Master's thesis

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

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Metrics development strategy for VDC in Design management

Master's thesis in Civil and Environmental Engineerin
Supervisor: Eilif Hjelseth
July 2019

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Preface

The following master's thesis was written in the spring of 2019, at the Department of Civil and Environmental Engineering at Norwegian University of Science and Technology (NTNU). The thesis concludes the five-year master program with a specialization towards project management within Civil and Environmental Engineering. The introductory work for this thesis was done as part of assignments in the courses TBA4128 - Project Management advanced and TBA4531 - Project Management, Specialization Project Course during the preceding autumn.

The thesis presents the current approach of performance metrics in design management in projects utilizing Building Information Modeling (BIM), challenges with the approach and steps to improve upon it. The method of the thesis consists of a literature study, interviews, and document study.

First and foremost, I would like to thank my supervisor Eilif Hjelseth (Professor in BIM, department of Civil and Environmental Engineering, NTNU) for counseling and giving me the "freedom under responsibility" to pursue the topic.

In addition, I would like to thank Bjørn Andersen (Professor in performance measurement and management, Department of Mechanical and Industrial Engineering, NTNU) and Kai Haakon Kristensen (Senior project manager, Ph.D., Bodø Kommune Utbygings- og eiendomskontoret) for reviewing the proposed models and giving recommendations for future work.

The interviewees need special recognition for taking time off their busy schedules, making this thesis possible. Lastly, I would like to give my warmest gratitude's to Cecilie Haugstvedt for assisting during the final stages of the thesis.

Abstract

Virtual Design and Construction (VDC) has existed as a framework for effective project management for over ten years. It enables a better way to plan and implement projects than traditional project management methods. Although many have experienced significant improvements in several areas using VDC, it turns out that they have problems documenting the same positive results on the bottom line.

Performance metrics is a key element of the VDC framework for evaluating how projects perform. The choice of performance metrics and the quality of the measurement can be one of the reasons why the use of VDC has not had a greater impact on the bottom line. Correct measurement of how projects perform is crucial for planning, executing, controlling, and correcting projects. It is also essential in providing the relevant information needed for decision making. With the increased use of performance metrics, there has been more focus on some of the challenges that it presents. Such as, what are the correct performance metrics and how they work with the fragmented state that characterizes projects in the construction industry.

This thesis aims to identify the current approach to performance metrics in the design process in projects that use building information modeling (BIM), as well as what challenges this presents and what steps can be taken to improve this.

The master thesis consists of literature/document study and interviews. The study of academic and scientific literature forms the theoretical basis for the thesis. It is followed by a document study of VDC certification material from the Center for Integrated Facility Engineering (CIFE) Stanford, VDC course at NTNU and documents shared by those who are interviewed. The nine semi-structured interviews were conducted with key personnel from the consultants and contractors.

The thesis focuses on how performance metrics work together with the control areas in design, quality, time, cost, interdisciplinary collaboration, BIM, and project production management (PPM). The thesis stresses that performance metrics should be used to increase the understanding of the design process and avoid sub-optimization within specific areas.

The thesis identifies thirty-five performance metrics (key performance indicators, KPIs) with corresponding controllable factors. The thesis also shows that project managers and design managers are struggling to keep the performance metrics up to date and the potential of automating the performance metrics. The thesis also finds concrete actions for each of the control areas to improve the management of the design.

The thesis concludes with proposing a framework called "Circle of Alignment for Performance Metrics" (CAPM), with three new conceptual models for the development of performance metrics. The models are intended to work with current VDC practices and the VDC certification program to CIFE Stanford.

CAPM clarifies the process for VDC metric management. The models help participants in VDC projects to gain an increased understanding of what contributes to value creation for the project and facilitates agreement on how this should be measured, as well as how continuous improvement can be documented in a precise and comprehensive manner.

Sammendrag

Virtual Design and Construction (VDC) har eksistert som et rammeverk for effektiv prosjektstyring i over ti år. Det muliggjør en bedre måte å planlegge og gjennomføre prosjekter på enn tradisjonelle prosjektstyringsmetoder. Selv om mange har erfart store forbedringer på flere områder med å bruke VDC, viser det seg at man har problemer med å dokumentere de samme positive resultatene på bunnlinjen.

Målstyring (Metrics) er et sentralt element i VDC-rammeverket for å evaluere hvordan prosjekter presterer. Valg av målstyring og kvaliteten på målingen kan være en av årsakene til at bruken av VDC ikke har gitt større utslag på bunnlinjen. Korrekt måling av hvordan prosjekter presterer er avgjørende for å kunne planlegge, utføre, kontrollere og korrigere prosjekter. Dette er også grunnleggende for å fremskaffe relevant informasjon som trengs for beslutningstaking.

Med økt bruk av målstyring har det blitt mer fokus på noen av utfordringene som følger. Hvilke kriterier og indikatorer er best, og hvordan de fungerer de med den fragmenterte tilstanden som kjennetegner prosjekter i bygg- og anleggsnæringen.

Målet med dette studiet er å identifisere dagens tilnærming til målstyring i prosjekteringsprosessen i prosjekter som benytter bygningsinformasjonsmodellering (BIM), samt hvilke utfordringer dette presenterer og hvilke skritt som kan tas for å forbedre dette.

Masterstudiet er gjennomført som en kombinasjon av litteratur-/dokumentstudie, og intervjuer. Studiet av faglig- og vitenskapelig litteratur danner det teoretiske grunnlaget for avhandlingen. Det er etterfulgt av et dokumentstudie av VDC-sertifiseringsmateriale fra Center for Integrated Facility Engineering (CIFE) Stanford, VDC-kurs ved NTNU og dokumenter delt av de som er intervjuet. De ni semistrukturerte intervjuene ble gjennomført med nøkkelpersonell fra rådgiverne og entreprenører.

Studiet fokuserer på hvordan målstyring virker sammen med kontrollområdene i prosjekteringen, kvalitet, fremdrift, kostnad, samprosjektering, BIM og prosess- og produksjonsledelse. Studiet legger vekt på at målstyring skal bidra til å få frem helheten i prosjekteringsprosessen, og unngå suboptimalisering innen enkelte områder.

Studiet identifiserer trettifem målstyrings-indikatorer (key-performance indicators, KPI-er) med tilhørende kontrollerbare faktorer. Studiet viser også at prosjektledere og prosjekteringsledere sliter med å holde målstyring oppdatert og potensialet med å automatisere målstyring. Studiet finner også konkrete tiltak til hvert av kontrollområdene for å forbedre målstyring av prosjekteringen.

Studiet oppsummer med å foreslå et rammeverk «Circle of Alignment for Performance Metrics» (CAPM), med tre nye konseptuelle modeller for utvikling av målstyring. Modellene er ment å fungere sammen med nåværende VDC praksis og VDC sertifiserings programmet til CIFE Stanford.

CAPM konkretiserer prosessen for VDC målstyringer. Modellene bidrar til at alle som er med i VDC-prosjekter får en økt forståelse for hva som bidrar til verdiskapning for det felles prosjektet og enighet om hvordan dette skal måles, samt hvordan kontinuerlig forbedring kan bli dokumentert på en konkret og helhetlig måte.

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Acronyms and Abbreviations

AEC	Architecture engineering & construction
BIM	Building information modelling
BSc	Balance score card
CBPP	Construction Best Practice Program
CII	Construction Industry Institute
EFQM	Excellence foundation quality model
ICE	Integrated Concurrent Engineering
IMRaD	Introduction, Method, Result and Discussion
LOD	Level of development
LoD	Level of detail
MMI	Model maturity index
NTNU	Norwegian University of Science and Technology
PDCA	Plan-Do-Check-Act
PPM	Project production management
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RFI	Request for information

1 Introduction

The following chapter will explain the background, limitation and scope and the outline of the report.

1.1 Background

To be able to plan and control projects, one needs to know how they perform (Drucker, 2008). This is not only crucial for the cost of the projects but essential information for planning and the quality (Jha and Iyer, 2007). It is also the necessary information needed for decision-making (Andersen and Fagerhaug, 2002, Haymaker and Chachere, 2006).

The use of performance metrics to evaluate outcome has broad academic standing, as seen in (Kaufman, 1988, Neely et al., 1996, Andersen and Fagerhaug, 2002, Spitzer, 2007, Dumas et al., 2013, Fischer et al., 2017). It is not only used to evaluate the outcome of projects but utilized to control the outcomes and to continuously improve the process (Fischer et al., 2017).

With the introduction of BIM and the digitalization of the architecture, engineering & construction (AEC)-industry, current methods of measuring performance in design need to change. Performance measurement systems must be kept up to date with new technological opportunities to stay relevant (Andersen and Fagerhaug, 2002). The efforts of VDC seem to be the most current approach in building design management (Knotten et al., 2015), utilizing both performance metrics and BIM (Kunz and Fischer, 2012).

Even though there is a plethora of published material on the topic of performance metrics and a decent amount of material on performance metrics and VDC in construction (Kunz and Fischer, 2009, Knotten and Svalestuen, 2014, Fischer et al., 2017, Fosse et al., 2017), there is apparently a knowledge gap in the practical use of the performance metrics and VDC in design management. In "A review of performance measurement for successful concurrent construction" (Ahmad et al., 2016) the authors put forth six research questions in need of further development, where four of them are prevalent to be answered.

- Fragmentation of the construction industry
- Confusion over performance measurements
- Most construction Key performance indicators (KPI's) are lagging indicators
- Continues performance measurement during the concurrent process

With the two-hundred industry professionals set to be VDC CIFE certified this coming fall at NTNU (Strand, 2019), and performance metrics being a fundamental part of VDC, having clarification and empirical data of the uses of performance metric in design management is essential.

As a result of this, researching the implementation of performance metrics in design management and how it relates to the use of VDC is important and fascinating, and relatively academically undocumented. The thesis, therefore, aims at answering this through the following research questions.

RQ1: How are performance metrics used in the design process in project utilizing BIM?

RQ2: What challenges are we faced with when trying to use performance metrics in the design process?

RQ3: What steps can be taken to improve the performance metrics?

1.2 Scope and Limitations

The thesis focusses on performance metrics in the design process in projects containing BIM. This is because of the design phase having the highest value realization potential (Samset, 2015), academic papers requesting for an overhaul of current performance metrics in the design phase (Abdirad, 2017, Ahmad et al., 2016), and BIM changing the traditional work-process extensively (Succar, 2010), as well as it enables exploration and optimization of cost, quality and schedule (Fischer et al., 2017).

The timeframe has limited the thesis to nine interviews, document study, and a literature study. The interviews cover design and project managers from the consultants and construction industry and designers with extensive BIM knowledge. With this, it is possible to evaluate the management approach and the designers' interpretation, as the main challenge with performance measurement system is acceptance and understanding from the employees (Andersen and Fagerhaug, 2002).

The introductory work for this thesis was done as part of assignments in the course TBA4128 - Project Management advanced and TBA4531 - Project Management, Specialization Project Course during the preceding autumn. In this aspect, Chapter 3.5 and 3.6 were originally published there.

1.3 Outline of Report

This report follows the structure IMRaD with introduction, method, result, and discussion in accordance with NTNU guidelines (Engebø, 2018, Lohne, 2018). The thesis also contains a theory chapter that provides a theoretical background.

Part 1:

Chapter 1, Introduction

Background information, limitations, and scope and outline of the report.

Chapter 2, Methodology

Break down of methodology used and the reasoning.

Chapter 3, Theoretical background

Theoretical background based on the literature study conducted.

Chapter 4, Results

Results from the interviews and document study structured sequentially from the research questions.

Chapter 5, Discussion

Discussion of the result related to the literature study.

Chapter 6, Conclusion

Conclusion of the main findings and recommendations for future work.

Appendix

List of performance metrics, interview guide, and flowchart of literature study

2 Methodology

This method chapter is written with the intent that the reader may verify the academic process and ensure that a transparent process has been conducted. This chapter goes through the reasoning of the method and its limitations.

2.1 Research Method

The research method is the strategy or process used to solve the research question and arrive at new knowledge (Everett and Furseth, 2012). It is the ideas, instruments, and models used to conduct research (Blumberg et al., 2011).

The formulation of the research questions and time limitations were the main contributors in the choice, an abductive method with high specificity and qualitative method. This chapter concludes with three parts to answer the research questions, interviews, a document study, and a literature review.

Choice of research method

The choice of research method follows the approach of Busch (2013), starting with the research questions. The research questions where created in the early part of the course TBA4128 - Project Management advanced Course. They were chosen to complement each other in accordance with Busch (2013).

Given Busch (2013) method of classifying the research question, RQ1 is a descriptive question, RQ2 is a problem-identifying question, and RQ3 is a problem-solving question. Where RQ1 describes a phenomenon with the intent of understanding a field of study, RQ2 identifying a problem where research is required to solve it, and RQ3 intention is to solve a problem. Analyzing the research questions, it becomes clear that it requires a study of current practices, with extensive knowledge of the field to answer questions two and three.

