive experiences in those areas between the countries.

Although major cost factors are identified in this research, the next issue is to what extent they can be controlled or managed. To elaborate, it is very likely that each cost factor has a limited potential to be reduced. Therefore, less expensive cost factors with larger cost reduction capacity may be of more interest than expensive cost factors with limited cost reduction capacity.

Regarding the cost factors there is also a huge potential for future researches. It is possible to study detailed cost factors of one of the categories mentioned in this thesis in greater details. For instance, factors under building and HVAC categories have been identified as more important than the others. Therefore, future researches are encouraged to focus on the aforementioned factors. The comparison between academic publications and practice has also showed that less attention has been given to the electrical and aesthetic factors. Moreover, the contrasting difference of opinions between the American experts and the Norwegian experts regarding the 'land-related cost and aesthetic decoration' cost factor, may indicate there are some cultural differences affecting the costs. This subject is also interesting to follow in the future.

Furthermore, both quantitative and qualitative cost factors have been derived from literature which are available in Appendix A. These factors can be useful in independent researches. Meaning, future studies could test these factors and see how the factors are in the context of the study. This study dropped two questionnaires which were based on these factors. Both questionnaires are included in Appendix B and C.

From the methodological point of view, in identifying the most important factor a 5-Likert scale was utilized in this study. However, it is also interesting to use other data collection methods such as a Delphi-type interview to explore the reasons behind the differences in experts' opinions. These differences may lead the researchers to a better insight over cost factors and reveal new methods to control them. In addition, it was realized that the international cost comparison methods' application in construction has the potential to be investigated more. As a suggestion, maybe advantages and disadvantages of different method in different scenarios could be explored in future studies

The following issues were brought up by the experts in the questionnaire as factors which should be investigated:

Hospital functions such as emergency treatment, diagnostic imaging clinic; design efficiency (area per function unit); material selection; production or delivery effectiveness; quality; durability; energy; environment; operability; climate demands; seismic demands; changes in orders, redesigns; project organization; optimal project size; decision making process; contract strategy; demolition scope or hazardous abatement; location; site constraints.

This research also has plans to expand the number of respondents and case studies and publish the results in a journal. Moreover, the plan also includes performing deeper statistical analysis such as factor analysis and Spearman's correlation rank to larger datasets.

5.1 Comparison between literature and questionnaire cost factor

This final section of the thesis compares the questionnaire cost factors, which were obtained from the projects, with the literature factors could identify the gap between previous academic works and the current construction practices which would subsequently help the construction industry and researchers set their visions on unresolved issues.

Regarding the common cost category, the literature had covered almost all of the factors in the questionnaire. To elaborate, excavation conditions and workspace in site (Elhag & Boussabaine, 1998), site facilities and transportation of materials (Gurcanli et al., 2015) plus material properties (Tiwari et al., 1996) are the cost factors mentioned in the literature which encompass the questionnaire factors more or less. Contractor's administration cost was the only factor which was not covered in the literature. However, S. Y. Kim et al. (2017) has indirectly indicated to this factor by mentioning the increase in project administration cost as a factor affecting the project cost.

From the building category perspective, the previous literature has covered the factors of the questionnaire. In this cost category, previous studies have pointed out cost items such as external walls, fittings, floor finishes (Harding et al., 2000), structural frame type (Günaydın & Doğan, 2004; Li et al., 2005; Mills, 2013; Sonmez, 2008), and foundation type (G.-H. Kim et al., 2004; Latief et al., 2013). However, Emsley et al. (2002) tested and identified the prominent variables in a study which involved 288 building projects. Duration, frame type, piling, and internal finishes were among those prominent variables which could be relevant to this cost category. Form this cost category, insulation works expenses seem to have attracted less attention than the others.

Moving to the HVAC group, the past researches had more or less named the cost factors under this category. To elaborate, air conditioning (Emsley et al., 2002; Harding et al., 2000), protective installations (Emsley et al., 2002), which could cover the fire suppression system on questionnaire's side, and sanitary appliances (Harding et al., 2000), which would be an indication for sanitary installation in the questionnaire were all studied in the literature. Heating installation was the one factor missing in the literature results. However, all these factors were also mentioned in a more general tone. Meaning, mechanical installation is a term referring to "installing pipes, heating, ventilation and air conditioning" (Albers et al., 2005). In this respect, Riley et al. (2005) has investigated one of the cost aspects of mechanical systems. Furthermore, two studies have indicated that mechanical installation is one of the key cost factors in building construction (Emsley et al., 2002; Lowe et al., 2006), which is in accordance with project data as well.

Electrical cost category seems to be among the topics that has a lot of potential for future researches. Although, this cost category has been one of the top costs in the US projects, not many studies have investigated it. Electrical installation was the only factor that Emsley et al. (2002) and Harding et al. (2000) has mentioned it as a cost variable to predict future building costs. Moreover, Riley et al. (2005) also included electrical systems while investigating a particular cost aspect of building construction. As a result, this topic could be a suitable choice for future investigations.

The telecommunication and automation category follows the same footsteps as the electrical in terms of literature publication. Meaning, only one study was found in this regard (Harding et al., 2000) referring to it by mentioning IT installation. However, this cost category had a smaller share of the total costs than the other categories in the Norwegian projects. Maybe the low share of total cost has made this factor less appealing for researchers. Nevertheless, small share of total cost should not always be a criterion for selecting the cost category as a research subject. To elaborate, when the project is extensive with large amount of funding, the small shares could still mean a large amount of money.

Regarding the “other installation” group, the past studies have divulged number of elevators (Emsley et al., 2002; Harding et al., 2000; Stoy et al., 2008) and elevator stops (Sonmez, 2008), disposal installation (Harding et al., 2000) which could entail waste and vacuuming cost factor in questionnaire, and special installation (Emsley et al., 2002; Harding et al., 2000) which may refer to the use of automated guided vehicles, pneumatic tubes etc.

With respect to outdoor construction cost category, it seems there is a lack of research. Maybe the search terms did not quite capture all the possible cost factors. Furthermore, on Norwegian projects, outdoors was the second lowest cost category in terms of total costs’ share. Maybe this low share of the costs is a ubiquitous phenomenon which explains the lack of interest in investigating such costs.

The general costs category maybe had the biggest difference between the questionnaire factors and the literature factors. The project included factors such as costs for designing, planning, owner’s administration, and miscellaneous costs. In this regard, most of the factors expressed in the literature were non-quantifiable. For instance, there were papers discussing different design processes (Harty et al., 2015; Pennanen et al., 2011) or design quality (Elhag et al., 2005) but not design in its entirety affecting the costs. The quantifiable elements in this regard were resumption/accommodation works (S. Y. Kim et al., 2017), additional works (Le-Hoai et al., 2008), duration (G.-H. Kim et al., 2004), productivity (Erdis, 2013; Wasmi & Castro-Lacouture, 2016), and safety costs (Gurcanli et al., 2015) which are different aspects of design and planning. Project administration cost increase (S. Y. Kim et al., 2017) as well as site overheads (Cunningham, 2013) could also be relevant in this category, covering the owner’s administration costs. The studies did not cover the miscellaneous costs which include costs of traveling, communication, copying the documents etc. In the questionnaire, the respondents ranked this factor in the bottom three, so apparently there is no interest from the management side in this factor as well.

Regarding special costs category, previous literature has indicated tax policies as a factor (Gurcanli et al., 2015). However, in a broader term, “regulations” is also indicated as an element affecting the costs (Ayman et al., 2004; Le-Hoai et al., 2008; Pennanen et al., 2011). With respect to aesthetics effect, the past literature had investigated it on choice of materials (Tam et al., 2007), as an environmental benefit (Morel et al., 2001), and as a reason for structural design changes (Perez-Garcia et al., 2007). However, in the literature search, a study which investigates aesthetics as an independent cost item was not found thus making this subject an interesting topic for future researches.

Finally, the projects data showed that there are some fields specific to the project. For instance, the gross floor area or the number of bed spaces. As a result, those information was classified as “project-specific cost aspect”. It seems there is an abundance in the previous researches in this regard. Questionnaire factors such as gross floor area, wall area, and number of stories were investigated in detail by the researchers. To elaborate, the subject of area was mentioned as average floor area (Li et al., 2005), building area (Latief et al., 2013; Sonmez, 2008), floor area (Skitmore, 1987), wall area (Harding et al., 2000), or even wall-to-floor ratio (Cunningham, 2013; Emsley et al., 2002). Moreover, number of stories were also mentioned in details such as height (Cunningham, 2013; Emsley et al., 2002; Latief et al., 2013; Picken & Ilozor, 2003), number of stories (Aibinu et al., 2015; Elhag & Boussabaine, 1998; G.-H. Kim et al., 2004; Sonmez, 2008), number of stories above or below the ground (Emsley et al., 2002; Li et al., 2005). Cost contingency was also pointed out as contingency allowances (Gunner & Skitmore, 1999; B. Lim et al., 2016) which can affect the accuracy of cost estimation in buildings. In addition, contract form (Emsley et al., 2002), contract type (Harding et al., 2000; Skitmore, 1987) could also be indicative of cost contingency indirectly. Furthermore, number of parking spaces from questionnaire factors were not observed in the literature.

On the other hand, there were a number of cost factors on the literature that was not included on the questionnaire, most notably labor and material cost (Arditi et al., 1985; Gurcanli et al., 2015; Kaming et al., 1997; Wasmi & Castro-Lacouture, 2016). The reason is that these two cost factors were already included in the projects’ cost factors along with the machinery costs. Furthermore, some units within hospital seem to be more important when it comes to construction cost. The research has included inpatient nursing unit and outpatient clinics and operating theater suit (Sherif, 1999) as hospital units. However, since the questionnaire was based on the project results which are more tangible for the project managers, the aforementioned factors were not included.

In conclusion, comparing the questionnaire cost factors with the filtered literature cost factors revealed that there are some categories which seem to be unexploited entirely such as electrical, special costs, and telecommunication and automation. Moreover, there are also areas which apparently literature has covered parts of it but there is potential for investigating deeper such as HVAC or common costs. However, there is room for almost all of the project cost categories to be further investigated.

6 REFERENCES

Ackroyd, S., & Hughes, J. A. (1981). *Data collection in context*. London; New York: Longman.

Aibinu, A. A., Dassanayake, D., Chan, T. K., & Thangaraj, R. (2015). Cost estimation for electric light and power elements during building design A neural network approach. *Engineering Construction and Architectural Management, 22*(2), 190-213. doi:10.1108/ecam-01-2014-0010

Albers, J., Estill, C., & MacDonald, L. (2005). Identification of ergonomics interventions used to reduce musculoskeletal loading for building installation tasks. *Applied Ergonomics, 36*(4), 427-439. doi:https://doi.org/10.1016/j.apergo.2004.07.005

Arditi, D., Akan, G. T., & Gurdamar, S. (1985). Cost overruns in public projects. *International Journal of Project Management, 3*(4), 218-224. doi:http://dx.doi.org/10.1016/0263-7863(85)90053-5

Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management, 24*(4), 349-357. doi:https://doi.org/10.1016/j.ijproman.2005.11.010

Attalla, M., & Hegazy, T. (2003). Predicting Cost Deviation in Reconstruction Projects: Artificial Neural Networks versus Regression. *Journal of Construction Engineering and Management, 129*(4), 405-411. doi:doi:10.1061/(ASCE)0733-9364(2003)129:4(405)

Ayman, A. E. O., Tarek, M. H., & Christine, L. P. (2004). Drivers for dynamic brief development in construction. *Engineering, Construction and Architectural Management, 11*(4), 248-258. doi:10.1108/09699980410547603

Bayram, S., & Al-Jibouri, S. (2016). Efficacy of Estimation Methods in Forecasting Building Projects' Costs. *Journal of Construction Engineering and Management, 142*(11). doi:10.1061/(ASCE)CO.1943-7862.0001183

Best, R. (2008). The development and testing of a purchasing power parity method for comparing construction costs internationally.

Bilec, M. M., Ries, R. J., Needy, K. L., Gokhan, M., Phelps, A. F., Enache-Pommer, E., Horman, M. J., Little, S. E., Powers, T. L., McGregor, E., & Sheane, C. (2009). ANALYSIS OF THE DESIGN PROCESS OF GREEN CHILDREN'S HOSPITALS: Focus on Process Modeling and Lessons Learned. *Journal of Green Building, 4*(1), 121-134.

Butcher, N., & Demmers, L. (2003). *Cost estimating simplified*: Libris Design Project.

C.S.I. (2016). MasterFormat (Vol. 22314). Alexandria, VA: Construction Specifications Institute.

Cassidy, R. (2012). 3 important trends in hospital design that Healthcare Giants are watching closely. *Building Design & Construction*.

Chan, A. P. C., Scott, D., & Chan, A. P. L. (2004). Factors Affecting the Success of a Construction Project. *Journal of Construction Engineering and Management, 130*(1), 153-155. doi:doi:10.1061/(ASCE)0733-9364(2004)130:1(153)

Chung, B. Y., Syachrani, S., Jeong, H. S., & Kwak, Y. H. (2009). Applying Process Simulation Technique to Value Engineering Model: A Case Study of Hospital Building Project. *Ieee Transactions on Engineering Management, 56*(3), 549-559. doi:10.1109/tem.2009.2013831

Coetzee, D. A., & Brent, A. C. (2015). Perceptions of professional practitioners and property developers relating to the costs of green buildings in South Africa. *Journal of the South African Institution of Civil Engineering, 57*(4), 12-19.

Cunningham, T. (2013). Factors affecting the cost of building work-an overview.

DC&D Technologies, I. (2014). *D4COST Demo*.

de Carvalho, M. M., Patah, L. A., & Bido, D. D. (2015). Project management and its effects on project success: Cross-country and cross-industry comparisons. *International Journal of Project Management, 33*(7), 1509-1522. doi:10.1016/j.ijproman.2015.04.004

De Marco, A., & Mangano, G. (2013). Risk and value in privately financed health care projects. *Journal of Construction Engineering and Management, 139*(8), 918-926. doi:10.1061/(ASCE)CO.1943-7862.0000660

de Melo, R. S. S., Do, D., Tillmann, P., Ballard, G., & Granja, A. D. (2016). Target value design in the public sector: evidence from a hospital project in San Francisco, CA. *Architectural Engineering and Design Management, 12*(2), 125-137. doi:10.1080/17452007.2015.1106398

Ekeskar, A., & Rudberg, M. (2016). Third-party logistics in construction: the case of a large hospital project. *Construction Management and Economics, 34*(3), 174-191. doi:10.1080/01446193.2016.1186809

Elhag, T. M. S., & Boussabaine, A. H. (1998). *An artificial neural system for cost estimation of construction projects.* Paper presented at the Proceedings of the 14th ARCOM Annual Conference.