The analysis of the research questions leads to a choice of abductive method. This is due to their being a limited amount of literature on VDC and metrics in design, requiring new observations. Also, there exists a large amount of established theory in performance metrics and some in design management. With an abductive method, the author can establish broad bases theoretical background conserving Performance metrics and design management and supplements this with specific observations in VDC and metrics in design. Abductive method lets the author move back and forth between theory and empire.

Building on Busch (2013) approach, there are two types of research design, known as high sensitivity and high specificity. In short high sensitivity tries to cast a broad net, where the goal is to obtain a broad spectrum of data, while high specificity looks to go into detail in the few available data sources (PhD On Track, 2018). Since the time will limit the amount of data obtained and the research questions being broad and having a high level of variability, a high specificity approach was chosen. The combination of abductive method and the high specificity approach works well as they enhance each other's strengths and reduces some of the negative aspects of each.

According to Engebø (2018) and the next step in Busch (2013) approach, one will need to evaluate the use of a qualitative or quantitative method. The quantitative method can be viewed as a survey of large numbers of units, where its purpose is to test a hypothesis (Dahlum, 2018a). The qualitative method looks at the characteristics, and it emphasizes understanding and analysis within a process (Dahlum, 2015). Due to the high specificity approach, the width of the research question, different interpretation, and implementation of performance metrics, a qualitative method was chosen. The set choices of abductive method and the high sensitivity approach works well with the qualitative method due to the limited data required. There are problems with conducting a qualitative method, and the most pressing in this case is the limited sample size.

The world of BIM and VDC and its processes and frameworks are still under development (Fosse, 2017, Succar, 2010), how we work with the methods today is not how we will work with them in the future. Performance metrics are under continues and ongoing development, adapting to the change of time and knowledge acquired (Andersen and Fagerhaug, 2002). This leads to the result of the report being a cross-section study, representing a view of the industry at a set point in time.

2.2 Assessing the Quality of the Researcher Design

Inherent of evaluating the quality of research the term validity and reliability are commonly used. Reliability has to do with the precision and accuracy of the measurement procedure (Blumberg et al., 2011). "The goal of reliability is to minimize the errors and biases in a study" (Yin, 2014). The objectivity with ensuring reliability is that if a researcher tries to recreate the result, they should reach the same conclusion.

Validity is the degree that the result of the research is sound in answering the research question (Dahlum, 2018). Yin (2014) distinguishes validity into three categories, constructed validity, internal validity, and external validity.

<u>External validity</u>: Dahlum (2018) defined external validity as the means that the results of the study can be generalized and thus considered to apply to a more substantial amount of data than the study examined.

<u>Internal validity</u>: Dahlum (2018) defined internal validity as the possibility of an experiment, or a study indicates that the findings can be explained through the supposed hypothesis.

<u>Constructed validity</u>: Dahlum (2018) defined constructed validity as to whether a selected indicator measures what the researcher wants to measure. Choosing and identifying the correct operational measures for the study. To increase the constructed validity, the thesis will be view by key informants, as recommended by Yin (2014)

The qualitative method usually has problems ensuring that the data is reliable rather than valid. This is because the qualitative method looks at the meaning and emphasizes understanding within a process, which is based on its perceived validity. To mitigate this, the focus was on acquiring sources specific to the research topic.

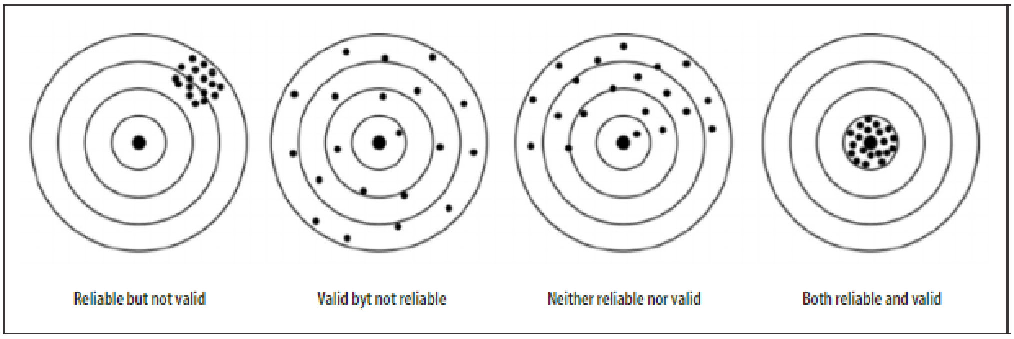


Figure 2.1 Illustration of validity and reliability (Goldbaum, 1996)

2.3 Literature Review

There are few books, and doctoral thesis's written than can be used on the matter of performance metrics in design management in AEC-industry (Fischer et al., 2017, Kalsaas(red.), 2017, Kristensen, 2013). However, there are many in the subject of performance metrics (Andersen and Fagerhaug, 2002, Brown, 1996, Brown, 2007, Neely et al., 2002, Schiemann and Lingle, 1999, Spitzer, 2007) and some in design management (Hughes and Gray, 2007, Emmitt, 2017). The research is primarily found in paper and articles. There is also a need to find the most relevant literature in a research study (Blumberg et al., 2011). Therefore, a business-study was done following the five steps by Blumberg et al. (2011) and recommendations put forward by Phd on track (2019).

Literature review method

The literature search was conducted based on two strategies recommended by Phd on track (2018), known as high sensitivity and high specificity:

- High sensitivity – Obtain as much relevant literature on the topic
- High specificity – To be very precise ensuring high relevance in the literature

These strategies were combined with the two conventional search methods, tracing references, and topic search recommended by Phd on track (2018):

- Tracing references – "to build on the literature you already have, using reference lists and citations in relevant works, going forwards and backward in citation indexes."
- Topic search – "to actively search out relevant literature using bibliographic databases, search engines, library catalogs, and indexes."

The literature study follows two parts, a topic search and tracing references search. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Prisma) flow diagram is used to illustrate the workflow from initial search to final inclusions (Moher et al., 2009), see attachment 1. The most relevant were summarized and evaluated using a matrix called TONE-criteria's (innsida.ntnu.no, 2018).

The search strategy was documented, where an overview can be found in attachment 2. The databases used were Scopus, Web of Sciences, Oria, and Google scholar. The databases were chosen as they are used in renowned literature reviews in the subject area of performance metrics and design management, as in Knotten et al. (2015) and Ahmad et al. (2016).

One of the challenges with this literature review is the validity of the literature connected to performance metrics for organizations and other industries being applicable for construction projects. The author view that their general principles apply, as so is the consensus seen in Ahmad et al. (2016) and Kristensen (20013).

Topic search

The main search method used the five steps by Blumberg et al. (2011) and the framework developed by PhD on track (2018). This was then adapted for this specific literature search through recommendations from a literature search course with Lohne (2018) and tips from Innsida.ntnu.no (2018). The main literature search process in detail is as follows.

1) Searches with Boolean operators and different keywords related to the research questions: "Design", "BIM", "Key performance indicators (KPI)", "Metrics", "VDC", "Design management", "Performance measures" in search engines Scopus, Google Scholar, Oria and Web of Science. Going from high sensitivity to high specificity specific searches.

2) The inclusion of the articles was determined by the relevance of the title, keywords, abstract in the given sequence. The articles that were deemed relevant were added to the program EndNote.

3) The Endnote library was then screen using the approach of Taticchi et al. (2010), which uses citation/co-citation analysis of performance metrics. The publication relevant to current AEC practices were selected.

4) The articles were read in the order of most relevant to least based on its publisher. The order was as follows scientific journal, conference articles, master's thesis, and public reports (Lohne, 2018).

5) Articles that were deemed most relevant were summarised and evaluated using a matrix called TONE-criteria' s (innsida.ntnu.no, 2018). These articles were included in the tracing references search.

Tracing references search

From the literature acquired from the topic search, a tracing reference process was conducted. The literature review of Knotten et al. (2015) and Ahmad et al. (2016) were two of the articles that underwent the tracing references search.

1) The citations of the most relevant articles were analyzed going forward, searching for the stated of the art papers on the subject.
2) The reference lists in the article that was most relevant from the Topic search where analyzed, going backward in the references.
3) The results were evaluated from step 2 in Topic search prosses.

The literature search resulted in a total of twenty-six documents. Twenty-two of them were thoroughly examined, and their validity and reliability evaluated using the matrix called TONE-criteria's. The literature study was an ongoing process throughout the entirety of the thesis. The first draft was delivered as part of the subject TBA4531 - Project Management, Specialization Project in October of 2018. It has been revisited as part of the master thesis with a focus on finding new "state of the art" literature. The revised searches will also become more specific with more precise Boolean operators adapted from "failed" results from previous searches-

2.4 Interviews

Qualitative research interviews attempt to see the word from the view of the subject, unfolding the meaning of their experience (Kvale and Brinkmann, 2009). The interviews were semi-structured, meaning that they followed an interview guide, which the interviewer could deviate from if necessary (Blumberg et al., 2011). They follow the seven stages of an interview investigation put forward by Kvale and Brinkmann (2009). The interview guide can be found in attachment 3.

Interviews method

A total of nine semi-structured interviews was conducted, with five design/project managers and four BIM technicians/ designers. The interviewees are employed at leading consultant organizations and contractors, working on different building and infrastructure projects. They are considered key individuals (Yin, 2014). BIM coordinators and designers were interviewed, as they have a different perspective, which is needed to get a holistic view of the project (Kaplan and Norton, 2007). They are also a critical part of the development of performance measurement systems, as the people doing the work (Fischer et al., 2017). The questions follow the two question levels of Yin (2014): Level 2, satisfying the need of your line of inquiry and level 1, putting forth "friendly" and "nonthreatening" questions to "open up" the interviewees.

The interview was set to last an hour, defined as being short interviews (Yin, 2014). The interviews were recorded, transcribed, and analyzed in accordance with Kvale and Brinkmann (2009) recommendations and guidelines. All interviews were face to face except one.

The interviews were fully anonymized, meaning that name, project, and organization were redacted. This is due to the nature of the performance metrics as they may present sensitive or confidential information (Andersen and Fagerhaug, 2002). This can be considered to be more prominent in the AEC industry, due to it still being litigious, claims oriented, and siloed (Fischer et al., 2017). The sensitive nature also resulted in the need for face to face interviews, as the interviewer needs to pick up on non-vocal responses. It also has the advantage that information presented is not cherry-picked, as the interviewees may want to present the organization in the best possible way. These steps increase the validity of the interview research method.

To ensure some reliability, the interview where transcribed. However, the interview research method has low reliability on its own, and unfortunately, the confidentiality aspect lowers this further. There is an intrinsic conflict between confidentiality and the basic principles of inter-subjective control and repeating of the study (Kvale and Brinkmann, 2009). The author views the validity of the interview research method as more precedence than reliability.

Kvale and Brinkmann (2009) point out that one needs to “Interview as many as necessary to find out what you need to know,” which is hard to determine. The number of interviewees is within the range of 15 +/- 10 in common interview studies (Kvale and Brinkmann, 2009). To summarize the interview research method, it has high validity, but consequently low reliability.

Since the interviews were fully anonymized, identifiers have been removed. This means that systems or methods that are specific to that organization are replaced with generic terms.

Tabell 2.1: Information of interviewees

Role	Organization	Experience(years)
VDC Manager	Consultant	15 +
Design/project manager	Consultant	15 +
Project manager	Consultant	10 +
BIM coordinator	Consultant	5 +
BIM coordinator	Consultant	10 +
BIM consultant	Consultant	5 +
Structural engineer	Consultant	5 +
Project manager	Contractor	10 +
Project manager	Contractor	10 +

2.5 Document Study

A document study is a process of collecting, processing, and interpretation of secondary data (Jacobsen, 2005). Secondary data are classified as information collected by others and prepared for purposes other than the current issue (Engebø, 2018). A document study of VDC certifications material from CIFE Stanford, VDC course at NTNU and documents shared by the interviewees was conducted.

Document study method

The first step in a document study is to determent the relevance of the data to the research questions, and this was done by determining the authenticity, credibility, accuracy, and representativeness of the selected documents (Bowen, 2009). In this study, the TONE-criteria's where used to evaluate the documents.

The document study was done in two stages, before and after the interviews. The first study was done to acquire a holistic view of the field. There were three main steps in the first document study.

1. To ensure that the interview questions are specific.
2. To find what information is assessable and which is not.
3. Ensure that enough information is acquired to ask the right questions.

The second document study was done after the interview. The goal here is to use the acquired information from the interview to increase the specificity of the study. The three steps here are:

1. Analyzed the newly acquired information in connection to the previous first document study,
2. Fix any errors from the previous study.
3. Increase the specificity of the review bases on the enquired information from the interview.

Document studies are mostly used as a complement to other studies (Bowen, 2009), making them ideal to complement the literature study and interviews. The validity of the document can be deemed as high as the document has been created by Martin Fisher and his team, reducing the errors.

3 Theoretical Background

In the following chapter the theoretical background from the literature study will be presented.

3.1 Fundametals of Performance Measurment Systems

A performance measurement system should have a holistic view, using different measurement and different perspectives (Kaplan and Norton, 2007), and is ever-changing, by adapting to internal and external information and evaluating business management processes (Bititci et al., 1997). It enables decision-making processes by accessing the data that allows us to answer questions (Neely et al., 2002). Haponava and Al-Jibouri (2012) develop a proposed system for process performance measurement system based on a series of questions regarding quality and completeness. They also found several previous attempts in developing process performance measurement systems for the construction industry (as (Kueng, 2000, Alarcon and Ashley, 1996, Kagioglou et al., 2001))

Clarification: There is inconsistency in the terminology used when describing performance measures and systems (Dumas et al., 2013, Fischer et al., 2017). Therefore, performance measures, (performance) metrics and (key) performance indicators are treated as synonyms. Fischer et al (2017) defined all metrics as "performance" metrics, and categories them after performance objectives. For these reasons and consistency, performance metrics is used as a general term for this thesis.

However, when citing works in this chapter, the authors' terminology preference is kept, out of respect for their work and due to some authors lack of consistency and definitions in their work.

Organizational Performance measurements

The organizational performance measurement system looks at providing a holistic view of an organization by considering different performance perspectives (Van Looy and Shafagatova, 2016). The most used organizational performance measurement model is the Balance Scorecard (BSc) by Kaplan and Norton (2001) (Taticchi et al., 2010, Van Looy and Shafagatova, 2016). It looks at translating the organizational strategy through objectives with targets into performance measures indicators with four perspectives, financial, customer, internal business perspective, and learning and growth (Kaplan and Norton, 2001). Many other organizational performance measurements system looks at similar perspectives (Van Looy and Shafagatova, 2016). Another approach that is widely used is business excellent models, where their focus lies in self-assessment rather than strategic alignment (Van Looy and Shafagatova, 2016). One of the better known is Excellence Foundation Quality Model (EFQM), which looks at the enablers of the processes and their results (Taticchi et al., 2010). Both BSc and EFQM have been adjusted and used by the construction industry (Haponava and Al-Jibouri, 2012).

Business process performance measurements

Performance measurement systems can focus on single business processes, as statistical process control, traditional control, workflow-based monitoring, or process performance measures (Van Looy and Shafagatova, 2016). Dumas et al. (2013) use four perspectives in business process performance measurement, time, cost quality and flexibility, and the need to define performance measures or indicators for each perspective. Kueng (2000) has a more holistic approach, looking at five views: financial, customer, employee, societal, and innovation.

Kagioglou et al. (2001) consider projects as business processes, as a project can be viewed as a sequence of tasks in a similar way that processes can be seen as a sequence of activities. From this consideration, they determined that practices that initially belonged to standard business process performance measurements can be extended to project management.

Project performance measurements

A project performance management system is the set of metrics/performance measures used to quantify the efficiency and effectiveness of actions (Neely et al., 1996). Effectiveness refers to the extent to which the customer requirement is met, while efficiency is the measurement of the organization/project use of resources when providing the service to the customer (Neely et al., 1996). In the construction industry efficiency is more specifically viewed as strong management and internal structures (Adhere to schedule, budget and specification) while effectiveness refers to user satisfaction and use of the project (Takim and Akintoye, 2002). The need for both efficiency and effectiveness in projects is further emphasized in the work of (Ogunlana, 2008), as a project may seem successful from the client perspective but be an unsuccessful venture for the contractor.

The effectiveness achieved in a project is the degree to which the managers of the project make use of method and techniques in which to improve the efficiency of the project execution (Swink et al., 2006).

Traditional project performance is viewed as the ability to accomplish the project on time and within budget (Pillai et al., 2002). Managing a project involves the use of different kinds of performance indicators to make decisions, like the time and cost progress of each task (Kagioglou et al., 2001).

More recent is the use of the benchmarking program Construction Industry Institute (CII) with performance indicators, latest being 10-10 with ten leading indicator and ten lagging indicators.

Performance indicators, metrics and performance measures

Performance measures are designed to help people track whether they are moving in their desired direction (Neely et al., 2002). Performance measures are the metrics used to quantify the efficiency and/or effectiveness of actions (Neely et al., 1996). Kaufman (1988) view performance indicators as evidence to prove that a planned effort achieved the desired outcome. It has two uses – identifying what should be accomplished and providing criteria for success or failure. Pillai et al. (2002) stated the importance of performance measures to ensures project success in terms of both efficiency and effectiveness.

Neely et al. (1996) definitions:

> Performance measurement: the process of quantifying the efficiency and effectiveness of action
> Performance measure: a metric used to quantify the efficiency and/or effectiveness of action
> Performance measurement system: the set of metrics used to quantify the efficiency and effectiveness of actions

Tabell 3.1: Criteria of testing metrics (Schiemann and Lingle, 1999), redrawn from Kristensen(2013)

Criteria of testing	**Considerations**
Validity	Does the measure really measure the intended concept?
Reliability	Does the measurer exhibit a minimum amount of noise or error, changing only when the underlying concept of interest changes?
Responsiveness of change	Does the value of the measurement change quickly when the underlying concept changes?
Ease of understanding	Can the measurer be easily explained and understood?
Economy of data collection	How much additional cost will be required to calculate this measure on quarterly basis?
Balance	Are the measures formed as a group balanced along important dimensions? (E.g. result vs drivers? Short vs long term, across multiple stakeholders?)

Key performance indicators

Key performance indicators enable measurement of project and organization, where they focus on critical aspects of outcomes (Chan and Chan, 2004). KPIs are based on the concept of benchmarking used in business process and production and are used in the construction industry to benchmark projects or companies processes to identify areas for improvement (Haponava and Al-Jibouri, 2012). Their usefulness has been questioned as they do not give insight into how to improve performance (Bassioni et al., 2004). The construction industry has started the change going from lagging KPIs to leading indicators KPIs, as seen in the development from CII-BM&M to CII 10-10 benchmarking programs.

Tabell 3.2: Examples of KPI's

Metric	Target
PPC	% of task to be completed by planned date
RFI's	% of Request for information (RFI's) shall be answered without the need for revision or resubmittal.
Participation	% Participation in meetings
Submittals	% of Submittals shall be reviewed without the need for resubmittal.
PCI	Potential change impacts (PCIs) shall be approved within XX days from start of pricing.

Benchmarking

Benchmarking is the systematic process of measuring one's performance against industry leaders to determine best practice (Hudson, 1997). The construction industry has three primary benchmarking programs, Construction Best Practice Program (CBPP) KPIs, CII-BM&M, and CII 10-10(Ahmad et al., 2016). Measurements themselves are relative, as they need to be compared with reference values in order to be valid (Atkinson et al., 1997). Benchmarking is building on the need to have a set of industry standards to reference on performance. Benchmarking in itself may offer very little indication of the performance of the organization, as they are too project-specific, apart from maybe the customer perspective (Lam et al., 2007).

Thresholds and targets

Control limits (i.e., thresholds) are the limit in which if surpassed, action must be initiated (Andersen and Fagerhaug, 2002). Targets are the agreed-upon target value for the performance indicator (Andersen and Fagerhaug, 2002). Some recommend targets should be defined as a part of negotiations (Schneiderman, 1999), others say they should be based on analysis and research (Brown, 2007).

Leading and lagging metrics

Diagnostic measure (i.e., leading indicator/drivers) predicts future events while result measures (i.e., lagging indicator) measures past performance (Andersen and Fagerhaug, 2002). Leading indicators deal with the issues that will eventually impact the lagging indicators, providing information before the issues have had time to affect the results (Kagioglou et al., 2001).

Qualitative and quantitative measures

Hard measures (i.e., quantitative measures) are pure fact-based and can be measured directly while soft measures (i.e., qualitative measures) are intangible and must be measured indirectly (Andersen and Fagerhaug, 2002). An example of a qualitative measure is the "Diamond of User Emotion" by Ph.D. BJ Foog at Standford persuasive Technology Lab, which assesses the cooperation of project participants and development (Hjelseth, 2017). In the performance measurement system, both qualitative and quantitative metrics is needed for a complete picture (Andersen and Fagerhaug, 2002).

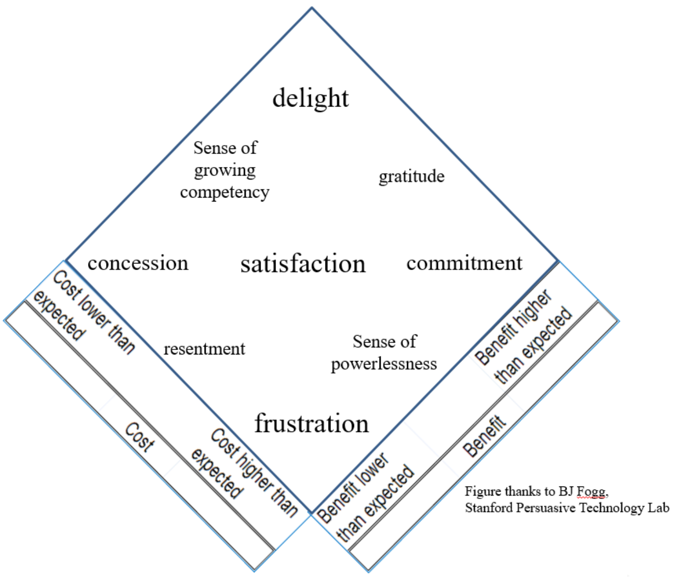


Figure 3.1: Diamond of User Emotion(Hjelseth, 2017), original author BJ Fogg

3.2 Control

Control is a verb, and choosing and making the measurement is the first step towards control (Fischer et al., 2017). To control is to direct the project to the desired outcome, where control deals with expectations and the future (Drucker, 2008). Controls deals with the facts and the events of the past (Drucker, 2008). Project controls are the measurement and analysis that allow us to apply the correct control to manage the project (Fischer et al., 2017).

Fischer et al. (2017) use Deming's "Plan-Do-Check-Act" (PDCA) circle for continuous improvement to illustrate the relationship between project controls and controls. Where planning involves assessing the current state (project controls), doing involves applying control, studying involves using project controls to determine if the control change the outcome and acting is applying control successfully to the project (Fischer et al., 2017).

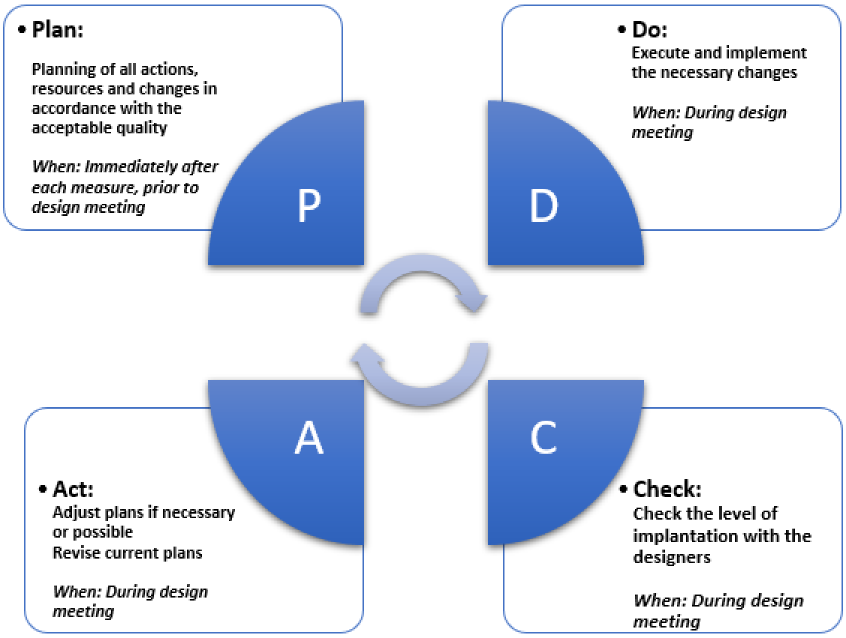


Figure 3.2: PDCA for design management, redrawn by author (Kristensen, 2013)

3.3 Design Management

Design management is about managing people and information (Emmitt, 2013), where project management is the act of gaining control of the process in regards to time, cost and quality (Eynon, 2013). Kestle and London (2012) view the design management process as complex's social situation as value is a social construct and decision-making, therefore inherently unpredictable (Kestle and London, 2002). The complexity is further emphasized as the iteration of design in the early phases is necessary for value creation (Ballard, 2000b). The design process can be seen as a continuous reciprocal process and the construction process as a strictly sequential process in traditional terms (Knotten et al., 2015).

There are four processes for design: pooled interdependencies, sequel interdependencies, reciprocal interdependencies, and intensive interdependencies (Knotten et al., 2015). These can accrue in different phases of the design phase or at the same time (Knotten et al., 2015). This can be seen in decision making were going forward with a solution can set of sequential processes, while turning it down starts a reciprocal process (Knotten et al., 2015).

According to Otter and Emmitt (2008), there are two ways of communicating: asynchronous and synchronous. Asynchronous communication is the remote flow of information without a direct aspect of time, like email and drawings (Knotten et al., 2015). Synchronous is the flow of information where the flow is more direct through speech and sight, like meetings (Knotten et al., 2015).