Elhag, T. M. S., Boussabaine, A. H., & Ballal, T. M. A. (2005). Critical determinants of construction tendering costs: Quantity surveyors' standpoint. *International Journal of Project Management, 23*(7), 538-545. doi:http://doi.org/10.1016/j.ijproman.2005.04.002

Emsley, M. W., Lowe, D. J., Duff, A. R., Harding, A., & Hickson, A. (2002). Data modelling and the application of a neural network approach to the prediction of total construction costs. *Construction Management and Economics, 20*(6), 465-472. doi:10.1080/01446190210151050

Erdis, E. (2013). THE EFFECT OF CURRENT PUBLIC PROCUREMENT LAW ON DURATION AND COST OF CONSTRUCTION PROJECTS IN TURKEY. *Journal of Civil Engineering and Management, 19*(1), 121-135. doi:10.3846/13923730.2012.746238

EuropeanCommission. (2012). *Eurostat-OECD methodological manual on Purchasing Power Parities*: Luxembourg: Publications Office of the European Union.

Eurostat. (2017). Purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates. Retrieved March 14, 2017, from Eurostat, the statistical office of the European Union https://goo.gl/Ne3Yra

Flick, U. (2002). *An introduction to qualitative research* (2nd ed.). London: Sage.

Fuerst, F., & McAllister, P. (2011). Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values. *Real Estate Economics, 39*(1), 45-69. doi:10.1111/j.1540-6229.2010.00286.x

Günaydın, H. M., & Doğan, S. Z. (2004). A neural network approach for early cost estimation of structural systems of buildings. *International Journal of Project Management, 22*(7), 595-602.

Gunner, J., & Skitmore, M. (1999). Comparative analysis of pre-bid forecasting of building prices based on Singapore data. *Construction Management and Economics, 17*(5), 635-646. doi:10.1080/014461999371240

Gurcanli, G. E., Bilir, S., & Sevim, M. (2015). Activity based risk assessment and safety cost estimation for residential building construction projects. *Safety Science, 80*, 1-12. doi:10.1016/j.ssci.2015.07.002

Harding, A., Lowe, D., Hickson, A., Emsley, M., & Duff, R. (2000). Implementation of a neural network model for the comparison of the cost of different procurement approaches. *CIB REPORT*, 269-280.

Harty, C., Jacobsen, P. H., & Tryggestad, K. (2015). Constructing healthcare spaces - The complex role of visualisations in negotiating hospital designs and practices. In K. Kalle (Ed.), *8th Nordic Conference on Construction Economics and Organization* (Vol. 21, pp. 578-585). Amsterdam: Elsevier Science Bv.

Hong, W. M., Liu, H. M., Liu, S. Q., Yuan, J., & Wu, H. J. (2010). *Comparison of alternative construction project transaction method costs.* Paper presented at the 2010 International Conference on Management and Service Science, MASS 2010, Wuhan.

IMF. (2017). Financial Sector: Exchange rates & prices. International financial statistics Retrieved March 30, 2017 http://databank.worldbank.org/data/reports.aspx?source=2&type=metadata&series=PA.NUS.PPPC.RF

Ioannou, P. G., & Leu, S. (1993). AVERAGE-BID METHOD - COMPETITIVE BIDDING STRATEGY. *Journal of Construction Engineering and Management-Asce, 119*(1), 131-147. doi:10.1061/(asce)0733-9364(1993)119:1(131)

Kaming, P. F., Olomolaiye, P. O., Holt, G. D., & Harris, F. C. (1997). Factors influencing construction time and cost overruns on high-rise projects in Indonesia. *Construction Management and Economics, 15*(1), 83-94. doi:10.1080/014461997373132

Kannan, I. D. R. (2016). *Essentials of Microbiology for Nurses, 1st Edition - Ebook*: Elsevier Health Sciences.

Khodakarami, V., & Abdi, A. (2014). Project cost risk analysis: A Bayesian networks approach for modeling dependencies between cost items. *International Journal of Project Management, 32*(7), 1233-1245. doi:http://doi.org/10.1016/j.ijproman.2014.01.001

Kim, G.-H., Yoon, J.-E., An, S.-H., Cho, H.-H., & Kang, K.-I. (2004). Neural network model incorporating a genetic algorithm in estimating construction costs. *Building and Environment, 39*(11), 1333-1340.

Kim, J. L., Greene, M., & Kim, S. (2014). Cost comparative analysis of a new green building code for residential project development. *Journal of Construction Engineering and Management, 140*(5). doi:10.1061/(ASCE)CO.1943-7862.0000833

Kim, S. Y., Tuan, K. N., Lee, J. D., Pham, H., & Luu, V. T. (2017). Cost overrun factor analysis for hospital projects in Vietnam. *Ksce Journal of Civil Engineering*, 1-11. doi:10.1007/s12205-017-0947-5

Kothari, C. R. (2004). *Research Methodology : Methods and Techniques* (2nd ed.). New Delhi: New Age International Pvt. Ltd., Publishers.

Latief, Y., Wibowo, A., & Isvara, W. (2013). *Preliminary Cost Estimation Using Regression Analysis Incorporated With Adaptive Neuro Fuzzy Inference System* (Vol. 4).

Le-Hoai, L., Lee, Y. D., & Lee, J. Y. (2008). Delay and Cost Overruns in Vietnam Large Construction Projects: A Comparison with Other Selected Countries. *Ksce Journal of Civil Engineering, 12*(6), 367-377. doi:10.1007/s12205-008-0367-7

Li, H., Shen, Q. P., & Love, P. E. D. (2005). Cost modelling of office buildings in Hong Kong: an exploratory study. *Facilities, 23*(9/10), 438-452. doi:doi:10.1108/02632770510602379

Lim, B., Nepal, M. P., Skitmore, M., & Xiong, M. (2016). Drivers of the accuracy of developers' early stage cost estimates in residential construction. *Journal of Financial Management of Property and Construction, 21*(1), 4-20. doi:doi:10.1108/JFMPC-01-2015-0002

Lim, J. N., Schultmann, F., & Ofori, G. (2010). Tailoring Competitive Advantages Derived from Innovation to the Needs of Construction Firms. *Journal of Construction Engineering and Management-Asce, 136*(5), 568-580. doi:10.1061/(asce)co.1943-7862.0000151

Lipovetsky, S. (2009). Pareto 80/20 law: derivation via random partitioning. *International Journal of Mathematical Education in Science and Technology, 40*(2), 271-277. doi:10.1080/00207390802213609

Love, P. E. D. (2002). Influence of project type and procurement method on rework costs in building construction projects. *Journal of Construction Engineering and Management, 128*(1), 18-29.

Lowe, D. J., Emsley, M. W., & Harding, A. (2006). Predicting construction cost using multiple regression techniques. *Journal of Construction Engineering and Management-Asce, 132*(7), 750-758. doi:10.1061/(asce)0733-9364(2006)132:7(750)

Manning, R., & Messner, J. I. (2008). Case studies in BIM implementation for programming of healthcare facilities. *Journal of Information Technology in Construction (ITcon), 13*(18), 246-257.

McKee, M., Edwards, N., & Atun, R. (2006). Public-private partnerships for hospitals. *Bull World Health Organ, 84*(11), 890-896.

Meikle, J. L. (1990). International comparisons of construction costs and prices. *Habitat International, 14*(2), 185-192. doi:http://dx.doi.org/10.1016/0197-3975(90)90049-7

Miller, K. R., & Newitt, J. S. (2005). *MasterFormat 2004 impact on construction organizations.* Paper presented at the ASC Proceedings of the 41st Annual Conference University of Cincinnati.

Mills, A. (2013). Construction cost performance of structural frames in Australia. *International Journal of Project Organisation and Management, 5*(1-2), 57-68. doi:10.1504/IJPOM.2013.053154

Morel, J. C., Mesbah, A., Oggero, M., & Walker, P. (2001). Building houses with local materials: means to drastically reduce the environmental impact of construction. *Building and Environment, 36*(10), 1119-1126. doi:https://doi.org/10.1016/S0360-1323(00)00054-8

Murphy, J. (2006). Temperature & humidity control in surgery rooms. *ASHRAE Journal, 48*(6), H18.

OECD. (2017a). Average annual wages. OECD.Stat Retrieved May 25, 2017 http://stats.oecd.org/Index.aspx?DataSetCode=AV_AN_WAGE#

OECD. (2017b). FDI flows (indicator) (Publication no. 10.1787/99f6e393-en). Retrieved June 15, 2017 https://data.oecd.org/price/price-level-indices.htm

OECD. (2017c). Inflation (CPI) (indicator) (Publication no. doi: 10.1787/eee82e6e-en). Retrieved March 29, 2017 https://data.oecd.org/price/inflation-cpi.htm

OECD. (2017d). Price level indices (indicator) (Publication no. 10.1787/c0266784-en). Retrieved June 15, 2017 https://data.oecd.org/price/price-level-indices.htm

OECD. (2017e). Value added by activity (indicator) (Publication no. 10.1787/a8b2bd2b-en). Retrieved June 21, 2017 https://data.oecd.org/natincome/value-added-by-activity.htm

OECD, & Eurostat. (2017). 2014 PPP Benchmark results. Retrieved March 15, 2017 http://stats.oecd.org/Index.aspx?DataSetCode=PPP2014

Olsson, N. O. E., & Hansen, G. K. (2010). Identification of Critical Factors Affecting Flexibility in Hospital Construction Projects. *Herd-Health Environments Research & Design Journal, 3*(2), 30-47.

OxfordEnglishDictionary. (2017a). "questionnaire, n.". Retrieved July 1, 2017, from Oxford University Press (http://www.oed.com) http://www.oed.com/view/Entry/156364?redirectedFrom=questionnaire

OxfordEnglishDictionary. (2017b). "survey, n.". Retrieved July 1, 2017, from Oxford University Press (http://www.oed.com) http://www.oed.com/view/Entry/195089?rskey=lYtglC&result=1&isAdvanced=false

Pennanen, A., Ballard, G., & Haahtela, Y. (2011). Target costing and designing to targets in construction. *Journal of Financial Management of Property and Construction, 16*(1), 52-63. doi:doi:10.1108/13664381111116089

Perez-Garcia, J., Lippke, B., Briggs, D., Wilson, J. B., Bowyer, J., & Meil, J. (2007). The environmental performance of renewable building materials in the context of residential construction. *Wood and Fiber Science, 37*, 3-17.

Picken, D. H., & Ilozor, B. D. (2003). Height and construction costs of buildings in Hong Kong. *Construction Management and Economics, 21*(2), 107-111. doi:10.1080/0144619032000079671

Pinto, J. K. (2013). *Project management : achieving competitive advantage*. Boston: Pearson.

Rehm, M., & Ade, R. (2013). Construction costs comparison between green and conventional office buildings. *Building Research and Information, 41*(2), 198-208. doi:10.1080/09613218.2013.769145

Riley, D. R., Varadan, P., James, J. S., & Thomas, H. R. (2005). Benefit-Cost Metrics for Design Coordination of Mechanical, Electrical, and Plumbing Systems in Multistory Buildings. *Journal of Construction Engineering and Management, 131*(8), 877-889. doi:doi:10.1061/(ASCE)0733-9364(2005)131:8(877)

Rosenbaum, S., Toledo, M., & Gonzalez, V. (2014). Improving Environmental and Production Performance in Construction Projects Using Value-Stream Mapping: Case Study. *Journal of Construction Engineering and Management, 140*(2), 11. doi:10.1061/(asce)co.1943-7862.0000793

Rungi, M., & Hilmola, O. P. (2011). Interdependency management of projects: survey comparison between Estonia and Finland. *Baltic Journal of Management, 6*(2), 146-162. doi:10.1108/17465261111131785

Rybkowski, Z. K., Shepley, M. M., & Ballard, H. G. (2012). Target Value Design: Applications to Newborn Intensive Care Units. *Herd-Health Environments Research & Design Journal, 5*(4), 5-22.

Sharma, R., Marti, K., Monegro, J., Liu, Y., & Ieee. (2014). Integrated Headwall Systems - Hybrid Headwall Design *2014 40th Annual Northeast Bioengineering Conference*. New York: Ieee.

Shehu, Z., Endut, I. R., & Akintoye, A. (2014). Factors contributing to project time and hence cost overrun in the Malaysian construction industry. *Journal of Financial Management of Property and Construction, 19*(1), 55-75. doi:doi:10.1108/JFMPC-04-2013-0009

Shehu, Z., Holt, G. D., Endut, I. R., & Akintoye, A. (2015). Analysis of characteristics affecting completion time for Malaysian construction projects. *Built Environment Project and Asset Management, 5*(1), 52-68. doi:10.1108/bepam-10-2013-0056

Sherif, A. H. (1999). Hospitals of developing countries: design and construction economics. *Journal of Architectural Engineering, 5*(3), 74-81. doi:10.1061/(ASCE)1076-0431(1999)5:3(74)

Shields, T. J., Silcock, G. W., & Bell, Y. (1986). Fire safety evaluation of dwellings. *Fire Safety Journal, 10*(1), 29-36. doi:http://dx.doi.org/10.1016/0379-7112(86)90029-9

Skitmore, M. (1987). *Construction prices: the market effect*: University of Salford Environmental Resources Unit.

Sonmez, R. (2008). Parametric Range Estimating of Building Costs Using Regression Models and Bootstrap. *Journal of Construction Engineering and Management-Asce, 134*(12), 1011-1016. doi:10.1061/(asce)0733-9364(2008)134:12(1011)

Stoy, C., Pollalis, S., & Schalcher, H. R. (2008). Drivers for cost estimating in early design: Case study of residential construction. *Journal of Construction Engineering and Management-Asce, 134*(1), 32-39. doi:10.1061/(asce)0733-9364(2008)134:1(32)

Stoy, C., & Schalcher, H. R. (2007). Residential building projects: Building cost indicators and drivers. *Journal of Construction Engineering and Management-Asce, 133*(2), 139-145. doi:10.1061/(asce)0733-9364(2007)133:2(139)

Suranovic, S. (2010). *International Finance: Theory and Policy*: The Saylor Foundation.