The strategic definition of the overall design process does exist, but a shared understanding and the specific content is not normative (Kristensen, 2013). In this thesis, the overall design process is divided into two, pre-design, and detail design. Where Kristensen (2013) generic process definition (figure 3.3) is merged into two processes, where outline design and scheme design are defined as the pre-design and detail design and design during construction is defined as detail design.

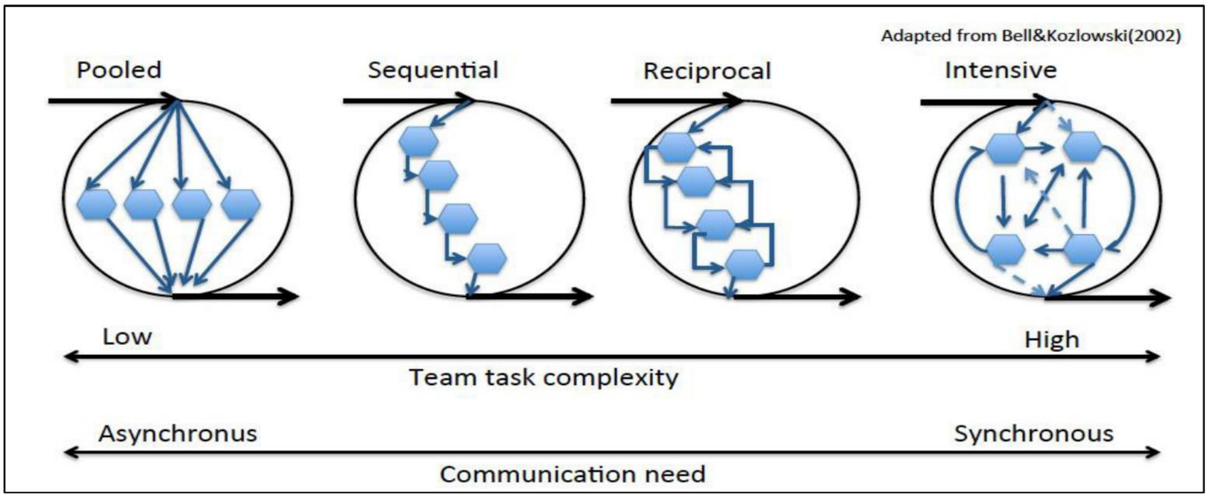


Figure 3.3: Team task complexity (Knotten et al., 2015)

3.4 Performance Measurement System Design, Andersen and Fagerhaug (2002)

Andersen and Fagerhaug (2002) in their book "Performance measures explained" developed an eight-step process for performance measurement system design, development for organizations. The following steps are as follows:

1) Understanding and mapping business structures and processes

Getting the designer of the system to think through and reacquaint themselves with the organization, its competitive position, the environment it exists in and business processes (Andersen and Fagerhaug, 2002). This is done through stakeholder analysis, business process identification, and business process mapping.

2) Developing business performance priorities

Ensuring that the chain of stakeholder's requirements from organizations strategy through its business processes is a consequence of and supports the performance measuring system (Andersen and Fagerhaug, 2002). This is done by quantifying the stakeholder requirements, translating the strategy into strategic performance requirements, and then integrating the different performance requirements.

3) Understanding the current performance measurement system

There are two ways of designing the new performance measurement system, building on the current system, or scrapping the old system (Andersen and Fagerhaug, 2002). To do this, one needs to review the current system and find out if the infrastructure and performance indicators can be incorporated into the new system.

4) Developing performance indicators

Broadly there are two ways of developing performance indicators top-down cascading approach or bottom-up approach. A combined approach is recommended for organizations (Andersen and Fagerhaug, 2002). One way this can be done is by clustering the processes found, form a proficient group for each cluster, train the group in performance metrics, have the group develop performance metrics with one of performance measurement system designers overseeing the process.

5) Deciding how to collect the required data

Finding the solution that collects the necessary data for the final performance indictors (Andersen and Fagerhaug, 2002). The data collection is closely linked to the preceding step of developing performance indicators (Andersen and Fagerhaug, 2002).

6) Designing reporting and performance data presentation formats

Designing how the performance data will be presented to the user; how they present the data for management, monitoring, and improvements (Andersen and Fagerhaug, 2002). It can be seen as the dashboard of a car, choosing what data is needed to steer the organization (Andersen and Fagerhaug, 2002).

7) Testing and adjusting the performance measuring system

The first pass the performance measuring system will not be entirely right. Therefore one will need to test and adjust elements (Andersen and Fagerhaug, 2002). However, it will never be perfect as “A performance measurement system should be construed as a never-ending journey towards perfection” (Andersen and Fagerhaug, 2002)

8) Implementing the performance measurement system

Involves the aspect of training, access management and demonstration of the system, and living by the principles of the system (Andersen and Fagerhaug, 2002)

3.5 Performance Measurement as a Tool for Design Management

Kristensen (2013) developed a generic performance measurement system for building design management as a part of his doctoral thesis. The performance measurement system process had six steps, which are as follows:

1) Process definition and strategy

Establishes the relationship between overall strategy, design phase strategy, the key success factors for the stakeholders, and the various indicators which monitor the key success factors (Kristensen et al., 2013).

2) Stakeholder analysis

Identifying the stakeholders, create a stakeholder map, rank them internally, and from this, determine their critical success factors.

3) Development of key performance indicators

The indicators where developed based on critical success factors. There is a focus on a ratio of 6:1 between non-financial and financial measurers, long-term and short-term measures, soft and hard measurements with a 70 % to 30 % distribution.

4) How and when to collect data

The data is divided into two categories, data to be collected and existing data. Deciding on when to collect data needs to be done in connection with the planning and schedule effort made by the design managers. In the development of indicators, it is essential to that take advantage of existing data, and evaluate the data collection economy (Kristensen, 2013).

5) Presentation format: dashboards

The dashboards use a quality function deployment and a strategy map for the performance indicators. The performance indicators are grouped according to their relevance to each other.

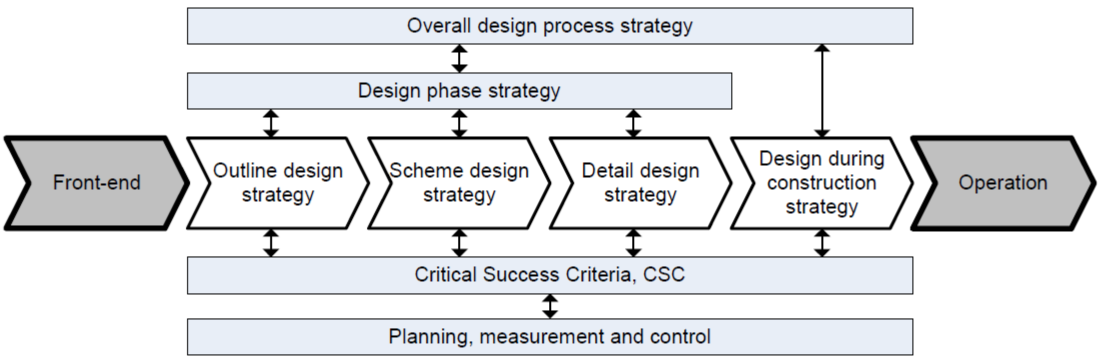


Figure 3.4: The strategic framework (Kristensen et al., 2013)

3.6 Virtual Design and Construction

Virtual Design and Construction (VDC) uses a combination of tools and methods in combination with a set framework. Fisher and Kunz (2012) define it as the "*use of integrated multi-disciplinary performance models of design-construct projects to support explicit and public business objectives"*. It can be view as BIM best practices systemized (Hjelseth, 2017).

Its predecessor was developed in 1996 by NASA JPL as their Integrated Concurrent Engineering (ICE) methodology. It has been significantly developed since then, with Centre for Integrated Facility Engineering (CIFE) at Stanford University leading the way(Hjelseth, 2017).

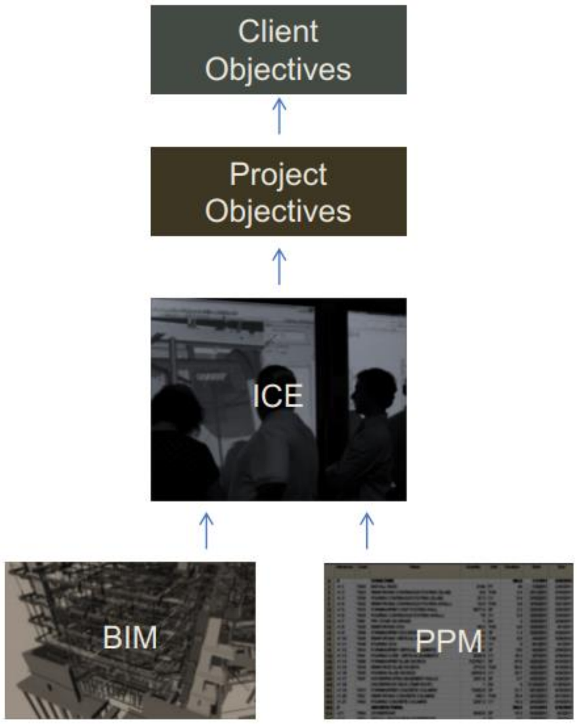


Figure 3.5: VDC Framework (Fischer, 2017)

VDC is about using the correct tools and project prosses, BIM models, and ICE methodology in combination to achieve shorter and more efficient management decisions and minimize the variation. (Hjelseth, 2017, Kunz and Fischer, 2012). VDC is also about the development of the organization and its people, where VDC sets the stage for a good workflow so that people can make the most of their effort. However, having the right tools, prosses, and people do not help if one cannot measure the products of the work and how they measure up against the client objectives. For this VDC uses metrics, which can be read about in the VDC metrics section further down.

In practice, VDC is about comprehensive planning, and implementation of best practice work methodology that optimizes the project work and reduces the resources used, resulting in quality enhancement, increases efficiency and cost savings.

Fisher and Kunz (2012) found that users implement VDC in three distinct phases, where each has its value and cost producing strategies. The three phases were described by Fisher and Kunz (2012) as follows:

> *Visualization and Metrics: In this first phase, project teams create models of the Product in 3D, of the Organization that performs design, construction and operations and the Process followed by organizational participants to do design, construction and operations and management, based on performance metrics that are predicted from models and tracked in the process.*
>
> *Integration (computer based): In this phase, projects develop computer-based automated methods to exchange data among disparate modeling and analysis applications reliably.*
>
> *Automation: In this phase, projects use automated methods to perform routine design tasks or to help build subassemblies in a factory.*

Project production management

PPM tries to optimize time, cost and scope by using the levers of process design, capacity, variability and inventory (Shenoy and Zabelle, 2016). PPM sees conduction projects as production systems, where it takes an operations management approach to project delivery (Fischer, 2017). Operation management areas of management are designing, overseeing, and controlling the process of production (Fischer, 2017). Ensuring that operations are effective by using few recourses and effective by meeting customer requirements (Fischer, 2017).

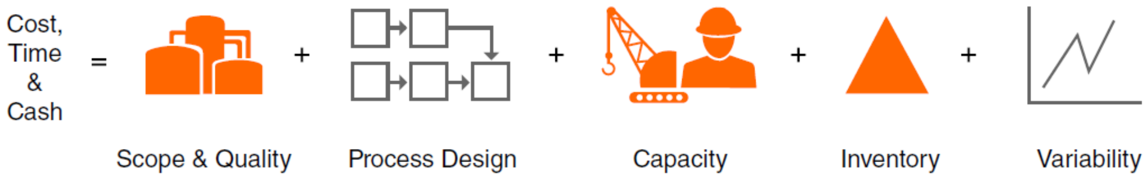


Figure 3.6: Production management (Shenoy and Zabelle, 2016)

Integrated Concurrent Engineering (ICE) meeting

CIFE Standford (2014) defines ICE as a methodology for effective, rapid, and reliable development of product and process design. The intent of ICE meetings, also referred to as ICE-sessions, is to reduce non-value time(waste), such as clarification of goal, agenda, mythology, definitions/vocabulary, and crash control and internal control, all of which should be clarified/completed before the meeting. ICE methodology enables a process for standardizing the meetings for a specific project. It ensures that everyone working on the same project uses a set methodology for what to do before, during, and after a meeting.

Figure 3.7: ICE meeting (Fosse et al., 2017)

Metrics in VDC

Metrics are a way to ensure that a project moves towards a common goal (Hjelseth, 2018). Goals should be made actionable through objects that are defined with metrics that have targets and methods for predicting and measuring them (CIFE, 2017). Measurable elements and properties provide the basis for controlling and managing projects against desired quality and progress, through controllable process and performance metrics. The CIFE has created a metric framework, showing how performance interactions between client objectives, project objectives, and process objectives.

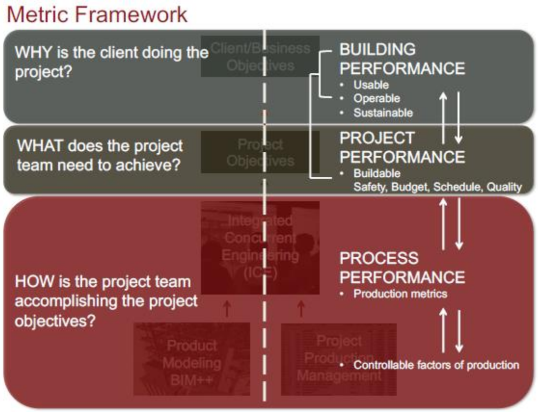


Figure 3.8: Metrics Framework (Fischer, 2017)

There are two essential elements to know when talking about VDC performance, Controllable Factors, and Process Performance Metrics. CIFE Stanford (2018) defines the two as:(Fischer, 2017)

Controllable *Factor*: *a condition that a designer or manager can actually control, such as a design choice about a product, the choice of what teams and people to hire, and the design of a work process. Controllable factors affect process performance and project outcomes.*

Process Performance *Metric*: *an aspect of project performance that a team can measure frequently (hourly, daily or every week or two) and use to judge how well past management choices (see Controllable factors) are moving toward the final project outcome objectives.*

Type of Objective	Objective	Metric	Target Value
Client objective	Earn income from building	Opening day	Oct. 31, 2015
Project objective	*Complete project on time*	*Completion milestone compliance*	*Oct. 30, 2015 (exactly)*
Production objective	Work according to plan	PPC (Plan Percent Complete)	>85% (good) between 75% and 85% (OK) <75% (unacceptable)
Controllable Factor	Planning approach	Level of detail of work plan	Daily

Figure 3.9: Example Metrics (Fischer, 2017)

3.7 Level of Development and Model Maturity Index

Level of development (LOD) has had different definitions, and the industry has had problems agreeing on a set standard. The LOD level is used to specify and articulate the content and reliability of the BIM (bimforum.org, 2018). It defines and clarifies what LOD level the information and geometry of the BIM model is at the various stages of the design and construction phase. It gives the practitioners a way to define at what stage the combined information and geometry meet the objectives. This makes the exchange of models much easier as it is possible to know the reliability of the information and geometry without it being complete.

LOD level can be set on object level, the discipline model itself or both. For an object to go up a level, both information and geometry need to pass a set threshold. By this, an object can have geometry equal to LOD 300, but since information equal to LOD 200, the LOD level of the object is still LOD 200. Determining LOD level on discipline models is tricky as they usually include various objects at different LOD levels.

A common misunderstanding is the use of Level of Detail (LoD) for LOD or vice versa. Leve of detail is in short how much information that is included in the object (bimforum.org, 2018). Bimforum.org (2018) view the Level of detail as input to the element, whiles LOD is the reliable of the output.

When we talk about the completion of the model, it is important to note that the different LOD levels do not directly represent a percentage of completion. An object at LOD 200 does not mean that the object is 40% completed. The percentage of work needed for each level is not equal and may differ from object to object.

Model maturity index (MMI) describes in many ways the same as LOD, where LOD describes the reliability and MMI describes the maturity. It also helps reduce the misunderstanding between LOD and LoD. MMI is more used as a method/process for communicating throughout the design (Fløisbonn et al., 2018).

4 Result

In the following chapter, the result from the interviews and document study will be presented. A detailed list of all performance metrics and corresponding controllable factors is presented in attachment 4, 5, and 6.

4.1 RS1- Current Approach to Performance Metrics

The following chapter presents the performance metrics deemed most important and the areas of control connected to them. It should be noted that their importance is dependent on the participant and stage of design.

How is performance in the design process measured today?

Seven areas are used to control the performance of the design process, progress control, cost control, quality control, interdisciplinary collaboration (e.g., Ice meetings), BIM, PPM, and performance metrics. These areas are aligned to complete project objectives, which in turn completes the client's goal. In controlling the design process, they work with six databases, project objectives, design basis, requirements, review system, design basis, and risk assessment. The controllable factors and performance metrics are used to clarify what factors we can choose to implement to steer the project towards project objectives and how these factors perform. The performance metric is also used to make decisions and evaluate performance trends.

Current approach to design performance measurement systems

The consultants interviewed are using or on their way of using the VDC methodology of managing with performance metrics and integrating it into their current performance measurement system. They collect the data from internal accounting systems, cloud project management systems, Microsoft projects, Microsoft teams, BIM, and Excel. The contractors used an in-house developed cloud-based performance measurement system, Microsoft projects, BIM, and Excel. Both consultants and contractors used spreadsheets extensively to collect, develop, and report performance metrics.

Project objectives for the design

Project objectives were dependent on the phase of design. In pre-design focus leaned more towards cost and time and in detailed design, it shifted towards time and quality.

The project objectives in pre-design consist of the deliverables being approved, within the design budget, delivered on time and without conflicting information between them. In detailed design, they consist of ensuring that that design was buildable, reliable, and on time, leading to consistent construction with no stops. The focus on cost was dependent on the contract in both pre-design and detailed design. However, in the detailed design phase, time generally supersedes cost in priority.

Current approach to Performance Metrics

Consultants and contractors were using performance metrics on projects and in their organization to determine if their planned efforts were achieving their desired outcome.

There were primarily six areas that performance metrics where deployed, cost, time and quality, following with the sub-divisions of VDC CIFE framework, ICE meetings, PPM and BIM. The six areas elaborate on the performance metrics and corresponding controllable factors found from the interview and document study, see attachment 4, 5, and 6.

Time

Both consultants and contractors used a customized version of the Last Planner to schedule the design in the different stages. In addition to the Last planner, SCRUM and ICE meetings are used. They have different approaches and interpretations of how-to measure progress. The approach chosen is dependent on the stage of design. The performance metrics used can be seen in attachment 5 and 6.

Milestone approach: A generic break down of delivery is into milestones, where each milestone represents a percent complete (e.g., milestones within a drawing).

Review approach: Each review stage of delivery act as a milestone representing a percent complete of the task.

MMI approach: MMI levels for each discipline per section.

The focus of both the consultants and contractors were on getting deliveries on time. The construction-start controls the priority of the deliverables in the detailed design phase. The consultants said they only deviated from this if the organizational, contractual bases made it necessary.

Cost

The cost was determined by work break down structure of the design, with the number of hours for the task determined by organizational standards and employees, then corrected using a factor based on the Law of large numbers (Kenton, 2018), determining the design budget. The hours determined after applying the corrective factor for the task become the basis they work against. The actual hours spent on task get measured up against planned hours, improving the corrective factor. Actual hours spent on task against planned hours become the leading performance metric to determine the cost. If a task is not pre-determined; the hours spent are set on a broader task. The current expenditure against the budget becomes the overall indicator for cost.

Quality

Quality here refers to deliverables (decisions, solutions, clarification, or drawings (Knotten and Svalestuen, 2014)) having the intended value to the customer. The customer being the next person in line in the delivery. To ensure this, six main approaches is used by consultants and contractors. The application of the approaches is depended on the phase of design. The performance metrics used can be seen, in attachment 4, 5, and 6.

<u>Review systems</u>: Deliverables need to complete different review levels before delivery can be sent to production (e.g., internal control, technical control, interdisciplinary control, etc.).

<u>Request for information</u>: RFI's due to conflicts in construction between building systems.

<u>Comment/issue system</u>: Integrated into the review system, there is a comment system, where "problems" are noted, discussed, and assigned. Tracking the comments/issues from different disciplines and client.

<u>Root cause analysis</u>: Finding the root causes on a non-completed task.

<u>Clash control</u>: The disciplines BIM models are clashed against each other.

<u>Risk matrix</u>: Register of risks with controls and mitigation measures.

ICE meeting

ICE meetings were used to identify, coordinate, integrate information, and content. They were used to reduce the response latency and decision latency of the work, giving an efficient way of identifying problems, solving them, and making decisions. The meetings were evaluated qualitatively through questionnaires and quantitively through PPC of the task in the meeting, percent participants and percent of changes, see attachment 4.

Project production management

Interviewees are trying to treat construction projects as production systems where PPM provides the process of pushing the project towards their intended targets. Ensuring efficiency by using as few resources as needed and effectiveness by meeting the customer requirements.

Different performance metrics were used to evaluate PPM, see attachment 5. The consultants had a higher focus on the completeness of deliveries at target dates, then measuring PPC of the deliveries. In contrast, the contractor highly focused on the weekly PPC of the different disciplines. The PPC was connected to root cause analyses of the deliveries that weren’t met. The performance metrics connected to comments/issues were also widely used, where the number of open and closed comments was the prevailing performance metric.

4.2 RS2- Challenges of Current Approach

Not all areas of performance measures came forth as challenging in the interviews and document study. In this chapter, one will find the ones that did. It included an extra sub-heading for unwanted behavior.

Challenges to Current design performance measurement system

It is clear from the interviews that one of the challenges where getting project managers and design managers to use the new process and performance measurement system and not fall back into the old ways. In some firms, there were "dual" implementation where both the old system and the new was used. The contractors also pointed out the resistance of some consultants to use their performance measurement system, resulting in the need to contractually state them. Some of the interviewees stated that the resistance was due to the technology threshold and that it took too much time from other tasks.

Challenges to Current approach to Performance Metrics

Keeping the performance metrics up to date were considered highly challenging, demanding extra work that was not a part of the design manager task previously. If the project became delayed or changed in scope, data entry was one of the tasks that buckled. Resulting in later data entry, irrelevant trend data, or discarding of the performance metric. Finding controllable factors that had a clear cause-effect relationship on the performance metric was another problem. Also, when the production in design is at a standstill, few controllable factors may help the design managers. The contractors also pointed out the resistance of some consultants to use the performance metrics, resulting in the need to state them contractually.

Time

From the interviews, it was clear that the progress of design where one of the main challenges, especially in its earlier phases. Also, the progress between "milestones" was a challenge as there were no easy controls there.

<u>Milestone approach</u>: Problem with the generic milestone approach was twofold. First, there was the problem of defining the task within the milestones. Second that the implementation and use were time-consuming, it was especially challenging to keep up to date.

<u>Review approach</u>: The problem here was that the percentage of complete was not representative of the task. Making the aggregation of the complete percentages non-representative. It also gives no feedback before the first review stages have started.

<u>MMI approach</u>: The problem with MMI was what it represents in the lower levels, especially for the contractors. Also, what the MMI needs to be before a meeting or decision gate was a problem. The more detailed implementation of MMI, the more difficult was the data extraction and follow up (e.g., MMI on object level vs. MMI on discipline model)

Cost

Both consultants and contractors agreed that the design budget tended to exceed its limits. They determined the primary cause being changes in scope or unclear scope, resulting in rework. Another problem for the consultant arises if there is a task where they have no experience-data, or the employees set to the task had not done it before. This becomes transparent when they work with an hour ceiling for the task. For the contractor, the challenges with the cost were ensuring that the hours were spent on the right task at that time.

A second challenge where that consultant did not find increased productivity resulted in higher hours rates. Where the customer expected the same improvements (e.g., automated update of federated BIM models) for the same rates, when it in turn reduced the number of billable hours for the consultants. Some of the consultants were experimenting with trying to sell value-added and fix price contracts due to the above mention reasons.

There are two clear challenges when it comes to using, actual hours spent on task against planned hours for the project. First is that consultants usually are selling hours, which gives no incentive to increase their productivity more than needed to win tenders. Second, within the consulate organization, they are subject to two behavior effects. That increased performance becomes the standard of how you are expected to performance and Parkinson law; the time given for a task is the time it takes (Kaufman, 2012). That said is not always so that consultants use all planed hours, as the time limit can supersede it in priority. It can also be used as a tactical decision, where they use fewer hours than estimated in the pre-design phase to increases their likelihood of winning the detailed design phase.

Quality

Quality is an area with many challenges for both the consultants and contractors. For the consultants, one of the most apparent challenges was the feedback loop. Where the designer does not get substantial feedback on the work, they performed. The feedback that reaches designers in the pre-design phase is mostly approved/not approved, and issues from the comment system, which is not optimal for improving performance. In the detail phase, there are more areas of feedback (e.g., clash control, RFI's, etc.). However, the approaches are lagging further behind, resulting in the "mistakes" rarely leads back to the person that did the task. For the contractor, the challenge was ensuring that the design was buildable, coordinated, and that the documentation was unambiguous.

ICE Meeting

Interviewees found it time-consuming to prepare productive ICE meetings, which took a lot of time from different tasks. The need for high participant representation makes alignment of schedules difficult and expensive. Participants lack the knowledge to make decisions in the meeting or/and did not have the mandate to make them. All participants are not familiar with the method of ICE, and the roles used in the ICE meeting are hard to keep. The commitment and decisions made in the meeting are not kept.

Meetings that have been productive in all aspects of the metrics were less productive then presented. As a lot of the decisions made need to change on a later date, due to participants had not thought through the problems correctly.

Project production management

Keeping the metrics up to date was a recurring problem that came forth within the interviews. There is a need for a better way to handle the data and a structured way to work with the performance metrics. The performance metrics need to adapt to stay relevant. Changes in base conditions and scope creeps can make the metrics non-representative.