SykehusbyggHF. (2014). Purpose. Retrieved April 19, 2017, from Sykehusbygg http://sykehusbygg.no/om/formal/

Tam, V. W. Y., Tam, C. M., Zeng, S. X., & Ng, W. C. Y. (2007). Towards adoption of prefabrication in construction. *Building and Environment, 42*(10), 3642-3654. doi:https://doi.org/10.1016/j.buildenv.2006.10.003

Tiwari, P., Parikh, J., & Sharma, V. (1996). Performance evaluation of cost effective buildings—A cost, emissions and employment point of view. *Building and Environment, 31*(1), 75-90. doi:http://dx.doi.org/10.1016/0360-1323(95)00010-0

Trost, S. M., & Oberlender, G. D. (2003). Predicting accuracy of early cost estimates using factor analysis and multivariate regression. *Journal of Construction Engineering and Management, 129*(2), 198-204.

Tsai, W. H., Yang, C. H., Chang, J. C., & Lee, H. L. (2014). An Activity-Based Costing decision model for life cycle assessment in green building projects. *European Journal of Operational Research, 238*(2), 607-619. doi:10.1016/j.ejor.2014.03.024

Tse, R. Y. C., & Ganesan, S. (1997). Causal relationship between construction flows and GDP: evidence from Hong Kong. *Construction Management and Economics, 15*(4), 371-376. doi:10.1080/014461997372926

Turner, & Townsend. (2016). International Construction Market Survey. Retrieved from http://www.turnerandtownsend.com/insights/international-construction-market-survey-2016/

Ulrich, R. S., Zimring, C., Zhu, X., DuBose, J., Seo, H.-B., Choi, Y.-S., Quan, X., & Joseph, A. (2008). A review of the research literature on evidence-based healthcare design. *HERD: Health Environments Research & Design Journal, 1*(3), 61-125.

UNCTAD. (2016). *World Investment Report 2016*. United Nations, Geneva.

Van Biesebroeck, J. (2004). *Cross-country conversion factors for sectoral productivity comparisons*. Retrieved from

van der Zwart, J., & van der Voordt, T. J. M. (2016). Adding Value by Hospital Real Estate: An Exploration of Dutch Practice. *Herd-Health Environments Research & Design Journal, 9*(2), 52-68. doi:10.1177/1937586715592649

Walsh, K. D., Sawhney, A., & Brown Iv, A. (2005). International comparison of cost for the construction sector: Purchasing power parity. *Journal of Construction Engineering and Management, 131*(2), 160-167. doi:10.1061/(ASCE)0733-9364(2005)131:2(160)

Walsh, K. D., Sawhney, A., & Vachris, M. A. (2006). Improving inter-spatial comparison of construction costs. *Engineering, Construction and Architectural Management, 13*(2), 123-135. doi:doi:10.1108/09699980610659599

Wasmi, H. A., & Castro-Lacouture, D. (2016). *Potential Impacts of BIM-Based Cost Estimating in Conceptual Building Design: A University Building Renovation Case Study*. Paper presented at the Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan, CRC 2016.

Wibowo, A. (2015). *Returns to scale in buildings construction costs: Indonesian cases.* Paper presented at the 5th Euro Asia Civil Engineering Forum Conference, EACEF 2015.

Wilkinson, L. (2006). Revising the Pareto Chart. *The American Statistician, 60*(4), 332-334. doi:10.1198/000313006X152243

Wilson, V. (2014). Research Methods: Triangulation. *2014, 9*(1), 2. doi:10.18438/b8ww3x

WorldBank. (2017). World development indicators. International comparison program database Retrieved March 30, 2017 http://databank.worldbank.org/data/reports.aspx?source=2&type=metadata&series=PA.NUS.PPPC.RF

Zhao, P. A., & Wang, C. C. (2014). *A Comparison of Using Traditional Cost Estimating Software and BIM for Construction Cost Control.* Paper presented at the 2014 International Conference on Construction and Real Estate Management: Smart Construction and Management in the Context of New Technology, ICCREM 2014.

Zimina, D., Ballard, G., & Pasquire, C. (2012). Target value design: using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics, 30*(5), 383-398. doi:10.1080/01446193.2012.676658

APPENDIX A: COMPLETE LIST OF LITERATURE COST FACTORS

Study	Dataset	Method	Cost driver
Emsley et al. (2002)	288 building projects	Neural network and linear regression analysis	• Contract form • **Duration** • Procurement strategy • Purpose • Quality of building • Tendering strategy • **Site access** • Type of the location • Topography • Type of site • Air conditioning • Ceiling finishes • Electrical installations • Envelope • External doors • External walls • Floor finishes • **Frame type** • **Function** • **GIFA** • Height • Internal doors • Internal walls • **Internal wall finishes** • Number of lifts • Number of storeys above ground

			• Number of storeys below ground • **Mechanical installations** • **Piling** • **Protective installations** • Roof construction • Roof finishes • Roof profile • Shape complexity • Special installations • Stair types • Substructure • Structural units • Upper floors • Wall-to-floor ration • Windows
Picken and Ilozor (2003)	24 public housing developments	Descriptive approach	• Height (increasing height does not appear to cause increasing costs until 100m)
Elhag and Boussabaine (1998)	30 schools	Artificial Neural Networks	• Project type • Contract type • Market conditions • Number of tenderers • Site slope • Start Conditions • Ground conditions • Excavation conditions • Site access • Workspace in site • Number of storeys • Gross floor area • Duration

			• Lowest tender price
Harding et al. (2000)	A pilot study	ANN	• Project duration • Gross internal floor area • Wall area • IT installation • Air conditioning • Number of lifts • Number of stories • Quality • Access to site • Site topography • Type of location • Roof construction • Shape complexity • Type of contract (fixed/fluctuating) • Nature of site (greenfield/brownfield) • Roof finishes • External walls • Stairs • Windows/external doors • Internal walls/partitions • Internal wall finishes • Floor finishes • Ceiling finishes • Fittings • Sanitary appliances • Disposal installation • Mechanical installation • Electrical installation • Special installations

			• Tendering strategy • Purpose • Procurement
Cunningham (2013)	Overview on factors	Theoretical	• Quality • Budget • Architect choice • Function • (Plan shape • Size • Wall to floor ratio • Degree of circulation space • Total height) • Grouping of buildings • Choice of materials • Sustainability level • Approach towards life cycle costs • Location value • Physical site conditions • Availability of services • Availability of resources • Climate • Procurement method • Socioeconomic factors • Market conditions • Labor costs • Productivity • Materials • Site overheads
Meikle (1990)	10 previous publications	Literature study	• Climate conditions • Local regulations • Construction practices

			• Materials • Workmanship • Function • Project content • Location • Project quality • Project duration
Skitmore (1987)	Overview on factors	Theoretical	• General demand • Building type • Size • Quality • Procurement type • Client type (public/private) • Contract type • Geographical location • Using new technologies • Availability of contractors • Laws and regulations
Gunner and Skitmore (1999)	181 contracts for offices in Singapore	Parametric	• Contract type • Building function • Floor area • Locality of architect • Locality of contractor • Commercial negotiation[4] • Contract regulations • Sector (public/private) • Market situation • Number of bidders

[4] It is common in South East Asian countries for owner to perform price negotiation to get a discount after they place their bids

Li et al. (2005)	37 Office buildings in Hong Kong	Parametric (regression models)	• **Average floor area** • **Total floor area** • Average story height • **Total building height** • Number of stories above the ground • Number of basements • Types of construction
Elhag et al. (2005)	218 UK quantity surveyors with 31% response rate	Literature Survey and Interviews	**Main categories:** • Client characteristics • Consultant and design parameters • Contractor attributes • Project characteristics • Contract procedures and procurement methods • External factors and market conditions **Top 10 factors:** • No alterations and late changes to design on consultant's side • Sustainability, experience, and performance of the contractor's management team • Priority of construction time/deadline requirements on client's side • Magnitude, timing, and inference level of variation orders and additional works on consultant's side

			• Quality of design and specifications on consultant's side • Intensity/complexity of building services on project's side • Complexity on project's side • Level of competition and level of construction activity on market's side • Certainty of project brief on client's side
B. Lim et al. (2016)	Residential	Literature analysis	**Internal factors (project-specific):** • Project type/size • Project duration • Type of contract • Design data • Complexity of the project • Site conditions • Construction method • Contingency allowance **External factors (environmental):** • Market conditions • Number of bidders • Reduction of supply • Financial uncertainty • Good/bad years • Level of construction activity

			• Weather conditions • Labor costs/availability
Aibinu et al. (2015)	Cost of engineering services from 28 residential and 43 educational projects in Australia	Artifical Neural Networks, literature	• Internal perimeter length • Number of floors • Gross floor area (GFA) • Fully enclosed covered area (FECA) • Unenclosed covered area (UCA)
Lowe et al. (2006)	286 construction projects in UK	Regression (5 variables out of 41 were present in every model they have produced)	• Gross internal floor area (GFA) • Function • Duration • Mechanical installations • Piling
Shehu et al. (2014)	Respondents comprising 49 clients, 51 contractors and 105 consultants	Survey	• Contractor's cash flow problems • Contractor to sub-contractors' payment delays • Contractor's difficulties to finance the project • Issues among contractor and sub-contractors • Contractor's unproductive scheduling and planning • Owner's delay in progress payment • Bureaucracy in government agencies and contractor's ineffective control of the project progress

Stoy and Schalcher (2007)	Expert's interviews and 290 residential properties in BKI database in Germany	Regression	• Median floor height (gross volume/gross external floor area) • The share of ancillary area for services (ancillary area for services/gross external floor area) • The construction duration (end of construction – start of construction) • The compactness of the building (external wall area/gross external floor area)
Attalla and Hegazy (2003)	50 reconstruction projects in Canada	Survey and Statistical analysis	**Scope definition and planning** • Type of reconstruction project • As-built drawings • Budget baseline and budget allocation • Design committees **Tendering Stage:** • Quality standards and specifications • Prequalification of contractors • Unit prices • Cash allowances **Schedule:** • Coordination schedule • Bar charts • Critical path method • Incremental milestones

			Cost: • Cost variance (CV) **Quality:** • Independent inspection firms **Communication:** • Regular site meetings • Rapid response mechanism **Safety:** • Joint health and safety committee **Project completion:** • Inspection by operator, maintenance and end user
Shehu et al. (2015)	Data from 150 Malaysian quantity-surveyor organizations	Survey	• Construction sector (public/private) • Procurement method (construction management, design-build, traditional, negotiated tendering, selected tendering) • Project size
Stoy et al. (2008)	70 residential buildings in Germany	Regression	• Compactness of the building (external wall area/gross external floor area) • Number of elevators • Project size • Duration of the project • Proportion of openings in external walls • Region
Tsai et al. (2014)	Theoretical example	Activity-based cost (ABC) and	• Environmental and CO2 emission costs

		life cycle assessment	
Coetzee and Brent (2015)	1192 respondents from Engineering Council of South Africa	Survey	• Sustainability in Design
Fuerst and McAllister (2011)	24479 commercial buildings in US	Hedonic regression models	• Environmental certification
Sonmez (2008)	20 US building projects	Expert's opinion, regression	• **Construction cost index (Inflation)** • **City cost index (location factors)** • **Building area** • Number of stories • % area of commons and nursing facilities in total building area • % structured parking area in total area • Total gross building area per residential unit • Site area in m^2 • Major demolition on site • Site waste treatment • Wood frame • Steel frame • Concrete frame • Steel and concrete frame • Masonry structure • Wood exterior finish • Vinyl exterior finish

			• Masonry exterior finish • Number of elevator stops • Project duration
Erdis (2013)	1453 public construction projects in Turkey	Data mining methods including decision trees, artificial neural networks, and support vector machines	• Procurement laws • Preparation of the contracts and their supplements such as project drawings • Contractor's selection method • Application of management functions • Productivity • External factors such as market conditions
Tiwari et al. (1996)	Experimental	A mathematical model called COHOPE	• Energy consumption of the materials • Construction's CO2 emission • Labor • Functional utility • Technical standards • Technology
Le-Hoai et al. (2008)	87 Vietnamese large construction experts	Questionnaire survey, Spearman's rank correlation test, factor analysis technique	**Owner-related:** • Financial difficulties • Slow payment of completed works **Contractor-related:** • Poor site management and supervision • Financial difficulties • Unsuitable construction methods

			• Inaccurate estimates • Incompetent subcontractor • Mistakes during construction **Consultant-related:** • Poor project management assistance • Poor contract management • Slow inspection of completed work • Mistakes in design **Project-related:** • Design changes • Additional works • Slow information flow between parties **Material and labor:** • Shortage of materials • Shortage of skilled workers **External factors:** • Unforeseen site conditions • Price fluctuations • Bad weather • Obstacles from government
Ioannou and Leu (1993)	Theoretical example	Mathematical analysis and Monte Carlo simulation	• Bidding process
Rungi and Hilmola (2011)	288 Finnish and Estonian respondents form	Empirical study	• Interdependency issues between projects

	industry and services		
de Carvalho et al. (2015)	1387 projects from Brazil, Argentina, and Chile	Longitudinal field survey and structural equation modelling	• Country (environment) • Industry • Project complexity affect schedule • Project management trainings affect schedule
J. N. Lim et al. (2010)	18 OECD countries and expert's interviews from Singapore	Statistical Analysis (Pearson's correlation)	• Innovation
McKee et al. (2006)	Hospital cases from England, Spain, and Australia	Case studies	• Procurement method (PPP in specific)
Ekeskar and Rudberg (2016)	A large hospital project in Sweden	Explorative case study	• Supply chain management (Third party logistic providers in specific)
de Melo et al. (2016)	A hospital project in San Francisco	Single case study	• Contractual relations • Incentives to finish on time, budget etc. • Team meetings • Contractor selection • **Construction team's composition** • Training key members • **Project governance** • **Innovation**
Bilec et al. (2009)	Two children's hospitals in US	Case study (with process mapping)	• Sustainable design technologies (green building)