Unwanted behavior

Consultants and contractors expressed that they have experienced and conducted unwanted behavior due to performance metrics. From the interviews, two main reasons seemed to be consistent. First, the contract put them in a situation where they felt it was justified. Second, the performance metric was not representative of the work performed.

One of the performance metrics that led to this was ”Number of closed comments/issues”. Where the group had focus on solving a particular difficult issue and succeeded. However, this resulted in low ”Number of closed comments/issues.” To counter this, the group decided to complete easy comments/issues, which had low priority, to boosts the number of closed issues.

Root cause analysis for deliveries missing their target where another one, which resulted in unwanted behavior. Where their reluctance to point out internal problems, resulting in them categorizing the problem elsewhere. One of the design managers went away from categorizing the root causes, as the person deemed them not representative.

4.3 RS3- Improvement of the Current Approach

Not all areas of improving the performance metrics came forth in the interview and document study. In this chapter, one will find the ones that did.

Improvements to the Design Performance measurement system

The consultants and contractors were in a period of choosing a new system or implementing a new one. All the systems being considered or being implemented were cloud-based and had a server solution acting as a project "hotel". This was done to have a common platform, easy access, and entering of information and to get out the performance metrics. To improve implementation, "younger" employees were set to help them with the systems.

Time

Milestone approach: The milestone approach needs a standard for how to break down the tasks. It also needs a standard process of how to work and report progress.

MMI approach: Develop BIM with MMI adapted for data retrieval and metrics. This should be directly connected to the performance measurement systems where a dashboard of the data is presented. Create a standard list of tasks that needs to be completed for each level of MMI.

ICE Meeting

Ensure that the metrics are updated before meetings. Include participants in the planning of the meetings; this increases their preparation, ownership to the meetings, and their likelihood of attending. It is also essential to book the meeting early, send reminders and if necessary contractual obligate them to attend to ensure high attendance in meetings. To solve issues immediately in the meeting, ensure that participants have the mandate to make them.

Project production management

If the follow up of metrics becomes too tedious for design managers, delegate more resources before metrics loses their value. Implement metrics early, so they reflect the progress of the design. Develop metrics with their controllable factors, metrics without controllable factors are not that useful.

5 Discussion

The following chapter connects the established literature and the results from the interview and document study. It follows the same structure as Chapter 4. In chapter 5.4, three new performance metrics models are presented to improve the current approach to the development of performance metrics.

5.1 RS1- Current Approach to Performance Metrics

The following chapter discusses the findings in Chapter 4.1 in relation to established literature.

How is performance in the design process measured today?

The terminology is not always consistent with organizations nor the literature when talking about performance in the design process. However, they do somewhat break down to the same areas of control progress control, cost control, quality control, meetings (e.g., Ice meetings), BIM, PPM. Emmitt (2017) has six areas of control, planning, cost control, change control, review, progress reports, and meetings. Whiles Grey and Hughes (2006) defines them as performance, planning, cost, change, meetings, and decision control. The strategic definition of the overall design process does exist, but a shared understanding and the specific content is not normative (Kristensen, 2013).

Current approach to design performance measurement systems

The use of VDC methodology of managing with metrics as part of design performance measurement systems is consistent with new literature in design management (Fischer et al., 2017, Knotten et al., 2015). This is most likely due to the high number of VDC CIFE certified participants in the interviews and in general in the Norwegian AEC-industry. The use of VDC methodology of managing with metrics seems to be the most current approach still to deal with performance metrics (Ahmad et al., 2016).

Most of the AEC-industry has understood the need to integrate performance measurement systems to a higher degree in their current management system. This lines up with the literature emphasizing the need for an integrated system where all information is stored, see Fischer et al. (2017). This can also be seen in the efforts of Autodesk and others to deliverer a cloud-based project management system, with integrated performance measurement systems (Venugopal, 2019).

Project objectives for the design

Areas of project objectives are consistent with the change from traditional performance measures, being cost and time (Pillai et al., 2002) to more focus on time and quality (Haponava and Al-Jibouri, 2012, Kristensen, 2013). This can be further seen in KPI's used in UCSF Mission Bay Hospitals (Fischer et al., 2017). Different project objectives are present in the literature; however, in actual implementation and case studies, they seem to lose their importance to time, as seen in Kristensen (2013).

Current approach to Performance Metrics

The use of VDC has increased the number of measurements in the industry, which is contradictory to (Spitzer, 2007) recommendation, where he points out that the industries have buried themselves in them. The large amount of measures is also contradictory to the performance metrics criteria of Brown (1996), where fewer is better (Brown, 1996). The author sees it equally. The number of performance metrics used to steer the project should be limited. Meanwhile, it is good to have several situations specific performance metrics on hand. These should only be seen as specific tools in the toolbelt of the manager that can be deployed in the different scenarios and phases in construction as the project changes with time. That said, the cost of measurements must always be weighed against the value-added. The task lays in finding the correct performance metric for the situations (Kristensen et al., 2013).

The list of performance metrics in appendixes 4, 5, and 6 are from multiple projects, the author does not recommend trying to implement them all on a project. Brown (1996) recommends the use of 10 – 12 performance metrics, which should be distributed between value streams. The maximum limit is 20.

Time

The approach recommended for determining the progress of design is dependent on the phase, organizational situations, and performance measurement system. In the literature, there are different approaches presented, network planning, bar charts, information-transfer schedule, etc. (Emmitt, 2017, Hughes and Gray, 2007). The approaches from the literature do not go into detail on how to measure the progress of deliverables between start and finish. In both Emmitt (2017) and Hughes and Grey (2007) they use the percent complete of individual deliverables, without determining how or what it represents between start and finish.

The degree of difficulty to deploy the different approaches is dependent on the organization current approach. However, some general statements on their difficulty can be made. Where the Review approach is easiest, as it builds on a current established review system and MMI approach is more complicated, as it requires people to change how they work (Barnes and Davies, 2014). It is not said that one must choose one method, combining Milestone approach and Review approach in the pre-project phase can be beneficiary. Where Milestone approach is used to measure the progress before the review stages, and then the Review approach takes over. This is also true for the MMI approach combined with Milestone approach, where the Milestone approach looks at the completion of tasks within a section for an discipline and MMI represents when it is completed.

Cost

Emmitt (2016) uses historical data form similar projects as the bases to develop the design budget. Where the design is unique (e.g., no historical data) the recommendation is to bring the person with the best knowledge of the unique design. From Hughes and Grey (2007), the design budget is based on either the developer decision, statement of needs, or preliminary design. Where the cost plan is subdivided into separate targets for every designer, manager, and specialist contractor. They specify that the use of hard data from similar projects should be used as the bases for the proposals. The cost committed against each cost target should be monitored by the person responsible for the cost target and formally reported monthly.

Quality

The use and importance of the six identified approaches are dependent on the phase of design and contract type. Where the review system, comments system, and risk matrix are heavier used in pre-design phase and clash control, root cause analyses, RFI's as well as the above mentioned are more used in the detail design phase. If the design and construction overlap the use of RFI's due to conflicts during construction is a good measurement of the quality and clarity of the coordination and documentation of the design (Fischer et al., 2017), giving essential feedback to designers. Kristensen et al. (2013) used the review system to determine the quality of the design material by counting the errors corrected per cycle and tracing the backlog of unsolved errors.

ICE meeting

Participation in interdisciplinary meetings is one of the more recurring performance metrics in both interviews and literature (Fischer et al., 2017, Knotten and Svalestuen, 2014, Kristensen et al., 2013). In both Fischer et al. (2017) and Knotten and Svalestuen (2014) used qualitative assessment of the meetings similar to the ones presented in the result. The result revealed quantitative measures (e.g., PPC) to evaluate the task during the meetings and between the meetings, where Kristensen (2013) used only PPC to evaluate the task between meetings.

Project production management

PPC is one of the most used performance metrics from the literature. In design, its primarily used to evaluate the reliability of deliveries by the different disciplines (Knotten and Svalestuen, 2014, Kristensen et al., 2013). This was consistent with the contractors' implementation from the result. Some of the consultants used the PPC of weekly work plans; however, there was a higher focus on completeness of deliveries. The use of Tasks Made Ready and Tasks Anticipated described by Fisher et al., (2017), which provides leading performance metrics to PPC was not implemented.

5.2 RS2- Challenges of the Current Approach

The following chapter discusses the findings in Chapter 4.2 in relation to established literature.

Current challenges to Design Performance measurement system

The challenge of dual implementation and getting managers to use new performance measurement systems is a well-known challenge, see (Andersen and Fagerhaug, 2002). Since the challenge involves changing how people work, a level of resistance is to be expected, especially when the people in question have a high level of influence(Hussein, 2016).

Challenges to Current approach to Performance Metrics

Keeping the performance metrics up to date is one of the main challenges in performance measurement systems (Robinson et al., 2005). Brown (2007) and Spritzer (2007) both warn about painstakingly collecting data and the actual cost and opportunity cost of doing so (Brown, 2007). The data entry, in itself, adds almost no value (Williams, 2018).

The problem of data entry led Kristensen (2013) to rely on existing data as much as possible deliberately. In the end, he only needed to collect data for thirty percent of his performance metrics. Kristensen (2013) also noticed that the performance metrics were met with caution due to it taking time from other tasks.

The terminology of controllable factors is not that present in the performance metrics literature; however, the situation it presents is. Where it discusses what action can be taken for underperforming metric (Andersen and Fagerhaug, 2002). The difference in VDC literature is that it focuses more on what action can be taken proactively than action taken as a result of the performance metrics (Fischer et al., 2017).

In Kristensen (2013), the case study design manager noticed the negative performance trends but could not find controllable factors that solve them. This is consistent with the result. Where when a project first starts underperforming, few controllable factors can be implemented that gets the project back on track.

Fischer et al., (2017) viewed the challenge to define performance metrics that “relate to the project’s goals and that provide information to project managers that enables them to assert control over the factors that affect project outcome.”

Time

In general, the literature on the progress of the design does not go into detail on how it is done. It stops at the level of completion of the deliverables, not specifying how to determine the progress within the deliverables. Hughes and Grey (2007) view the qualitative assessment of progress for each deliverable as only a guide but useful for identifying problems. Emmitt (2016) says that the completion should be shown as actual progress compared to planned progress. He uses two methods of determining the progress of deliverables, percent complete or status report of not started, incomplete and completed. His uses of status report of not started, incomplete, and complete is consistent with the results.

In Hughes and Grey (2007) bar chart approach, the progress is based on the accumulation of the completion percentage for each drawing. The percentage of completion for each drawing is qualitatively determined between the start and finish. They viewed the completion of each particular drawing as little relevant due to the interconnection of the design information between participants being too difficult to portray. The bar chart approach is disregarding the need to specify milestones within deliverables and by consequence, the challenges it presents.

In Hughes and Grey (2007) approach to the information-transfer schedule, the progress is determined by the review/approval of the recipient of the information. It does not specify the method of determining the percentage of completion between the reviews. It only looks at the interdisciplinary review/approval, not using the other review phases to determine progress.

Cost

The effect of small scope changes was seen in Kristensen (2013), where it caused significant delays due to its propagating through the set solutions. The challenge of lacking historical data to determine the hours needed to complete a task and inevitable affecting the design budget is also present in Emmitt (2016).

One can reasonably question its validity for being a measurement for efficiency when it is more or less a measurement for activity. When timesheets are nearly never accurate, the reliability of the measure is low (Williams, 2018). Williams observed that the real problem with timesheets, is what they do not tell us and that it fosters a mentality of productivity instead of proactive innovation.

Quality

The further the completion of the task is from the approach used to control its quality, the less likely it was for the feedback to lead back to the person that did the task (e.g., user experience rarely reaches the person who did the task). This is one of the challenges within design management, where feedback from the facilities operations and maintenance is not considered or reaches the design team (Mohammed and Hassanain, 2010).

In the detailed design phase, when the construction overlaps two quality performance metric stands out. "RFI's due to conflict during construction" is a good indicator of the quality and clarity of the coordination and documentation of the design. "Percentage of deliveries approved without the need for resubmittal" indicates the quality of design before construction. Here the percentage of deliveries approved is better to foresee quality problems (lesser lag), and the RFI' is better to evaluate the overall quality.

ICE Meeting

Fischer et al. (2017) talks of the benefits of ICE but lacks details on the challenges it presents. Even though the ICE meeting presents challenges, the interviewees agreed that if conducted properly, it is a better way of meeting. The keyword here is properly, knowing the need, frequency, preparation required, and the participants needed in the meetings.

Hughes and Grey (2006) and Fischer et al. (2017) specifies the importance of having the right participation in the different design meetings, which is consistent with the result.

The challenge of implementing ICE has similarities to the challenge of implementing performance metrics. The tasks are new for the design managers, resulting in less time to do regular tasks in an already pressed schedule.

Emmitt (2016) points out that different performance metrics can be used to measure the meetings but emphasizes that the managers' focus should lie on the processes, communication, and perception of the product and processes.