			• Procurement method (design-bid-build) • Data system integration
Rybkowski et al. (2012)		Theoretical	• Time of making design decisions • Procurement method • Project delivery (Target value cost)
Olsson and Hansen (2010)	4 Norwegian hospitals	Case studies	• Late changes
Chung et al. (2009)	Hospital construction project in South Korea	Case study	• Project management practices (value engineering) • Accuracy of information for cost estimation • Contractors • Project duration • Construction complexity
Harty et al. (2015)	A hospital construction project in Denmark	Ethnographic field study	• Space design • Design methods (BIM) • Design changes • Duration
Rosenbaum et al. (2014)	Hospital construction in Chile	Case study	• Project management method (value stream mapping) • Customer demands
Sharma et al. (2014)	Personnel of an American hospital	Questionnaire survey	• Outdated hospital equipment
Rehm and Ade (2013)	17 office buildings in New Zealand	Empirical study with non-parametric Wilcoxon	• Building design (green vs. conventional)

		matched-pair signed rank test	
Wasmi and Castro-Lacouture (2016)	A university building	Case study using interviews	• Cost estimation method (BIM) • Productivity rate • Material cost • Material quantity • Labor cost
Zhao and Wang (2014)	Five 28-story residential buildings in China	Case study	• Cost control methods (BIM vs. traditional)
Hong et al. (2010)	A building complex including office building, water station , hydrology and meteorological facilities	Case study	• Procurement method (Design-bid-build vs design-build)
Bayram and Al-Jibouri (2016)	420 public building projects in Turkey	Traditional estimation methods such as unit area costs, client detailed costs and contract sum were compared with non-traditional methods such as radial basis function, grid	• Cost estimation methods (traditional vs non-traditional)

		partitioning algorithm, reference class forecasting and regression analysis	
Mills (2013)	Medium-rise commercial buildings' frame design prices in 5 Australian cities	Expert's opinion	• Structural frame choice • Construction technology (structure reinforcement) • Material supply • Availability of skilled labor
Gurcanli et al. (2015)	25 concrete residential buildings in Turkey	Hazard analysis and risk assessment techniques	• Safety costs • Labor wages • Tax policies • Transportation • Material costs • Site facilities
J. L. Kim et al. (2014)	A single family residential house in US	Cost comparative analysis	• Regulations (Green Building Code)
S. Y. Kim et al. (2017)	13 hospital construction experts and 197 questionnaire respondents in Vietnam	Survey questionnaire and exploratory factor analysis	• Additional work • Wet weather effect/rework • Quantity increased measure • Resumption/accommodation works • Project administration cost increase
Wibowo (2015)	1050 Indonesian construction projects	Regression analysis, analysis of variance	• size
Latief et al. (2013)	55 apartments in Indonesia	Regression analysis with adaptive neuro	• Gross floor area • Area per unit

		fuzzy inference system	• Height of building • Type of foundation • Number of units per number of stories
De Marco and Mangano (2013)	49 healthcare projects in UK	Exploratory data analysis, linear regression analysis	• Procurement method • Project size (hospital capacity) Project complexity: • Construction site conditions • Sophisticated design • Tight schedule pressure • Innovative building technologies • Construction logistics
Sherif (1999)	Egypt hospitals	Empirical study	• Availability of financial resources • Availability of technological tools • Inpatient nursing units • Outpatient clinics and operating theater suite • Built area • Structural system • Design quality • Design flexibility
Zimina et al. (2012)	Two hospitals in US	Case studies, action research	• Project delivery (Target value costing) • Contract management • Cost management
Ayman et al. (2004)	36 buildings in UAE	Case studies, surveying	• Changing the project's brief • Lack of information • Regulations

			• Technological advances
Love (2002)	161 Australian building projects	Questionnare survey	• Rework • Management practices (quality and learning) • Management strategies towards rework
Kaming et al. (1997)	31 project managers working on high-rise buildings	Questionnare survey, factor analysis	Top 5 factor influencing cost overrun: • In accurate quantity take-off • Materials cost increase by inflation • Labor cost increase due to environmental restriction • Lack of experience of project location • Lack of experience of project type Top 5 factor influencing delay: • Design changes • Inadequate planning • Inaccuracy of materials estimate • Poor labor productivity • Inaccurate prediction of craftsman production rate
Pennanen et al. (2011)	An office building extension in Finland	Case study	• Customer's business plan • Customer's willingness to pay • Customer's ability to pay • Design process management • Project delivery (target costing)

			• Regulation • Human factor in design process • Human factor in production on-site • Market fluctuations
Manning and Messner (2008)	Tow healthcare facilities: one hospital in Middle east and one in US	Case studies	• Design process management (BIM)
Khodakarami and Abdi (2014)	10 experts in Iran	Bayesian network and probabilistic risk analysis	• Dependency between cost components • People's experience • Material prices
Arditi et al. (1985)	44 public agency and 34 contractor in Turkey	Survey questionnaire	Top 5 cost overrun factors: • Inflationary pressure • Increase in material prices and workmen's wages • Difficulties in obtaining materials at official prices • Construction delays • Error in estimates Top 5 delay factors: • Difficulties in obtaining construction materials • Contractors' difficulties in receiving monthly payments from public agencies • Contractors' financial difficulties • Deficiencies in contractors' company organization

			• Deficiencies in public agencies' organization
Trost and Oberlender (2003)	67 construction projects around the world	Factor analysis and multivariate regression analysis	Top 5 affecting estimation accuracy: • Basic process design • Team experience and Cost information • Time allowed to prepare the estimate • Site requirements • Bidding and labor climate
G.-H. Kim et al. (2004)	530 residential buildings in Korea	Back-propagation neural network with generic algorithm	• Time (of construction) • Gross floor area • (number of) stories • Total unit (housing) • Duration • Roof types • FDN (foundation) types • Usage of basement • Finishing grades
Günaydın and Doğan (2004)	30 construction projects in Turkey	ANN to predict cost of 4-8 story apartment buildings with reinforced concrete structure	• Total area of the building • Ratio of floor area to total area of the building • Ratio of ground floor area to total area of the building • Number of floors • Console direction of the building • Foundation system of the building • Floor type of the building

			• Location of the core of the building • Structure system
Riley et al. (2005)	Four case studies: library, office building, research lab, and civic arena plus 37 laboratory and healthcare buildings. 35 project managers in US. 15 coordinators.	Case studies, questionnaire, regression	• Mechanical system • Electrical system • Pluming system

*The most significant factors indicated in the studies are bolded

APPENDIX B: FIRST QUESTIONNAIRE (BASED ON LITERATURE)

Literature: Expert's view on the most important cost factors in hospital construction

Dear Sir or Madame,

It seems there is a lack of research about the most important cost components in hospital construction, therefore a study in this regard is more than needed. Your input would help us determining the key cost factors in the construction of the hospitals which in return would enhance the efficiency and cost performance of the construction projects.

The following questionnaire is the result of investigating more than 63 academic publications as well as 6 international hospital projects for my Master's degree. With the help of academic scholars, the questions are filtered so that only essential data is gathered.

There are **only X questions** in this survey. With each question, we ask you to assess a factor's degree of influence on the construction cost of a hospital based on your valuable knowledge and experience. Also, it is interesting to know which stakeholder can affect that same factor the most from your perspective; is it consultants? contractors? etc. The estimated time to fill this questionnaire is approximately 15 minutes.

Finally, we assure you that your answers would be completly confidential and only for academic purposes so please answer the following questions to the best of your knowledge and experience.

We would like to thank you in advance for taking the time to answer these questions.

Yours faithfully,

Moein Barakchi

MSc student in project management at NTNU

1) Which of the options is the closest to your job position?

- Consultancy
- Contractor
- Financing party

Other

2) General information about you

How many years of experience do you have in construction? (just a number)

How many construction projects were you involved in? (just a number)

Next >>

33 % completed

Literature: Expert's view on the most important cost factors in hospital construction

The cost factors found in the literature were filtered three times and categorised according to Norwegian Standard NS 3453. The following questions are the costs listed in each category.

3) Common costs (Felleskostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Excavation conditions									
Site facilities									
Energy consumption of the materials									

4) Building costs (Bygning)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Structural frame type									
Type of foundation									
Piling									
Floor type of the building									
Floor finishes									
Internal doors									
Internal doors									
Internal wall finishes									
Masonary									
Roof construction									
Roof finishes									
Roof profile									
Roof type									
Stair type									
Stairs									
Structural units									

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Substructure									
Type of exterior finishes									
Windows									

5) HVAC (VVS)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Air conditioning									
Protective installations									
Sanitary appliances									

6) Electrical (Elektro)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Electrical installations									

7) Telecommunication and automation (Tele og automatisering)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
IT installations									

8) Other installations (Andre installasjoner)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Disposal installation									

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Number of elevator stops									
Number of lifts (elevators)									
Special installations									

9) Outdoors (Utendørs)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Transportation									

10) General costs (Generelle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Inspection by operator, maintenance, and end user									
Project administration cost increase									
Safety costs									
Site overheads									
Resumption/accommodation works									
Duration of construction									
Productivity									
Additional works in project									

11) Special costs (Spesielle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Cash allowances									
Location value									
Quantity increased measure									
Tax policies									

12) Project-specific cost aspect

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Other (laws and regulations, government, etc.)
Percentage area of common and nursing facilities in total building area									
Percentage structured parking area in total area									
Average floor area									
Average story height (average floor height)									
Building area									
Degree of circulation space									
Floor area									
Fully enclosed covered area									
Gross Internal Floor Area (GIFA)									
Gross floor area									
Height of the building									
Inpatient nursing units									
Internal perimeter length									
Labor cost									
Material cost (in the estimation phase)									
material qunatity									
Materials (when it is bought from supplier)									
Number of stories (floors)									
Number of stories above ground									
Number of stories below ground									
Number of housing units									
Number of units per number of stories									
Outpatient clinics and operating theater suite									
Proportion of openings in external walls									
Ratio of floor area to total area of the building									
Ratio of ground floor area to total area of the building									
site area in m^2									
Project size									
The compactness of the building (external wall area/ gross external floor area)									

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Other (laws and regulations, government, etc.)
The share of ancillary area for services (ancillary area for services/gross external floor area)									
Total gross building area per residential unit									
Unenclosed covered area									
Unit prices									
Wall area									
Wall-to-floor ratio									
Outdated hospital equipments									

Next >>

67 % completed

Literature: Expert's view on the most important cost factors in hospital construction

13) Where there any important cost factor that we missed? If yes, please just name them.

14) What is the single most important cost factor in your opinion? Could you explain briefly how it can be managed?

Send

100 % completed

APPENDIX C: SECOND QUESTIONNAIRE (BASED ON PROJECT DATA)

Expert's view on the most important cost factors in hospital construction

Dear Sir or Madame,

No one can deny the financial challenges in hospital construction. As a result, we are studying the reasons and solution regarding this issue from a practical point of view. The results of this study could improve the cost performance, efficiency and resource allocation of hospital construction projects.

Since the aim of this questionnaire is to find the cost factors from the practical perspective, we went after a number of Norwegian and American projects done in this regard. The projects' cost factors were gathered and listed. As for the next step, we need your professional judgment to find the most important factors.

We prepared a short survey in this respect; only the essential questions are included. We ask you to rate the importance of cost factors and also tell us who you think can affect them the most. Is the contractor? the consultant? etc. The estimated time to fill this questionnaire is approximately 10 minutes.

Finally, we assure you that your answers would be completely confidential and only for academic purposes so please answer the following questions to the best of your knowledge and experience.

We would like to thank you in advance for taking the time to answer these questions. Hopefully, your contribution would further the efficient cost performance and the research in the construction industry.

Yours faithfully,

Olav Torp	Moein Barakchi
Associated Professor	MSc. student in Project Management
Dept. Civil & Environmental Engineering	Dept. Civil & Environmental Engineering
Norwegian University of Science and Technology (NTNU)	Norwegian University of Science and Technology (NTNU)
Trondheim, Norway	Trondheim, Norway

The cost factors found in the literature were filtered three times and categorised according to Norwegian Standard NS 3453. The following questions are the costs listed in each category.

1) Common costs (Felleskostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Setting up the construction site	○	○	○	○	○	☐	☐	☐	☐
Operation of construction site	○	○	○	○	○	☐	☐	☐	☐
High voltage electricity for construction site	○	○	○	○	○	☐	☐	☐	☐
Temporary construction works	○	○	○	○	○	☐	☐	☐	☐
Contractor's administration costs	○	○	○	○	○	☐	☐	☐	☐

2) Building costs (Bygning)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Foundation and base	○	○	○	○	○	☐	☐	☐	☐
Support system	○	○	○	○	○	☐	☐	☐	☐
Exterior walls (excluding finishes and insulation costs)	○	○	○	○	○	☐	☐	☐	☐
Interior walls (excluding finishes and insulation costs)	○	○	○	○	○	☐	☐	☐	☐
Finishing (interior finishes, flooring, exterior wall finishes, etc.)	○	○	○	○	○	☐	☐	☐	☐
Roof	○	○	○	○	○	☐	☐	☐	☐
Fixtures and fittings (doors, door frames, glazing, window covering, freezer room, refrigerator room etc.)	○	○	○	○	○	☐	☐	☐	☐
Stairs, balconies, canopies etc.	○	○	○	○	○	☐	☐	☐	☐
Insulation works	○	○	○	○	○	☐	☐	☐	☐
Fireproofing	○	○	○	○	○	☐	☐	☐	☐
Partitioning	○	○	○	○	○	☐	☐	☐	☐
Painting	○	○	○	○	○	☐	☐	☐	☐

3) HVAC (VVS)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Sanitary installation (passing pipes, ducts, equipment etc.)	○	○	○	○	○	☐	☐	☐	☐
Heating installation	○	○	○	○	○	☐	☐	☐	☐
Fire suppression system	○	○	○	○	○	☐	☐	☐	☐
Equipment for medical gas and compressed air	○	○	○	○	○	☐	☐	☐	☐
Cooling systems (refrigerator and freezer rooms)	○	○	○	○	○	☐	☐	☐	☐
Air conditioning	○	○	○	○	○	☐	☐	☐	☐
Comfort cooling	○	○	○	○	○	☐	☐	☐	☐
Water treatment (pipes, equipment, etc.)	○	○	○	○	○	☐	☐	☐	☐
Other HVAC installations, temporary	○	○	○	○	○	☐	☐	☐	☐

4) Electrical (Elektro)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Basic installations for electrical power	○	○	○	○	○	☐	☐	☐	☐
Low-voltage equipment	○	○	○	○	○	☐	☐	☐	☐
Illumination (lighting)	○	○	○	○	○	☐	☐	☐	☐
Electric heating	○	○	○	○	○	☐	☐	☐	☐
Emergency power equipment	○	○	○	○	○	☐	☐	☐	☐

5) Telecommunication and automation (Tele og automatisering)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Basic installation for telecommunication and automation	○	○	○	○	○	☐	☐	☐	☐
Integrated communication (cabling for phone and data)	○	○	○	○	○	☐	☐	☐	☐
Telephony and paging (such as nurse call)	○	○	○	○	○	☐	☐	☐	☐
Fire alarm and patient call systems	○	○	○	○	○	☐	☐	☐	☐
Visual and auditory equipment	○	○	○	○	○	☐	☐	☐	☐

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Automation (switchboards, control centers, control equipment etc.)									

6) Other installations (Andre installasjoner)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Other installations, general									
Elevator									
Waste and vacuuming									
Pneumatic tube (rørpost)									
Transportation of personnel and goods (Person- og varetransport, vertical transportation)									
Transportation of small goods									
AGV (Automated Guided Vehicle)									
Special equipment for activities (fixed/movable)									
Other technical installations									

7) Outdoors (Utendørs)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Outdoors, general									
Preparing the terrain (surveying etc.)									
Outdoors' constructions(?)									
Outdoors' HVAC									
Outdoors' electrical									
Outdoors' telecommunication and automation									
Park and garden									
(Preparing) roads and locations on the site									
Construction of outdoor infrastructure									
Other outdoors construction (0)									

8) General costs (Generelle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Design all subjects including user equipment									
Field testing and laboratory costs									
Scheduling costs									
Administration BH including user equipment (Administrasjon BH, inkl. brukerutstyr)									
Insurance and fees									
Construction related thermal energy (Anleggsbidra termisk energi)									
High voltage electricity									
Common costs(?)									
Pre-project									
Communication and cooperation									
Additional refunds									
Architect									
RI and landscape (?, RI og landskap)									
Art									
Side costs (copying, travels, etc.)									
Miscellaneous (Diverse)									

9) Special costs (Spesielle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
VAT (Merverdiavgift)									
Movable equipment and furnishes (chattels)									
Reserves									
Land-related costs									
Financing costs									
Sale expenses									
Investment fees									
Artistic decoration									

10) Project-specific cost aspect

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
Cost contingency (uncertainty analysis, fixed etc.)									
Gross floor area									
Exterior wall area									
Interior wall area									
Number of stories									
Number of parking spaces									
Number of beds									

Next >>

50 % completed

Expert's view on the most important cost factors in hospital construction

11) Where there any important cost factor that we missed? If yes, please just name them.

12) What is the single most important cost factor in your opinion? Could you explain briefly how it can be managed?

Next >>

75 % completed

Expert's view on the most important cost factors in hospital construction

The following two questions are optional. However, your answers would help us tremendously in validating our questionnaire even more. Once again we want to assure you that your answers would be totally confidential.

13) Which of the options is the closest to your job position?

- Consultancy
- Contractor
- Financing party
- Other

14) General information about you

Your experience in construction (Number of years)

An estimate for number of projects you were involved in

Send

100 % completed

APPENDIX D: FINAL QUESTIONNAIRE (APPLIED)

Online questionnaire: most important cost factors in hospital construction

Dear Sir or Madame,

No one can deny the financial challenges in hospital construction. As a result, we are studying the reasons and solution regarding this issue from a practical point of view. The results of this study could improve the cost performance, efficiency and resource allocation of hospital construction projects.

Since the aim of this questionnaire is to find the cost factors from the practical perspective, we went after a number of Norwegian and American projects done in this regard. Norwegian Sykehusbygg and American healthcare organizations were involved in this process. The projects' cost factors were gathered and listed. As for the next step, we need your professional opinion to find the most important factors.

We prepared a short survey in this respect; only the essential questions are included. We ask you to rate the importance of cost factors and also tell us who you think can affect them the most. Is it the contractor? the consultant? etc. The estimated time to fill this questionnaire is approximately **10 minutes**.

Finally, we assure you that your answers would be **completely confidential** and only for academic purposes so please answer the following questions to the best of your knowledge and experience.

We would like to thank you in advance for taking the time to answer these questions. Hopefully, your contribution would further the efficient cost performance and the research in the construction industry.

Yours faithfully,

Olav Torp	Moein Barakchi
Associate Professor	MSc student in Project Management
Dept of Civil & Environmental Engineering	Dept of Civil & Environmental Engineering
Norwegian University of Science and	Norwegian University of Science and

Technology (NTNU) Technology (NTNU)
Trondheim, Norway Trondheim, Norway

The questions below consist of two parts:

The first part is about the **degree of influence** each factor has over the total construction cost. Here you can select only one option out of the five (not at all, slightly, moderately, very, extremely).

The second part asks for the **main stakeholder(s)** who can affect that factor the most. In case two (or more) stakeholders are equally effective, it is possible to choose all of them.

The questions with * are essential in this questionnaire. Please answer all parts of these questions based on your professional opinion.

1) * Common costs (Felleskostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
1.1) Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	○	○	○	○	○	☐	☐	☐	☐
1.2) Operation of construction site	○	○	○	○	○	☐	☐	☐	☐
1.3) Contractor's administration costs	○	○	○	○	○	☐	☐	☐	☐

2) * Building costs (Bygning)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
2.1) Foundation and base (excavation, laying foundation)	○	○	○	○	○	☐	☐	☐	☐
2.2) Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	○	○	○	○	○	☐	☐	☐	☐
2.3) Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	○	○	○	○	○	☐	☐	☐	☐
2.4) Walls (interior/exterior)	○	○	○	○	○	☐	☐	☐	☐

3) * HVAC (VVS)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government

	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
3.1) Sanitary installation (including plumbing, ducts, equipment etc.)									
3.2) Heating installation									
3.3) Air conditioning (ventilation)									
3.4) Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)									
3.5) Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)									

4) * Electrical (Elektro)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
4.1) Basic installations for electrical power									
4.2) Low-voltage equipment									
4.3) Illumination (lighting)									
4.4) Other equipment (high voltage, emergency, electrical heating system, reserve etc.)									

5) * Telecommunication and automation (Tele og automatisering)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
5.1) Fire alarm and patient call systems									
5.2) Integrated communication (cabling for phone and data)									
5.3) Automation (switchboards, control centers, control equipment etc.)									
5.4) Other equipment (telephony, nurse call, visual and auditory, etc.)									

6) * Other installations (Andre installasjoner)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
6.1) Elevator									
6.2) AGV (Automated Guided Vehicle)									
6.3) Transportation of personnel and goods									

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
6.4) Waste and vacuuming									
6.5) Other technical installations (pneumatic tube, prefabricated rooms, etc.)									

7) * Outdoors (Utendørs)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
7.1) Park and garden construction									
7.2) Preparing roads and locations on the site (preparing terrain, surveying, etc.)									
7.3) Construction of road's infrastructure									
7.4) Outdoors' constructions (HVAC, electrical, telecomm. and automation)									

8) * General costs (Generelle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
8.1) Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)									
8.2) Project owner's administration including user equipment (insurance and fees etc.)									
8.3) Other costs (copying, travels, communication, art, electricity etc.)									

9) * Special costs (Spesielle kostnader)

	Degree of influence on construction cost:					Who is(are) affecting the factor the most?			
	(Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Owner	Consultant	Contractor	Government
9.1) VAT									
9.2) Equipment and furnishes (chattels)									
9.3) Reserves									
9.4) Land-related costs and aesthetic decoration									

10) * Project-specific cost aspect

	Degree of influence on construction cost: (Not at all)	(Slightly)	(Moderately)	(Very)	(Extremely)	Who is(are) affecting the factor the most? Owner	Consultant	Contractor	Government
10.1) Cost contingency (uncertainty analysis, fixed etc.)									
10.2) Gross floor area									
10.3) Wall area (interior/exterior)									
10.4) Number of stories									
10.5) Number of parking spaces									
10.6) Number of bed spaces									

11) From your perspective, were there any important cost factor(s) that needs to be added to this list? If yes, please just name them.

Next >>

67 % completed

Online questionnaire: most important cost factors in hospital construction

The following two questions are optional. However, your answers would help us tremendously in validating our questionnaire even more. Once again we want to assure you that your answers would be totally confidential.

12) Which of the options is the closest to your job position?

- Consultancy
- Contractor
- Financing party
- Other

Please do not forget to **fill in the last row (*)** because it is needed to compare the views from different countries.

13) General information

Your experience in construction (in years)	
An estimate for number of projects you were involved in	
* The country you work in	

Send

100 % completed

APPENDIX E: QUESTIONNAIRE'S RESULTS

E1 Overall

Factors	Not at all (1)	Slightly (2)	Moderately (3)	Very (4)	Exteremely (5)	Score
Number of bed spaces	0.00%	9.09%	18.18%	45.45%	27.27%	3.91
Gross floor area	0.00%	18.18%	18.18%	45.45%	18.18%	3.64
Air conditioning (ventilation)	0.00%	18.18%	27.27%	36.36%	18.18%	3.55
Heating installation	0.00%	18.18%	36.36%	36.36%	9.09%	3.36
Wall area (interior/exterior)	0.00%	0.00%	72.73%	18.18%	9.09%	3.36
Walls (interior/exterior)	0.00%	18.18%	36.36%	36.36%	9.09%	3.36
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	0.00%	9.09%	45.45%	45.45%	0.00%	3.36
Foundation and base (excavation, laying foundation)	0.00%	18.18%	45.45%	36.36%	0.00%	3.18
Sanitary installation (including plumbing, ducts, equipment etc.)	0.00%	27.27%	27.27%	45.45%	0.00%	3.18
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	0.00%	27.27%	27.27%	45.45%	0.00%	3.18
Equipment and furnishes (chattels)	0.00%	18.18%	63.64%	9.09%	9.09%	3.09
Basic installations for electrical power	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Integrated communication (cabling for phone and data)	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Number of stories	9.09%	18.18%	36.36%	27.27%	9.09%	3.09
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	0.00%	27.27%	36.36%	36.36%	0.00%	3.09
Automation (switchboards, control centers, control equipment etc.)	0.00%	27.27%	45.45%	27.27%	0.00%	3.00
Construction of road's infrastructure	0.00%	36.36%	36.36%	18.18%	9.09%	3.00
Illumination (lighting)	0.00%	27.27%	45.45%	27.27%	0.00%	3.00
Low-voltage equipment	0.00%	27.27%	45.45%	27.27%	0.00%	3.00
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	0.00%	36.36%	27.27%	36.36%	0.00%	3.00
VAT	27.27%	18.18%	9.09%	18.18%	27.27%	3.00
Contractor's administration costs	0.00%	18.18%	72.73%	9.09%	0.00%	2.91
Fire alarm and patient call systems	0.00%	36.36%	36.36%	27.27%	0.00%	2.91
Number of parking spaces	0.00%	27.27%	54.55%	18.18%	0.00%	2.91
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	0.00%	27.27%	54.55%	18.18%	0.00%	2.91
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	0.00%	36.36%	45.45%	9.09%	9.09%	2.91
Project owner's administration including user equipment (insurance and fees etc.)	0.00%	36.36%	36.36%	27.27%	0.00%	2.91
Operation of construction site	0.00%	27.27%	63.64%	9.09%	0.00%	2.82
Other equipment (telephony, nurse call, visual and auditory, etc.)	0.00%	27.27%	63.64%	9.09%	0.00%	2.82
Transportation of personnel and goods	9.09%	27.27%	45.45%	18.18%	0.00%	2.73
Elevator	0.00%	45.45%	45.45%	9.09%	0.00%	2.64
Land-related costs and aesthetic decoration	9.09%	63.64%	0.00%	9.09%	18.18%	2.64
Park and garden construction	0.00%	45.45%	45.45%	9.09%	0.00%	2.64
Waste and vacuuming	0.00%	54.55%	27.27%	18.18%	0.00%	2.64
Reserves	18.18%	36.36%	27.27%	18.18%	0.00%	2.45
AGV (Automated Guided Vehicle)	18.18%	36.36%	36.36%	9.09%	0.00%	2.36
Cost contingency (uncertainty analysis, fixed etc.)	18.18%	36.36%	36.36%	9.09%	0.00%	2.36
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	0.00%	72.73%	18.18%	9.09%	0.00%	2.36
Other costs (copying, travels, communication, art, electricity etc.)	0.00%	90.91%	0.00%	9.09%	0.00%	2.18

Factors	Owner	Consultant	Contractor	Government
AGV (Automated Guided Vehicle)	63.64%	63.64%	45.45%	0.00%
Air conditioning (ventilation)	18.18%	81.82%	54.55%	36.36%
Automation (switchboards, control centers, control equipment etc.)	45.45%	81.82%	45.45%	0.00%
Basic installations for electrical power	18.18%	54.55%	63.64%	18.18%
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	45.45%	72.73%	54.55%	27.27%
Construction of road's infrastructure	18.18%	45.45%	54.55%	45.45%
Contractor's administration costs	45.45%	9.09%	90.91%	9.09%
Cost contingency (uncertainty analysis, fixed etc.)	81.82%	36.36%	45.45%	0.00%
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	72.73%	90.91%	27.27%	36.36%
Elevator	36.36%	63.64%	45.45%	27.27%
Equipment and furnishes (chattels)	90.91%	45.45%	9.09%	9.09%
Fire alarm and patient call systems	63.64%	72.73%	36.36%	27.27%
Foundation and base (excavation, laying foundation)	9.09%	90.91%	54.55%	9.09%
Gross floor area	72.73%	90.91%	18.18%	36.36%
Heating installation	27.27%	81.82%	63.64%	18.18%
Illumination (lighting)	54.55%	63.64%	45.45%	0.00%
Integrated communication (cabling for phone and data)	63.64%	81.82%	45.45%	0.00%
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	54.55%	72.73%	45.45%	27.27%
Land-related costs and aesthetic decoration	100.00%	36.36%	18.18%	9.09%
Low-voltage equipment	45.45%	54.55%	36.36%	0.00%
Number of bed spaces	90.91%	18.18%	9.09%	27.27%
Number of parking spaces	81.82%	27.27%	18.18%	45.45%
Number of stories	90.91%	100.00%	18.18%	27.27%
Operation of construction site	27.27%	9.09%	100.00%	9.09%
Other costs (copying, travels, communication, art, electricity etc.)	100.00%	63.64%	54.55%	9.09%
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	63.64%	54.55%	27.27%	27.27%
Other equipment (telephony, nurse call, visual and auditory, etc.)	72.73%	72.73%	36.36%	9.09%
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	54.55%	63.64%	45.45%	36.36%
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	72.73%	54.55%	45.45%	9.09%
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	54.55%	72.73%	27.27%	0.00%
Park and garden construction	81.82%	63.64%	27.27%	27.27%
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	54.55%	0.00%	100.00%	18.18%
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	54.55%	63.64%	36.36%	36.36%
Project owner's administration including user equipment (insurance and fees etc.)	100.00%	27.27%	18.18%	18.18%
Reserves	100.00%	27.27%	36.36%	0.00%
Sanitary installation (including plumbing, ducts, equipment etc.)	27.27%	63.64%	54.55%	18.18%
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	27.27%	90.91%	45.45%	9.09%
Transportation of personnel and goods	72.73%	54.55%	36.36%	0.00%
VAT	9.09%	0.00%	9.09%	90.91%
Wall area (interior/exterior)	36.36%	90.91%	18.18%	9.09%
Walls (interior/exterior)	54.55%	90.91%	45.45%	18.18%
Waste and vacuuming	72.73%	54.55%	36.36%	27.27%