Project production management

Keeping the performance metrics up to date is a recurring problem in the literature (Kristensen, 2013, Kristensen et al., 2013). The need for a structured approach and a way of developing and using performance metrics in design was the reasoning for the development of the performance measurement system by Kristensen (2013). The challenges connected to performance metrics is connected to the incremental implementation of VDC where the organization needs to develop its way of handling data, the structures of the process, and how to use the metric. The need for performance metrics to adapt to stay relevant is consistent with Succar et la. (2012)

Unwanted behavior

Andersen and Fagerhaug (2002), show numerous examples of how performance metrics have caused unwanted behavior. It is essential to be aware that this is within organizations, where they are usually less fragmented and siloed than projects are in the construction industry and still having plenty of examples of unwanted behavior. When unwanted behavior occurs, specific metrics might improve, but the critical performance will worsen(Spitzer, 2007).

In Kristensen (2013) unwanted behavior was one of the initial responses to performance metrics, where he points out the group had tendencies of 'trench warfare.' One of the reasons for the hostilities was that it was implemented later in the design process, according to the author. However, the performance metrics did help the designers to be aware of the problems they faced.

Somewhat of the same problem with the root cause analyses from the results can be found in Knotten and Svalestuen (2014). The design manager in the study points out the inconsistency with the main reason for delays being 'lack of information' when no one complained about this beforehand.

5.3 RS3- Improvement of the Current Approach

The following chapter discusses the finding in Chapter 4.3 in relation to established literature. It includes an extra sub-heading for targets.

Improvements of the design performance measurement system

The clearest academic recommendation to counter the problems regarding implementation is to include the people doing the work in the development, as seen in (Andersen and Fagerhaug, 2002, Emmitt, 2017, Hussein, 2016) A gradual implementation can also be useful as the recommended approach to VDC (Kunz and Fischer, 2012), which is also the recommendation of Spritzer (2007)

The use of an integrated cloud-based project management system, with a built-in performance measurement system, is where the construction industry is heading (Venugopal, 2019). Having an implementation strategy for these systems is essential, for one's organization and the outside participants. An undervalued tool in this process is video courses, as the typical courses have too high latency before they are used.

Improvements to the current approach to performance metrics

The extensive use of automated performance metrics in other industries (Spitzer, 2007), shows the need and potential for moving away from manual data entry in spreadsheets used on local computers. Andersen and Fagerhaug (2002) view manual data entry as the least efficient method of collecting data. Brown (2007) regards as spreadsheets and the uses of PowerPoint as one of ten problems with performance metrics, due to it being time-consuming and difficult to interpret. However, Spritzer (2007) emphasizes the importance of understanding what the measurement means, which might be lost with automation. It is necessary to get a better view of the actual cost and opportunity cost of assembling data, as its one of the areas were managers lack understanding (Christensen and Bever, 2014).

Management needs to understand the difference between what the dashboard of performance metrics represents, and the work performed. Management by measurement has been the death of many companies (Spitzer, 2007), and not knowing what one is measuring is a sure way to do it. The worse performance metrics is the one that shows the project is performing well when the opposite is true.

How one starts the implementation is not how one expects it to continue. The performance measurement system is a continuous improvement process (Andersen and Fagerhaug, 2002).

A way of improving the way we handle data in the design phase is to look at the software industry, and their approach and frameworks for project management as it seems like the design phase is becoming more and more equal to the software industry. One of the methods is Scrum from the software industry, which can be a source of inspiration (Streule et al., 2016).

Time

One of the areas in consistent need for improvement is determining the progress of design in the early stages. However, this is not easy due to the iterative nature of the design (Ballard, 2000a). It further affected by the different processes of design (Knotten et al., 2015), see Chapter 3.2.

That said, the number of iterations, if needed, is dependent on the difficulty of the design, as some design decisions "… are so well defined and understood that they can be fully automated" (Fischer et al., 2017).

With the milestone approach, there is a need for a standard way of breaking down the deliverables, where each milestone represents a percent complete. It also needs to be a standard process of how to work and report progress.

For the MMI approach, when developing the BIM manual for the project it is important that it's created with data retrieval and performance metrics in mind. Ensuring that the set up from the start works with the performance metric in place to evaluate it (e.g. file/object names that are unique). This should be directly connected to the performance measurement systems where a dashboard of the data is presented. There is also a need for a standard list of tasks to be completed for each level of MMI.

The need for more accurate planning of design is also controversial, as (Samset, 1998), view the problem more as finding the information than planning it and Hughes and Grey (2007) that the interconnection is too difficult to portray.

Cost

Emmitt (2016) suggest finding the most qualified to determining the length of the task when historical data is not present. Hughes and Grey (2007) recommend the cost controller to "walk" the place the work is performed, where decisions are made, examining the work (e.g., BIM models) and asking relevant questions.

There are automation opportunities in the construction industry (Fischer et al., 2017). However, the contradictory situation of increasing productivity while selling hours will hold back the development.

The industry's shift where consultants are now trying to sell "value-added" rather than hour-based contracts, will help them understand what they have pledged to serve the client. It will most likely incentive the sharing of good ideas within the organization. It is essential that consultants remember that "the value of a professional is the value of their outputs, not the sum of their inputs (Williams, 2018)"

However, from a consultant's perspective, the unwillingness to sell fix price contracts is understandable, as it increases the competitive basis between the different consultants' agencies.

Quality

Kristensen (2013) used Deming's PDCA wheel (see, Chapter 3.2) as a process of how to act based on the measurement. This can be used to provide feedback during the design and is consistent with Fischer et al. (2017) recommendation of the PDCA cycle.

In the pre-design phase, the review system can improve its level of feedback by changing the reviewers' job from approving deliverables to providing the feedback that ensures the most approval through the entire review process. In the detail design phase, ensuring that the information from RFI's finds their way back to the designers so that they can improve upon their process is essential.

There are BIM programs that allow users to trace their choices back in time, giving one the ability to determine who did the task (Mohammed and Hassanain, 2010). This can be used to determine why a task that was not up to par and providing the necessary feedback.

Haponava and Al-Jibouri (2012) identified six controllable aspects of quality, process performance, documentation, integration, review, the experience of the stakeholder, communication, and traceability. These were used to evaluate the quality of the KPI's identified. This system can help in identifying controllable factors for the quality performance metrics. If a metric has no controllable factor, there is no real way to impact its progress.

ICE Meeting

ICE meeting is a new way of conducting meetings, and as with all new things, there are challenges and ways of improving it. Getting it integrated with how we conduct business will be an incremental process, and the level of implementation will differ between organizations, which will present challenges.

The need for implementing the meeting into planning and scheduling is consistent with Emmitt (2017), which specified the need for implementing it in the project strategic process.

From the results, preparation is the key to successful ICE meetings. Involving the participants in the planning is an effective way of overall improving the meeting. Having them prepare a section or a short presentation, as recommended by Hughes and Grey (2006) ensures ownership of the meeting and increase their likelihood of attending. Beware that the effect of this is limited if participants hands it off to their assistant.

A priority checklist for what needs to be done and when before the meeting is essential, with pre-discussed action for what to do if they are not met (e.g., the client cannot attend, postpone meeting?). Determine what is needed for the meeting to have the desired value.

There also need to be an implementation plan for how to handle participant that are unfamiliar with this way of conducting meetings. This can be done as courses, preferably in a short time before the meeting.

Project production management

Delegating the processes of keeping the performance metric up to date can free up essential time for the manager (e.g., to the BIM-coordinator). However, the first time the manager uses performance metrics, they should do it themselves, as it is a learning experience and a crucial part of developing good performance metrics.

The need for implementing performance metric early is consistent with the finding by Kristensen (2013). First, the trend analysis of the performance metrics needs to cover enough time to be valid. Second, if the performance metrics are new, testing is needed, which is hard to do correctly in the middle of the project. Third, the metrics can quickly become merely a routine (e.g., the manager goes through the motion of reporting), instead of a process for improvement (Spitzer, 2007).

Developing performance metrics should happen in conjunction with controllable factors. The controllable factors need to be tested to determine that there is an action cause relationship with the performance metrics. Performance metrics without any identified controllable factors are not very useful. The use of controllable factors in relation to performance metrics has similarities to the step of data retrieval, where both are essential in the development of correct performance metrics. The controllable factors determine the action one can take to affect the performance metrics and data retrieval determines if one has the data needed for the performance metrics.

Unwanted behavior

Andersen and Fagerhaug (2002) state the importance of not using the performance measurement system to pinpoint blame. It should preferably be a tool for improving processes and the understanding of it. Using it to pinpoint blame corrupts the system and manifests the unwanted behaver we strive to avoid. The defragmentation and siloed nature of the current construction industry (Fischer et al., 2017), make this a high priority challenge. One of Andersen and Fagerhaug (2002) recommendations for avoiding unwanted behavior is to be forthcoming and explain why is being used and how it will work. Anticipate the reluctance and implement counter measurements before it can thrive in the project.

One way of countering unwanted behavior is to ensure that everyone economically benefits from the project, "design managers is dependent on design companies with a healthy economy" (Kristensen et al., 2013). If the economic situations lead participants to start exploiting the contracts, the recipient will respond with trying to find counter measures, starting a never-ending cycle of unwanted behavior. Some performance metrics are very easily manipulated if participants desire to do so, as seen in the result. This is why Ballard and Tommelein (2016) discourage connecting economic incentives to the performance metric PPC (Ballard and Tommelein, 2016).

Within one's own organization, including the employees in the development is essential to counter unwanted behaviour (Andersen and Fagerhaug, 2002, Spitzer, 2007). If project performance metrics do not align with organization performance metrics, talk with the employees about how to behave or have code of conduct training, can hinder them from doing regrettable actions.

Targets

The targets set by the consultants and contractors are quite consistent with the literature in Fischer et, al. (2017) and Ballard (2000b). The literature on setting targets is extensive, where some recommend it should be defined as a part of negotiations (Schneiderman, 1999) while others say they should be based on analysis and research (Brown, 2007).

The use of targets seems somewhat not well thought through from the results. This is due to the interviewees lack of connecting the volatility of the productivity that occurs in design to targets. The volatility of projects is higher at the start of the projects then stabilizes over time, as seen earn value analyses by Hussein (2016) (Hussein, 2016) Given this volatility, having the same targets at the start and the end is not logical.

One can question the problem of having targets that are the result of the productivity in later phase in design and construction as the same at the start of the project. As it might push the participants as stretch goals (Brown, 1996), and as long as the participants view the target as reasonable, unwanted behavior is not to be expected. The contradictory of this statement is not lost on the author, as revealing this might make target setting a more complexes problem.

It is essential that the one does not “manages by targets” (Spitzer, 2007). By this, the author means that the managers must not lose sight of what the metrics represent and have their actions only driven by the targets.

5.4 Circle of Alignment for Performance Metrics

As an answer research question three, and the current challenges and improvement potential in the current performance measurement systems, the Circle of Alignment for Performance Metrics (CAPM) was developed. CAPM consists of three new models. The models are based on renowned academic models, challenges from results, and elements of the discussion. The models are meant to work with the existing practice of VDC and the VDC certification program from CIFE Stanford.

Countering metrics model

Building on chief engineer Ichiro Suzuki's "Tension Yets" developed at Toyota's Lexus (Patty and Denton, 2010), a model for improving performance metrics were developed. The "Tension Yets" is a set of seemingly contradictory or mutually exclusive design targets that encourage engineers to discard accepted engineering solutions and come up with solutions that exceed the expected performance. Take the benchmarking criteria of noise inside a car, where the accepted engineering solution is to increase the weight to counter the vibrations. Then the opposite of the accepted engineering solution becomes a criterion, low weight. This results in designing a car that is quiet, yet lightweight.

The countering metric model works somewhat the same way, by getting the developer of the metric to find what might be unwantedly sacrificed in pursuit of the metric and countering it with its own metric. This ensures a more holistic approach to project performance measurement.

Say one want to increase the efficiency in the meeting and therefore decided to measure the performance metric PPC of deliverables in the meeting and then deploy the identified controllable factors, see attachment 4. This might lead to higher completion of deliverables in the meeting. However, this expedient of deliveries might result in a reduction of their quality resulting in changes in the deliverables on a later date. To ensure that the quality of the deliverables in the meeting is kept, the percent of changes to decisions made in the meeting is set as a criterion, resulting in expedient deliveries yet high quality.

The model provides the highest benefit if the countering metric is not lagging to the target metric. Take the metrics in Table 5.1 as an example. Where "% of submittals reviewed without the need for resubmittal" is a better counter metrics for "% completion per review phase" then "% of submittals without the need for an RFI" as it gives an earlier warning if the submittals are inadequate. However, the number of RFI's linked to the submittal is a better metric for determining the actual quality of the deliverable.