E2 Norwegian

Factors	Not at all (1)	Slightly (2)	Moderately (3)	Very (4)	Exteremely (5)	Score
VAT	16.67%	0.00%	16.67%	16.67%	50.00%	3.83
Number of bed spaces	0.00%	16.67%	16.67%	50.00%	16.67%	3.67
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	0.00%	0.00%	50.00%	50.00%	0.00%	3.50
Gross floor area	0.00%	33.33%	16.67%	33.33%	16.67%	3.33
Integrated communication (cabling for phone and data)	0.00%	16.67%	33.33%	50.00%	0.00%	3.33
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	0.00%	16.67%	33.33%	50.00%	0.00%	3.33
Walls (interior/exterior)	0.00%	33.33%	16.67%	33.33%	16.67%	3.33
Equipment and furnishes (chattels)	0.00%	16.67%	66.67%	0.00%	16.67%	3.17
Air conditioning (ventilation)	0.00%	16.67%	50.00%	33.33%	0.00%	3.17
Contractor's administration costs	0.00%	0.00%	83.33%	16.67%	0.00%	3.17
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	0.00%	16.67%	50.00%	33.33%	0.00%	3.17
Foundation and base (excavation, laying foundation)	0.00%	16.67%	50.00%	33.33%	0.00%	3.17
Heating installation	0.00%	16.67%	50.00%	33.33%	0.00%	3.17
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	0.00%	33.33%	16.67%	50.00%	0.00%	3.17
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	0.00%	0.00%	83.33%	16.67%	0.00%	3.17
Wall area (interior/exterior)	0.00%	0.00%	83.33%	16.67%	0.00%	3.17
Construction of road's infrastructure	0.00%	33.33%	33.33%	16.67%	16.67%	3.17
Automation (switchboards, control centers, control equipment etc.)	0.00%	33.33%	33.33%	33.33%	0.00%	3.00
Basic installations for electrical power	0.00%	33.33%	33.33%	33.33%	0.00%	3.00
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	0.00%	33.33%	33.33%	33.33%	0.00%	3.00
Operation of construction site	0.00%	16.67%	66.67%	16.67%	0.00%	3.00
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	0.00%	33.33%	50.00%	0.00%	16.67%	3.00
Project owner's administration including user equipment (insurance and fees etc.)	0.00%	16.67%	66.67%	16.67%	0.00%	3.00
Illumination (lighting)	0.00%	33.33%	50.00%	16.67%	0.00%	2.83
Low-voltage equipment	0.00%	33.33%	50.00%	16.67%	0.00%	2.83
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	0.00%	33.33%	50.00%	16.67%	0.00%	2.83
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	0.00%	50.00%	16.67%	33.33%	0.00%	2.83
Sanitary installation (including plumbing, ducts, equipment etc.)	0.00%	33.33%	50.00%	16.67%	0.00%	2.83
Number of parking spaces	0.00%	50.00%	33.33%	16.67%	0.00%	2.67
Other equipment (telephony, nurse call, visual and auditory, etc.)	0.00%	33.33%	66.67%	0.00%	0.00%	2.67
AGV (Automated Guided Vehicle)	0.00%	50.00%	50.00%	0.00%	0.00%	2.50
Elevator	0.00%	50.00%	50.00%	0.00%	0.00%	2.50
Fire alarm and patient call systems	0.00%	50.00%	50.00%	0.00%	0.00%	2.50
Number of stories	16.67%	33.33%	33.33%	16.67%	0.00%	2.50
Park and garden construction	0.00%	50.00%	50.00%	0.00%	0.00%	2.50
Transportation of personnel and goods	16.67%	33.33%	33.33%	16.67%	0.00%	2.50
Waste and vacuuming	0.00%	66.67%	16.67%	16.67%	0.00%	2.50
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	0.00%	83.33%	16.67%	0.00%	0.00%	2.17
Reserves	33.33%	33.33%	16.67%	16.67%	0.00%	2.17
Cost contingency (uncertainty analysis, fixed etc.)	33.33%	50.00%	0.00%	16.67%	0.00%	2.00
Land-related costs and aesthetic decoration	0.00%	100.00%	0.00%	0.00%	0.00%	2.00
Other costs (copying, travels, communication, art, electricity etc.)	0.00%	100.00%	0.00%	0.00%	0.00%	2.00

Factors	Owner	Consultant	Contractor	Government
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	50.00%	0.00%	100.00%	16.67%
Operation of construction site	33.33%	16.67%	100.00%	0.00%
Contractor's administration costs	50.00%	16.67%	100.00%	16.67%
Foundation and base (excavation, laying foundation)	0.00%	83.33%	66.67%	16.67%
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	16.67%	83.33%	66.67%	16.67%
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	50.00%	66.67%	66.67%	33.33%
Walls (interior/exterior)	50.00%	100.00%	50.00%	16.67%
Sanitary installation (including plumbing, ducts, equipment etc.)	16.67%	66.67%	50.00%	0.00%
Heating installation	33.33%	83.33%	66.67%	16.67%
Air conditioning (ventilation)	16.67%	83.33%	66.67%	33.33%
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	50.00%	83.33%	66.67%	16.67%
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	66.67%	66.67%	50.00%	33.33%
Basic installations for electrical power	16.67%	66.67%	66.67%	16.67%
Low-voltage equipment	50.00%	50.00%	50.00%	0.00%
Illumination (lighting)	50.00%	66.67%	66.67%	0.00%
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	50.00%	66.67%	33.33%	50.00%
Fire alarm and patient call systems	66.67%	83.33%	50.00%	33.33%
Integrated communication (cabling for phone and data)	83.33%	83.33%	66.67%	0.00%
Automation (switchboards, control centers, control equipment etc.)	50.00%	83.33%	66.67%	0.00%
Other equipment (telephony, nurse call, visual and auditory, etc.)	83.33%	66.67%	50.00%	16.67%
Elevator	16.67%	66.67%	66.67%	16.67%
AGV (Automated Guided Vehicle)	66.67%	83.33%	66.67%	0.00%
Transportation of personnel and goods	83.33%	66.67%	50.00%	0.00%
Waste and vacuuming	83.33%	66.67%	50.00%	16.67%
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	83.33%	66.67%	66.67%	0.00%
Park and garden construction	83.33%	100.00%	33.33%	16.67%
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	50.00%	83.33%	33.33%	33.33%
Construction of road's infrastructure	0.00%	66.67%	33.33%	66.67%
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	50.00%	100.00%	33.33%	0.00%
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	100.00%	100.00%	33.33%	50.00%
Project owner's administration including user equipment (insurance and fees etc.)	100.00%	33.33%	16.67%	16.67%
Other costs (copying, travels, communication, art, electricity etc.)	100.00%	66.67%	50.00%	16.67%
VAT	0.00%	0.00%	0.00%	100.00%
Equipment and furnishes (chattels)	83.33%	66.67%	0.00%	0.00%
Reserves	100.00%	33.33%	16.67%	0.00%
Land-related costs and aesthetic decoration	100.00%	50.00%	16.67%	0.00%
Cost contingency (uncertainty analysis, fixed etc.)	100.00%	33.33%	0.00%	0.00%
Gross floor area	83.33%	100.00%	16.67%	50.00%
Wall area (interior/exterior)	33.33%	100.00%	16.67%	0.00%
Number of stories	100.00%	100.00%	16.67%	33.33%
Number of parking spaces	100.00%	16.67%	16.67%	66.67%
Number of bed spaces	100.00%	0.00%	0.00%	33.33%

E3 The US

Factors	Not at all (1)	Slightly (2)	Moderately (3)	Very (4)	Exteremely (5)	Score
Land-related costs and aesthetic decoration	0%	25%	0%	25%	50%	4.00
Number of bed spaces	0%	0%	25%	50%	25%	4.00
Air conditioning (ventilation)	0%	25%	0%	50%	25%	3.75
Gross floor area	0%	0%	25%	75%	0%	3.75
Heating installation	0%	25%	25%	25%	25%	3.50
Number of stories	0%	0%	50%	50%	0%	3.50
Sanitary installation (including plumbing, ducts, equipment etc.)	0%	25%	0%	75%	0%	3.50
Basic installations for electrical power	0%	25%	25%	50%	0%	3.25
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	0%	25%	25%	50%	0%	3.25
Fire alarm and patient call systems	0%	25%	25%	50%	0%	3.25
Foundation and base (excavation, laying foundation)	0%	25%	25%	50%	0%	3.25
Illumination (lighting)	0%	25%	25%	50%	0%	3.25
Low-voltage equipment	0%	25%	25%	50%	0%	3.25
Number of parking spaces	0%	0%	75%	25%	0%	3.25
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	0%	25%	25%	50%	0%	3.25
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	0%	25%	25%	50%	0%	3.25
Wall area (interior/exterior)	0%	0%	75%	25%	0%	3.25
Walls (interior/exterior)	0%	0%	75%	25%	0%	3.25
Automation (switchboards, control centers, control equipment etc.)	0%	25%	50%	25%	0%	3.00
Construction of road's infrastructure	0%	25%	50%	25%	0%	3.00
Cost contingency (uncertainty analysis, fixed etc.)	0%	0%	100%	0%	0%	3.00
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	0%	50%	0%	50%	0%	3.00
Elevator	0%	25%	50%	25%	0%	3.00
Equipment and furnishes (chattels)	0%	25%	50%	25%	0%	3.00
Integrated communication (cabling for phone and data)	0%	25%	50%	25%	0%	3.00
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	0%	25%	50%	25%	0%	3.00
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	0%	25%	50%	25%	0%	3.00
Other equipment (telephony, nurse call, visual and auditory, etc.)	0%	25%	50%	25%	0%	3.00
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	0%	25%	50%	25%	0%	3.00
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	0%	25%	50%	25%	0%	3.00
Project owner's administration including user equipment (insurance and fees etc.)	0%	50%	0%	50%	0%	3.00
Reserves	0%	25%	50%	25%	0%	3.00
Transportation of personnel and goods	0%	25%	50%	25%	0%	3.00
Waste and vacuuming	0%	25%	50%	25%	0%	3.00
Contractor's administration costs	0%	25%	75%	0%	0%	2.75
Park and garden construction	0%	50%	25%	25%	0%	2.75
Operation of construction site	0%	50%	50%	0%	0%	2.50
Other costs (copying, travels, communication, art, electricity etc.)	0%	75%	0%	25%	0%	2.50
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	0%	75%	0%	25%	0%	2.50
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	0%	75%	0%	25%	0%	2.50
AGV (Automated Guided Vehicle)	50%	0%	25%	25%	0%	2.25
VAT	50%	25%	0%	25%	0%	2.00

Factors	Owner	Consultant	Contractor	Government
Preparation of construction site (such as building offices, temporary construction works, setting up cranes etc.)	50.00%	0.00%	100.00%	25.00%
Operation of construction site	25.00%	0.00%	100.00%	0.00%
Contractor's administration costs	50.00%	0.00%	75.00%	0.00%
Foundation and base (excavation, laying foundation)	25.00%	100.00%	50.00%	0.00%
Structure and insulation (structure frame, roof, balconies, stairs, canopies etc.)	50.00%	100.00%	25.00%	0.00%
Interior works and fireproofing (fixtures and fittings, finishes, flooring, doors, door frames, glazing windows, partitioning, painting)	75.00%	75.00%	25.00%	0.00%
Walls (interior/exterior)	75.00%	75.00%	25.00%	0.00%
Sanitary installation (including plumbing, ducts, equipment etc.)	50.00%	50.00%	50.00%	25.00%
Heating installation	25.00%	75.00%	50.00%	25.00%
Air conditioning (ventilation)	25.00%	75.00%	50.00%	25.00%
Comfort and process cooling (refrigerator and freezer rooms, cold water circuit for cooling coil)	50.00%	50.00%	50.00%	25.00%
Other HVAC installations (fire suppression system, medical gas equipment, compressed air equipment, etc.)	50.00%	50.00%	50.00%	25.00%
Basic installations for electrical power	25.00%	25.00%	50.00%	25.00%
Low-voltage equipment	50.00%	50.00%	25.00%	0.00%
Illumination (lighting)	75.00%	50.00%	25.00%	0.00%
Other equipment (high voltage, emergency, electrical heating system, reserve etc.)	75.00%	25.00%	25.00%	0.00%
Fire alarm and patient call systems	50.00%	50.00%	25.00%	25.00%
Integrated communication (cabling for phone and data)	50.00%	75.00%	25.00%	0.00%
Automation (switchboards, control centers, control equipment etc.)	50.00%	75.00%	25.00%	0.00%
Other equipment (telephony, nurse call, visual and auditory, etc.)	50.00%	75.00%	25.00%	0.00%
Elevator	50.00%	50.00%	25.00%	25.00%
AGV (Automated Guided Vehicle)	50.00%	50.00%	25.00%	0.00%
Transportation of personnel and goods	50.00%	50.00%	25.00%	0.00%
Waste and vacuuming	50.00%	50.00%	25.00%	25.00%
Other technical installations (pneumatic tube, prefabricated rooms, etc.)	50.00%	50.00%	25.00%	0.00%
Park and garden construction	75.00%	25.00%	25.00%	25.00%
Preparing roads and locations on the site (preparing terrain, surveying, etc.)	75.00%	25.00%	50.00%	25.00%
Construction of road's infrastructure	50.00%	25.00%	75.00%	25.00%
Outdoors' constructions (HVAC, electrical, telecomm. and automation)	75.00%	25.00%	25.00%	0.00%
Design and planning (engineering consultancy, architect, pre-project such as contracting, field testing and laboratory, scheduling)	25.00%	100.00%	25.00%	25.00%
Project owner's administration including user equipment (insurance and fees etc.)	100.00%	25.00%	25.00%	25.00%
Other costs (copying, travels, communication, art, electricity etc.)	100.00%	75.00%	50.00%	0.00%
VAT	25.00%	0.00%	25.00%	75.00%
Equipment and furnishes (chattels)	100.00%	25.00%	25.00%	0.00%
Reserves	100.00%	25.00%	75.00%	0.00%
Land-related costs and aesthetic decoration	100.00%	25.00%	25.00%	25.00%
Cost contingency (uncertainty analysis, fixed etc.)	75.00%	25.00%	100.00%	0.00%
Gross floor area	50.00%	100.00%	25.00%	0.00%
Wall area (interior/exterior)	25.00%	100.00%	25.00%	0.00%
Number of stories	75.00%	100.00%	25.00%	25.00%
Number of parking spaces	50.00%	50.00%	25.00%	25.00%
Number of bed spaces	75.00%	50.00%	25.00%	0.00%

This page intentionally left blank.

APPENDIX F: RESEARCH ARTICLE

Creative Construction Conference 2017, CCC 2017, 19-22 June 2017, Primosten, Croatia

Cost Estimation Methods for Transport Infrastructure: A Systematic Literature Review

Moein Barakchi[a*], Olav Torp[a], Alemu Moges Belay[a]

[a]*Norwegian University of Science and Technology, Department of Civil and Environmental Engineering, Høgskoleringen 7A, N-7491 Trondheim, Norway*

Abstract

Nowadays, large amount of money is invested on infrastructure projects within transport section. This attracts policy and decision makers a lot. Especially, project cost is one of the most discussed factors. This paper's goal is to investigate different types of cost estimation methods used in transport projects, identify their attributes that make them unique to specific infrastructure, and finally study their applications on transport infrastructure. In addition, the research looked to see if there is trend change on using cost estimation methods over time and checked the applications of methods in each transport infrastructure. The study used a systematic literature review (date cube creation, data filtering using primary and secondary search clusters, content analysis, etc.) to include as many estimation methods as possible. To find the trend, the study carried out a quantitative data analysis to investigate the frequency of each method over time in different modes of transport infrastructure. As a result, the research identified about 12 cost estimation methods and discusses them with three major cost estimation attributes i.e. accuracy, usability/application and easiness to understand. The quantitative analysis showed that parametric, Artificial Neural Networks and unit cost methods are the most used methods across the transport infrastructure. In addition, road infrastructure projects received the highest diversity and frequency of the cost estimation methods.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2017.

Keywords: Construction; Cost estimation, Geographical location, Infrastructure, Transport.

1. Introduction

Transport infrastructure plays a fundamental role in the economy of each country since it has the ability to enhance growth and social welfare [1]. A routine project evaluation includes cost estimation as an instrument for investment choice [2]. Moreover, considering the substantial building costs of transport infrastructures and their impacts, it is very important that decision makers are provided with reliable estimations of final costs [3].

Considering the importance and the long history of cost estimation, one would assume that it has achieved a level ensuring a relatively smooth and clear procedure. Yet studies have showed that cost overruns happen everywhere, all the time and within all major transport infrastructure projects such as roads, railways, bridges etc. [4-8]. Therefore, a number of researches was performed to find the factors affecting cost estimation. Also, different variables have been put forward such as strategic behavior, project complexity level, lack of adequate information, project size [6, 9-13].

Furthermore, there were studies indicating cost estimation methods as a major cause of cost overrun [8, 11, 14-20]. Therefore, there is a need to learn about the cost estimation methods in depth and see how diverse they are. It is also important to study the methods' attributes that separate them and make them stronger or weaker to be used in a specific transport infrastructure.

However, studying cost estimation methods is not new. There were a number of papers which have done such study, namely [2, 18, 21], but what separates this study from past studies is that the scope here is broader. For instance, all of the aforementioned researches were limited to one specific transport mode. In this study, we considered all modes of transport although the sea construction infrastructure did not show up any results.

The rigorous literature review on cost estimation methods led to defining the research question as the following: what are the cost estimation methods used in transport infrastructure construction? Why are there different

[*] Corresponding author. Tel.: +4794115587
E-mail address: moeinb@stud.ntnu.no; barakchi.moein@gmail.com

estimation methods? What are the estimation methods used in each transport mode? What is the trend in application of different cost estimation methods? Furthermore, after finding cost estimation methods which have been used the most, a deeper comparison among them is also presented.

2. Methodology

To address the questions posed in the previous section, a systematic literature review method was used. The literature review would reveal the history behind the topic, reflect the attempts that has been taken so far, and pinpoint the potential areas for future studies [22].

This study employed two scientific databases, namely Scopus and Web of Science (final search performed on 12.12.2016). The searching procedure considered title, abstract, keywords, concluding remarks, and the content of the search results.

2.1. Data selection process

This section is divided into three steps: establishing search clusters, topical data screening, and content screening:

I. Search clusters: In order to attain relevant results, the search terms were divided into two clusters: primary and secondary. The primary search terms were cost, estimation, and infrastructure; such terms were present in every search. The secondary cluster consists of the terms unit cost, parametric, judgment, capacity, America, Europe, Asia, Australia; only one of these terms was available in every search. For Web of Science, the aforementioned search terms were searched by “title and topic” with cost in the title. For Scopus, the same search clusters were used with “TITLE-ABS-KEY” category.

Moreover, another set of search terms was devised to give the holistic view of cost estimation within specific transport modes. To elaborate, the term “cost estimation” was used in combination with secondary terms of tunnel, rail, and road in both Scopus and Web of Science. The total number of hits added up to 564 from which 36 passed all the filters and were considered relevant.

II. Topical data screening: The hits were filtered based on their title, abstract and keywords first. If deemed irrelevant, such hits were not considered for further investigation.

III. Content screening: As for the final step, the whole document was obtained and examined to see if the content was relevant. Any search result which passes this step is included in the study. Needless to say, non-academic publications such as meeting results, news, book reviews are not considered for this study.

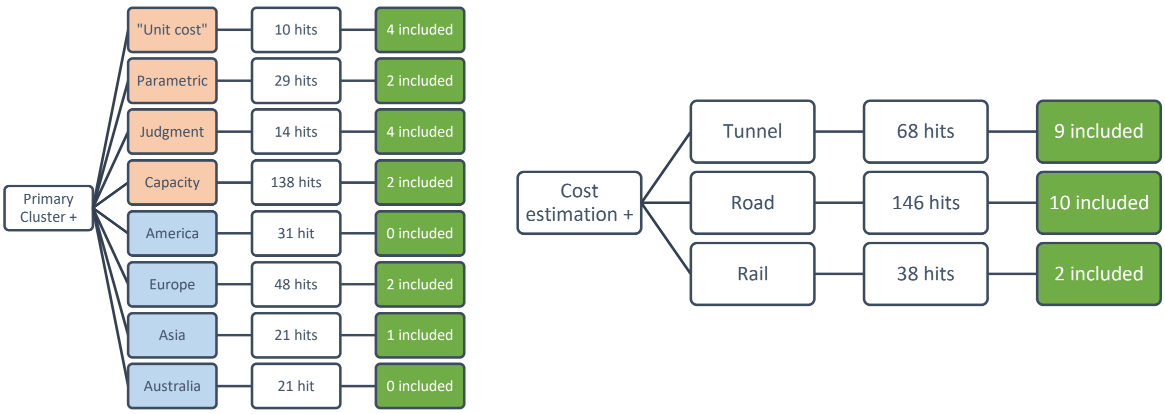


Figure 1. Combination of search terms in both Scopus and Web of Science

3. Results and discussion

By going through the content of every selected hit from methodology, the results were categorised into 13 different thematic categories based on the approaches they had taken regarding cost estimation methods.

3.1. What are the cost estimation methods used in transport infrastructure?

By investigating each method’s frequency, we can see which method has been used most in the literature and which method has been overlooked. Figure shows the methods' frequency in the relevant literature:

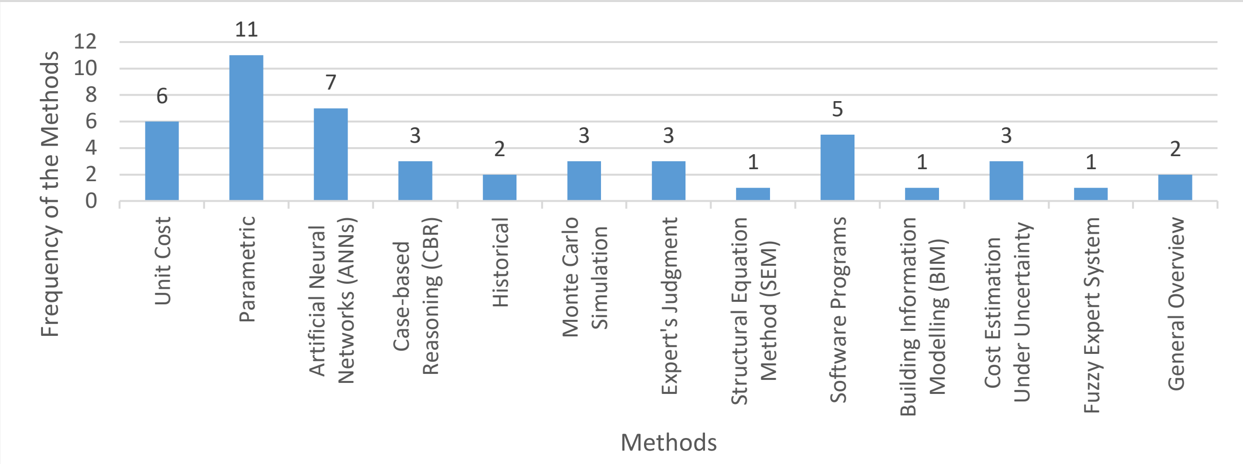


Figure 2. Cost estimation methods' frequency

It is clear that some methods have been used more than the others throughout the literature. As seen in Figure , parametric method has the highest frequency among the articles, which is in accordance with what [23] has claimed. In this context, parametric methods are defined as those using regression analysis on historical data in order to predict the costs. ANNs and Unit cost are the next two most-used methods; their properties, which are going to be explained in section 3.5, may play an important role here. Here, ANNs are models comprised of three layers: input, hidden and output; the model imitates the function of human brain by learning from previous experiences. Unit cost method is defined as an approach in which the volume of the work is calculated and then multiplied by the unit cost of the work.

Figure shows that much emphasis has been put on the aforementioned three methods and other methods have not been receiving the same amount of attention. Especially BIM, Fuzzy Expert System, and SEMs have the potential be investigated more. BIM is a digital depiction of physical and functional aspects of a facility by establishing a common knowledge platform [24]. In this regard, the Government Construction Strategy in UK has selected a 3D collaborative BIM as a must to win public projects above £ 5 million [25]. Therefore, this study believes that there is a lot of potential in BIM and the industry would use this method increasingly in the upcoming years. As a result, more studies in the BIM area is needed. Regarding other methods, Fuzzy Expert System utilizes the fuzzy logic concept which deals with approximate description of events [26]. Finally, SEM is a model which encompasses factor analysis, Multiple Regression Analysis (MRA) and path analysis [17]. The reason behind this lack of research could be due to the fact that the aforementioned approaches are relatively new and it takes some time for majority of the researchers to get acquainted with them. In the next section, we are going to explain different properties that have differentiated the cost estimation methods.

3.2. Why are there different cost estimation methods?

In order to explain why there are different methods, [27] has put forward an explanation. According to the study, a desirable method is a "good" and "simple" method. A good method means that it is accurate, transparent, objective etc. Similarly, a simple method means that it is easily understood, quick, inexpensive, practical etc. This creates a paradox between a good method and a simple method's characteristics. In other words, a precise cost estimation method may not be understandable by decision makers or may need expensive data collection procedures. In this context, variations of the methods could be interpreted as different attempts at achieving a method with acceptable characteristics. After investigating the literature, three main attributes were found which made a method more/less attractive in the eyes of the researchers:

I. Accuracy: Accuracy has been mentioned in different papers as either a strength or a weakness of an approach. Accuracy here is defined as the degree to which the actual costs are conforming to the estimated costs [28]. To elaborate, deterministic methods, such as unit pricing, has led to considerable cost underestimation or they lack in reflecting the risk associated with some infrastructure projects [15, 18]. Regarding ANNs, some studies have stated that they outperform regression models and CBR method when it comes to the accuracy [11, 17, 29, 30]. Only one study was found which compared SEM with ANN models and indicated the former's superiority [17]. However, one study may not be sufficient to prove this statement and more work should be done in this regard.

II. Usability/application: Another issue concerning the cost estimation methods is their usability; how easy they are to use? What are their weaknesses when it comes to application? To elaborate, with respect to deterministic methods, they are unable to cope with large amounts of data. Furthermore, deterministic methods become complicated if uncertainty is to be included in them [15]. On the other hand, it easy to calculate deterministic methods; the result is definite and they are cost effective [2]. In addition, analogues method is relatively cheap and quick or capacity-factored is a fast method to determine if a project should move to next phase [18]. Probabilistic methods on the other hand, need advanced users and data with enough quality and quantity [31].

Literature also pointed out issues which restrict other methods' usability. For instance, methods which are very dependent upon historical data are not suitable for the large projects because there are limited number of them [32]. Regarding the sensitivity analysis, the disadvantages are specifying the degree of variation subjectively and lack of probability estimation for costs being higher or lower [16].

III. Easiness to understand: Since cost estimation is used in decision making process, it should be understandable by someone other than the estimator. In this regard, estimators would rather use regression models than analytical tools such as neural networks due to the fact that the regression models are completely established and easy to describe and understand [17, 29, 33]. On the other hand, neural networks are "like black box" and have an opaque quality which makes it difficult to explain the final outcomes [11, 33, 34]. The literature indicated several methods popular in this area, among which are CBR, analogous, and SEM [11, 17, 18].

3.3. What are cost estimation methods used in each transport mode?

In this section, methods found in the literature were categorized based on the transport mode they were applied to. The result is illustrated in Figure 3.

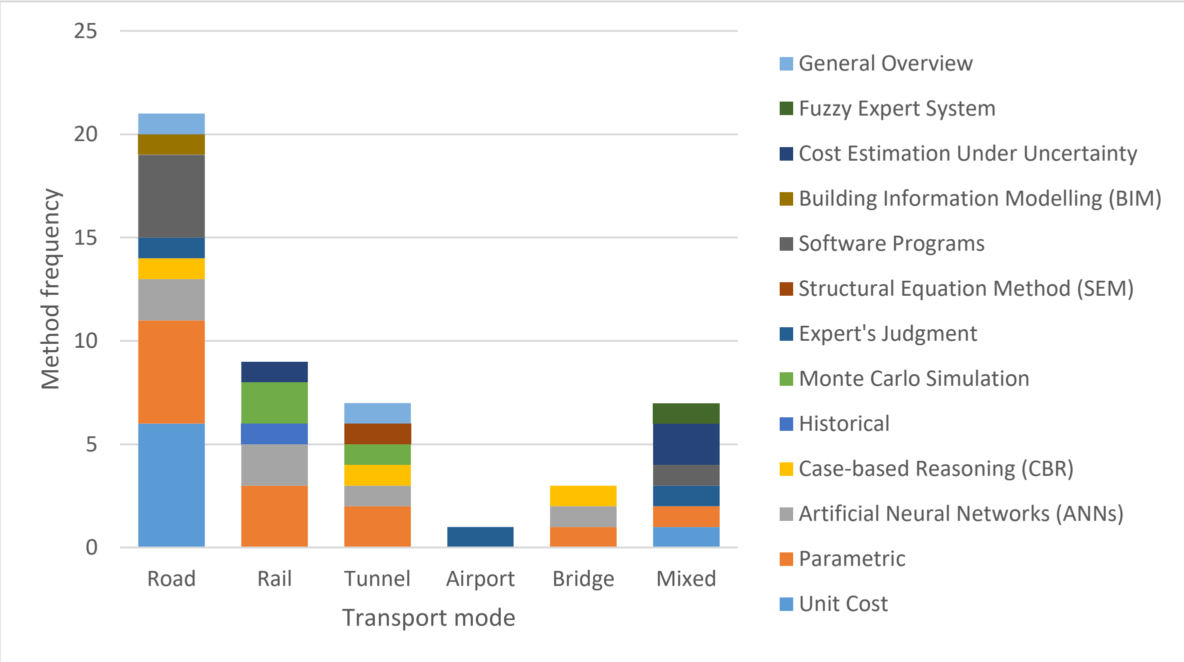
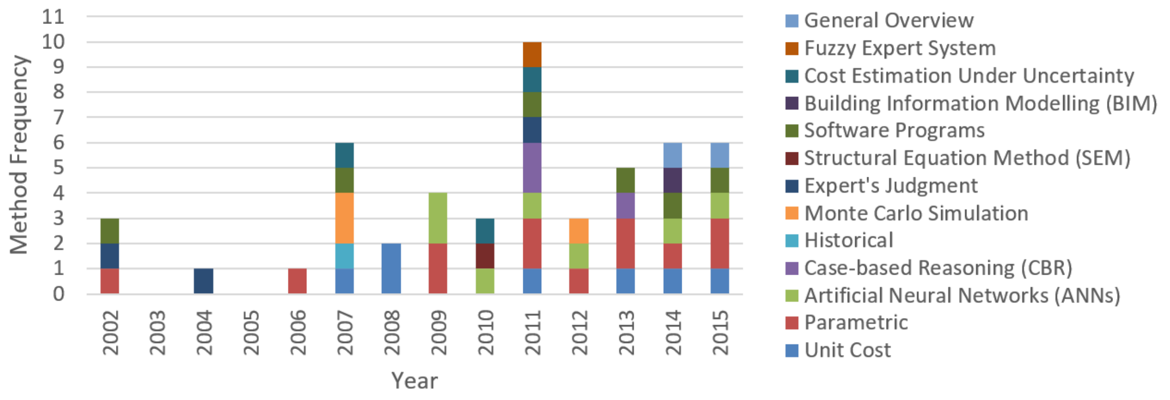


Figure 3. Cost estimation methods by each transport mode

Figure 3. depicts the methods used in each transport infrastructure. The mixed category is comprised of studies on transport infrastructure in general or studies on a mixture of other categories. Based on the figure, it is clear that the road sector has been receiving much more attention comparing with other sectors. It may be because of the fact that road projects usually surpass other transport projects in terms of investment [35]. ANNs and parametric methods have been applied to almost all of the infrastructures which shows the wide application range of this method. Therefore, it seems that the opaque quality of ANNs, explained in the previous section, is not considered a deal breaker for researchers. Monte Carlo simulation and software programs were observed in two infrastructure categories. Therefore, future studies could focus on using these methods in other areas. In addition, only one paper was found discussing cost estimation in airport. The reason for the low number of papers on airport may be the scarcity of airport construction comparing with other sorts of transport infrastructure. Nevertheless, the airport field seems like an unexploited area.

3.4. What is the trend in different application of cost estimation methods?

Showing the trend and the changes of cost estimation methods over time would help us see the past, present and predict the future of this issue. Figure depicts the distribution of the methods found in the literature per year plus the number of the unique methods. Furthermore, Figure illustrates the general trend, which indicates that researches are using more methods both in terms of diversity and frequency. The reason could be more and more researchers are getting to know newer methods. For instance, a method such as ANNs is not observed before 2009 but after, it is almost observed each year. On the other hand, it came as a surprise when no relevant article was found for the year 2003 and 2005 or for sea transport infrastructure. However, we do not have valid justification for this issue.



Year	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Number of unique methods	3	0	1	0	1	5	1	2	3	8	3	4	6	5

Figure 4. Cost estimation methods' application over time

3.5. Top three methods' comparison

Based on Figure , the top three methods were selected for further comparison. Since the methods' definitions have already been presented in section 3.2, here their characteristics are discussed. In terms of accuracy, it seems that there is no general consent about parametric method and ANN's performance. In other words, these two methods' accuracies had varied based on case-by-case basis. Regarding unit cost method, apparently its accuracy is not reliable [18]. For instance, its widespread use in Korea had led to large cost deviations [8].

With respect to applicability, using parametric method is claimed to be very common in the feasibility and pre-feasibility phases because of the powerful mathematical aspect, simplicity in application and easiness in obtaining the information needed [36]. For example, in MRA, as an approach used in parametric method, there is the ability to include statistical significance of individual variables and possible mathematical correlations between the variables [20, 23, 33]. However, using MRA for when variables' relationships are nonlinear has been argued [37]. Regarding ANNs, it takes non-parametric regression estimates which allows analysis of complex cases that need examining a lot of parameters in parallel [17]. Another advantage of ANNs compared with parametric method is that there is no need for a specific statistical distribution for input data and the relationships between the variables affecting the costs and costs do not need to be previously identified [33]. Therefore, it could be construed that when relationship between variables are nonlinear ANNs could be good substitutes for linear regression method or MRA. Moreover, ANNs have the ability to handle noisy, inaccurate or corrupted data very well [38]. However, it is difficult and time-consuming to construct ANNs models on the grounds that it requires trial and error process. Moreover, it appears that ANNs require a large pool of data in order to be dependable. Regarding unit cost, it seems this method is applied mostly in combination with other methods for example parametric model. In addition, unit cost is a deterministic method so it is easy to calculate but it is advised to use it with caution when the uncertainty is high and a precise figure is needed at the same time.

With respect to easiness to understand, apparently unit cost, on its own, is the simplest method which produces a definite result. Concerning, it appears that parametric models are easier to understand because of their strong mathematical basis whereas ANNs are difficult to explain and describe. The higher frequency of parametric methods could be due to the same reason.

4. Conclusion

The purpose of this research was to investigate cost estimation methods in transport infrastructure. A systematic literature search found most of the search results by creating search clusters, and step-by-step data filtering. The papers found showed 12 different cost estimation methods have been used in different transport infrastructure modes. Accuracy, usability/application, and easiness to understand were three properties that was derived from the literature; the methods had differences with respect to these properties. Among the methods, parametric method has been used the most followed by Artificial Neural Networks. With respect to infrastructure type, the focus was mostly on roads. Finally, the trend shows that research on cost estimation methods have been increasing over the years and more types of methods are being used. Moreover, most of the research found focused on the experimental use of different methods and not the analysis of the methods practiced in the industry. Future research could focus on the geographic differences between cost estimation practices, main elements affecting the quality of cost estimation, and cost management practices and its relationship to cost estimation in the transport infrastructure construction.

References

1. Sutherland, D., et al., *Infrastructure Investment: Links to Growth and the Role of Public Policies.* OECD Economics Department Working Papers, 2009. **NO.686**.
2. Makovšek, D., *Systematic construction risk, cost estimation mechanism and unit price movements.* Transport Policy, 2014. **35**: p. 135-145.
3. Marinelli, M., et al. *Non-parametric bill-of-quantities estimation of concrete road bridges' superstructure: An artificial neural networks approach*. in *31st Annual Association of Researchers in Construction Management Conference, ARCOM 2015*. 2015. Association of Researchers in Construction Management.
4. Cantarelli, C.C., B. Flyvbjerg, and S.L. Buhl, *Geographical variation in project cost performance: the Netherlands versus worldwide.* Journal of Transport Geography, 2012. **24**: p. 324-331.
5. Flyvbjerg, B., M.K.S. Holm, and S.L. Buhl, *How common and how large are cost overruns in transport infrastructure projects?* Transport Reviews, 2003. **23**(1): p. 71-88.
6. Odeck, J., *Cost overruns in road construction—what are their sizes and determinants?* Transport Policy, 2004. **11**(1): p. 43-53.
7. Cantarelli, C.C., et al., *Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases.* Transport Policy, 2012. **22**: p. 49-56.
8. Lee, J.K., *Cost overrun and cause in Korean social overhead capital projects: Roads, rails, airports, and ports.* Journal of Urban Planning and Development, 2008. **134**(2): p. 59-62.
9. van Wee, B., *Large infrastructure projects: a review of the quality of demand forecasts and cost estimations.* Environment and Planning B-Planning & Design, 2007. **34**(4): p. 611-625.
10. Gkritza, K. and S. Labi, *Estimating Cost Discrepancies in Highway Contracts: Multistep Econometric Approach.* Journal of Construction Engineering and Management-Asce, 2008. **134**(12): p. 953-962.
11. Kim, G.-H., S.-H. An, and K.-I. Kang, *Comparison of construction cost estimating models based on regression analysis, neural networks, and case-based reasoning.* Building and Environment, 2004. **39**(10): p. 1235-1242.
12. Sodikov, J., *Development Level of Analysis for Road Cost Models.* The Baltic Journal of Road and Bridge Engineering, 2006. **1**(3): p. 129-134.
13. Feng, C.M. and S.M. Wang, *The fully economic evluation for transport infrastructure project*, in *Proceedings of the Eastern Asia Society for Transportation Studies, Vol 5*, K. Satoh, Editor. 2005, Eastern Asia Soc Transportat Studies: Tokyo. p. 1778-1791.
14. Shane, J.S., et al., *Construction Project Cost Escalation Factors.* Journal of Management in Engineering, 2009. **25**(4): p. 221-229.
15. Lichtenberg, S., *Successful Control of Major Project Budgets.* Administrative Sciences, 2016. **6**(3): p. 8.
16. Tan, F. and T. Makwasha. *'Best practice' cost estimation in land transport infrastructure projects*. in *33rd Australasian Transport Research Forum, ATRF 2010*. 2010. Canberra, ACT.
17. Petroutsatou, K. and S. Lambropoulos, *Road tunnels construction cost estimation: A structural equation model development and comparison.* Operational Research, 2010. **10**(2): p. 163-173.
18. Membah, J. and E. Asa, *Estimating cost for transportation tunnel projects: a systematic literature review.* International Journal of Construction Management, 2015. **15**(3): p. 196-218.
19. Lim, B., et al., *Drivers of the accuracy of developers' early stage cost estimates in residential construction.* Journal of Financial Management of Property and Construction, 2016. **21**(1): p. 4-20.
20. Mahamid, I., *Conceptual Cost Estimate of Road Construction Projects in Saudi Arabia.* Jordan Journal of Civil Engineering, 2013. **7**(3): p. 285-294.

21. Anderson, S.D., K.R. Molenaar, and C.J. Schexnayder, *Guidance for cost estimation and management for highway projects during planning, programming, and preconstruction*. Vol. 574. 2007: Transportation Research Board.
22. Belay, A.M., et al., *A framework for Organizing a Resilient Cost Benefit Analysis for Construction Projects.* Procedia Engineering, 2016. **145**: p. 1169-1176.
23. Sayadi, A.R., et al., *A Preliminary Cost Estimation for Short Tunnels Construction Using Parametric Method*. Engineering Geology for Society and Territory, Vol 1: Climate Change and Engineering Geology, ed. G. Lollino, et al. 2015, Cham: Springer Int Publishing Ag. 461-465.
24. Eynon, J., *What is BIM?*, in *Construction Manager's BIM Handbook*. 2016, John Wiley & Sons, Ltd. p. 1-5.
25. Ngo, M. *UK construction industrys responses to government construction strategy BIM deadline and applications to civil engineering education*. in *Proceedings of 1st Civil and Environmental Engineering Student Conference*. 2012.
26. Idrus, A., M. Fadhil Nuruddin, and M.A. Rohman, *Development of project cost contingency estimation model using risk analysis and fuzzy expert system.* Expert Systems with Applications, 2011. **38**(3): p. 1501-1508.
27. Klakegg, O.J., O. Torp, and K. Austeng, *Good and simple – a dilemma in analytical processes?* International Journal of Managing Projects in Business, 2010. **3**(3): p. 402-421.
28. Skamris, M. and B. Flyvbjerg, *Accuracy of traffic forecasts and cost estimates on large transportation projects.* Transportation Research Record: Journal of the Transportation Research Board, 1996(1518): p. 65-69.
29. Sodikov, J., *Road Cost Models for Prefeasibility Studies in Developing Countries.* Journal of Infrastructure Systems, 2009. **15**(4): p. 278-289.
30. Kim, B.S., *The Approximate Cost Estimating Model for Railway Bridge Project in the Planning Phase Using CBR Method.* Ksce Journal of Civil Engineering, 2011. **15**(7): p. 1149-1159.
31. Schach, R. and R. Naumann, *Comparison of high-speed transportation systems in special consideration of investment costs.* Transport, 2007. **22**(3): p. 139-147.
32. Swan, D.J., et al., *Estimation of representative capital and maintenance costs for Canadian roads*, in *Transportation Research Record*. 2007. p. 3-11.
33. Cirilovic, J., et al., *Developing Cost Estimation Models for Road Rehabilitation and Reconstruction: Case Study of Projects in Europe and Central Asia.* Journal of Construction Engineering and Management, 2014. **140**(3): p. 8.
34. Petroutsatou, K., et al., *Early Cost Estimating of Road Tunnel Construction Using Neural Networks.* Journal of Construction Engineering and Management-Asce, 2012. **138**(6): p. 679-687.
35. Forum, I.T., *Trends in the Transport Sector 2008*. 2008: OECD Publishing.
36. Fragkakis, N., M. Marinelli, and S. Lambropoulos, *Preliminary cost estimate model for culverts*, in *Creative Construction Conference 2015, Selected Papers*, M. Hajdu and M.J. Skibniewski, Editors. 2015, Elsevier Science Bv: Amsterdam. p. 153-161.
37. Tam, C.M. and C.F. Fang, *Comparative Cost Analysis of Using High-Performance Concrete in Tall Building Construction by Artificial Neural Networks.* Structural Journal, 1999. **96**(6).
38. Kasabov, N.K., *Foundations of neural networks, fuzzy systems, and knowledge engineering*. 1996: Marcel Alencar.