Tabell 5.1: "Tension Yets", redrawn by author (Patty and Denton, 2010)

• Great high-speed handling/stability	Yet	Pleasant ride and low aerodynamic friction
• Fast and smooth ride	Yet	Low fuel consumption
• Super quiet	Yet	Lightweight
• Elegant styling	Yet	Great aerodynamics
• Warm	Yet	Functional interior

Tabell 5.2: Countering Metrics Model

Countering Metrics	
Performance metric (target)	Countering metrics
Explanation: Efficient decision making. Task set to be completed during the meeting (E.g., Decisions, questions) **Metric:** Completion % of task set to be completed in the meeting **Target:** 100 % by the XX	**Explanation**: Making the decision made in meeting stick **Metric:** % of changes on agreed upon decision made in the meeting **Target:** < 5 %
Explanation: Efficient review production of deliverables **Metric:** % completion per review phase (E.g., internal control, technical control, interdisciplinary control etc). **Target:** 100 % by the XX	**Explanation:** Ensuring that deliverables is done correctly the first time **Metric:** % of submittals reviewed without the need for resubmittal Target**: 90 - 95 %**
	Explanation: Request for information (RFI) due to conflict during construction **Metric:** % of submittals without the need for an RFI Target**: 90- 95 %**

Performance Metrics Johari window model

To align the different participant's organization performance metrics with the project performance metrics, a model was created based on Johari's window model. Johari's window model is used to understand an individual's relationship to oneself and others better and enhancing communication.

	Known to self	Not known to self
Known to others	Open area	Blindspot area
Not known to others	Hidden area	Unknown area

Figure 5.1: Johari Window model, redrawn from (Luft and Ingham, 1961)

The performance metric Johari model works by identifying the performance metrics within the participant organizations and the project. It helps identify the power dynamics and business strategies of the participants and the employees' interpretation of the performance metrics. The reason performance metrics can be used to interpret business strategy is that what is measured is what gets attention (Eccles, 1991). The model also helps identify which processes are performed in the project and which are outside of it.

The Johari model identifies potential filters that are in-between the performance of the participant's organization and the project. This is important as participants' organizational performance often have priority over project performance. Moreover, if one cannot trust the source of the data, the performance metric will not be very dependable (Andersen and Fagerhaug, 2002). The model facilitates the development of correct project performance metrics and countering metrics.

If a project performance metric is contradictory to the participants' business strategy, changes the power dynamic or requires participation to work, its reliability, validity, and likelihood to be consistent is questionable. Here one would need countering measures such as countering metrics.

The fourth window in the Johari model is the interpretation of the performance metric by the employees, as their interpretation is not known within once own organization or others organization, without including them in the development or talking to them. As it is their work, one wants to steer, getting input from the employees is an essential step in creating good project performance metrics. This is lacking from the current VDC approach, which is mostly top-down in the development of metrics.

Including employees in the development of performance metrics helps the project team members understand the three points that the collection of organizations must do to create valuable buildings put forward by Fischer et al. (2017):

- *Agree on how to measure the value they are creating for the owner;*
- *Align how they'll produce the value; and*
- *Measure production and progress along the way.*

The Johari model can also be used to determine what level or need, for including performance metric in the contracts. One can also use it within one's organization to evaluate the trend of project performance metrics and organizational performance metrics.

	Know to one's own organization	Not know to one's own organization
Know to other organization	The project performance metric	The performance metric of the other organization
Not know to other's organization	The performance metric within your organization	The interpretation of the performance metric by the employees

Figure 5.2: Performance Metric Johari model

Development of Project performance measurement system

A step by step approach for the development of project performance measuring system based on Andersen and Fagerhaug (2002) approached was created, see their approach in Chapter 3.4. It focuses on transforming Andersen and Fagerhaug (2002) model to apply to projects instead of organizations. It is fused with the VDC management with metric system and the improvement model already presented. From step 4 to 9, the steps are intensive, see Chapter 3.2.

1. Mapping the project processes: In collaboration with main project participants go through processes that are central for value creation (Value stream (Womack and Jones, 1996)) and draw flowcharts of them (e.g., MMI development). A good place to start is with the milestones in a phase.

2. Quantify the stakeholder requirements: In collaboration, identify and quantify the stakeholder requirements. From this, develop client objectives and project objectives and rank them. Identifying the stakeholder requirements and the related critical success factors is essential in developing correct performance metrics (Kristensen et al., 2013)

3. Review the existing performance metrics: Go through the already established performance metrics and performance measurement system reports from past projects (Andersen and Fagerhaug, 2002). Then evaluate what fits with the client objectives and project objectives.

4. Development of performance metrics: In collaboration develop performance metrics for client objectives, project objectives, production objectives. Simultaneously establish their controllable factors. Include the people doing the work and develop the metric with data retrieval in mind (Andersen and Fagerhaug, 2002).

5. Collect the required data. Find the data sources needed, coordinate collection of data with the participants, and determine where to store it. Determine when to collect data and measure and the precision needed. This needs to be done in connection with the planning and scheduling efforts (Kristensen et al., 2013).

6. Performance metric Johari model: Identify the organizations performance metrics of the participants and their alignment to the project performance metrics.

7. Countering metrics model: Establish what might be unwantedly sacrificed in pursuit of the performance metric and establish countering measures (e.g., countering metrics).

8. Data presentation: Define how the data will be presented (e.g., dashboard) and when (e.g., ICE meetings). The dashboard should show counter metrics and target metrics at the same time. Each performance metric should be pre-planned and scheduled within the design phase(Kristensen, 2013).

9. Testing system: Test if the collection of data(input) generates the required information and that the presentation of data(output) is representative of the work. Determine if the controllable factors affect the performance metrics. Continuously test metrics to ensure that they are valid and that the right combination of controllable factors is steering the project (Spitzer, 2007).

10. Implementation of performance measure system: Provide the necessary training and resources to participants using the system (Andersen and Fagerhaug, 2002, Spitzer, 2007). Focus on the participants who are unfamiliar with the system. Have a system champion who provides this support (e.g., design manager, BIM manager, etc.).

11. Using the system: Monitor the performance of key processes, use it as the bases for decision-making and improving the current performance.

12. Decision mapping: Determine what level the performance metrics need be at specific points (e.g. what level does the MMI need to be before an ICE meeting), thresholds/control limits (e.g., RFI exceeds threshold), how to follow up (e.g. leading metrics/controllable factors) and what action to take if the target is missed or exceeded. PDCA figure 3.2 develop by Kristensen (2013) is a tool that can help perform this step.

13. Change control: Develop procedures for what happens to the performance metrics if changes in base conditions and scope happen. Are the performance metrics still valid (e.g., trend analyses)? What needs to change for them to stay valid? Moreover, how and to whom is the information needed to be presented (e.g., client). Andersen and Fagerhaug (2002) say that changes in scope, especially fool managers.

14. Improvement: Create a performance metric system report, including the five biggest impediments, lesson learned etc. This is meant to be used as input in step 3 in the next project. Capture and sharing knowledge is the purpose of performance metrics (Spitzer, 2007)

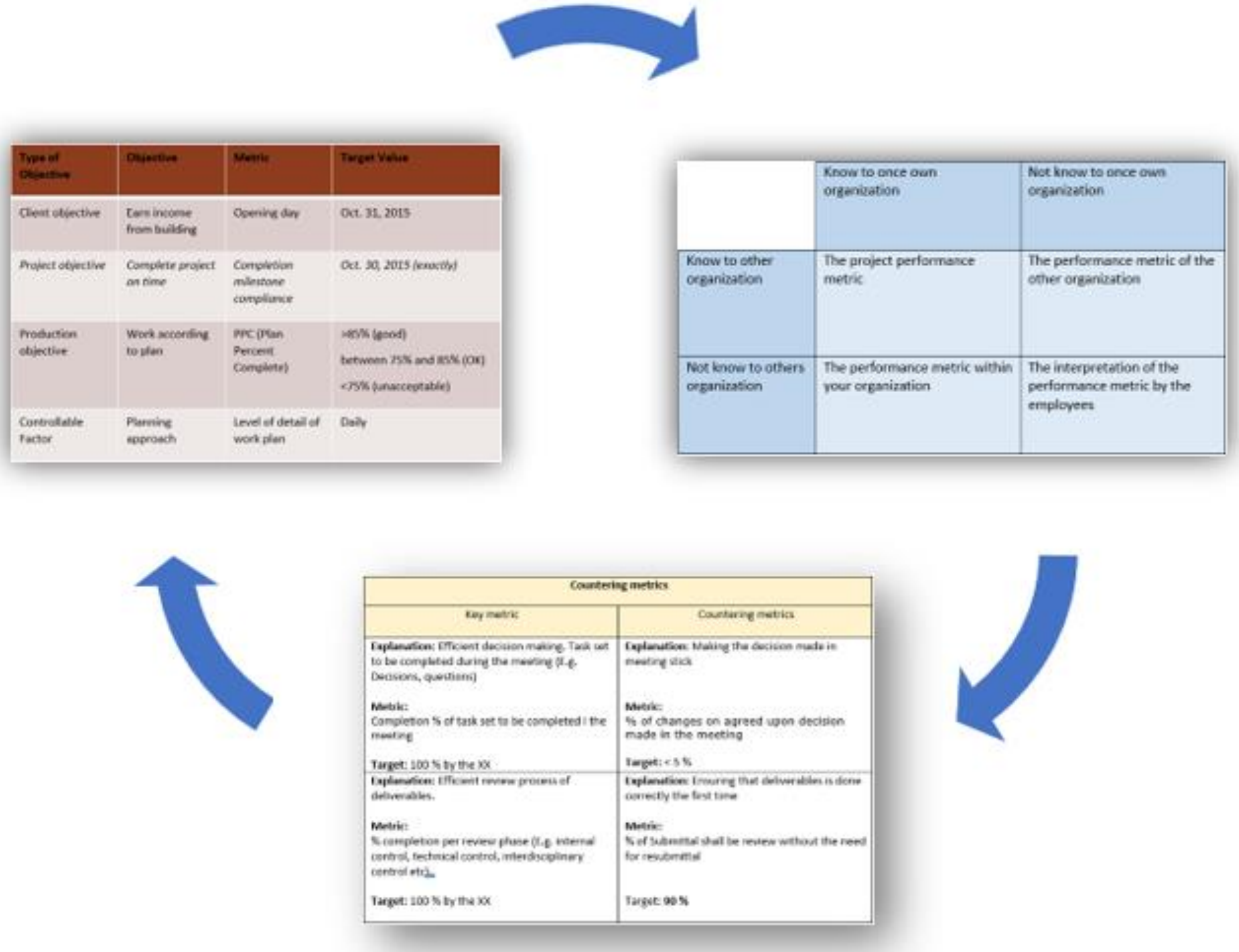


Figure 5.3: Circle of Alignment for Performance Metrics

The models are meant to be gradually implemented, as the recommended approach to VDC (Kunz and Fischer, 2012) and the recommendation of Spritzer (2007). It is also important to note that this is a continuous process, not something that is completed at the start of the project, as recommended by (Andersen and Fagerhaug, 2002).

Take advantage of analyses and organizational standard that's already a part of the processes and use them to develop the step by step approach (e.g., stakeholder analyses, value streams, BIM execution plan, etc.). Conducting a second stakeholder analysis for step 2, is just dual work, as noted in Kristensen (2013) when developing his method.

The level of detail in step 12 should follow two of the principles of Lean, where it should be planned in more detail the closer it gets to the precise execution and involve the people doing the work (Ballard et al., 2009). If one goes into too much detail here at the start of the project, one will rely too heavily on assumptions.

The models are meant to be adapted to each project or organization. Where they determine what works for them and their projects. The organization will also benefit from creating standards for the steps, which is meant to be included in the project start protocols and end protocols.

Reviews of the Models

The models have been revived by professor Bjørn Andersen, one of the original authors of the step by step approach. In an email correspondent, he viewed that the "Performance metric Johari window model" gives a new perspective and that it works well with the step by step approach. He also said that the "Countering metrics model" gave a new view, but that it needed to be clearer.

Ph.D. Kai Haakon Kristensen also reviewed the models. In an email correspondent, he viewed the models as good but emphasized that he was unsure if they were balanced enough. That the models ensured that user developed a good combination of leading and lagging metrics, qualitative and quantitative metrics. He also strongly advised testing or at least simulating the models, as this is "gold" in developing these models.

6 Conclusion

In this chapter, the result and discussion are connected to conclude the research questions. It follows the same structure as the result and discussion. In 6.5, future work is presented, where the areas that need further development are presented.

6.1 RS1- Current Approach to Performance Metrics

The following chapter will conclude the finding from Chapter 4.1 and Chapter 5.1

How is performance in the design process measured today

Seven control areas are used to control the performance of the design process, progress control, cost control, quality control, meetings (e.g., ICE meetings), BIM, and PPM. In controlling the design process, they work with five databases, project objectives, design basis, requirements, review system, cost basis, and risk assessment. Controllable factors and performance metrics are used to steer the project towards project objective.

Current approach to design performance measurement systems

The VDC methodology of managing with performance metrics is used by the majority of the interviewees. They extensively use spreadsheets to collect, develop, and report performance metrics. The data was also collected from internal accounting systems, cloud project management systems, review systems, Microsoft projects, Microsoft teams, and BIM models.

Project objectives for the design

The project objectives in pre-design consist of the deliverables being approved, within the design budget, delivered on time and without conflicting information between them. In detailed design, the project objectives consist of ensuring that that design was buildable, reliable, and on time, leading to consistent construction with no stops.

Current approach to Performance Metrics

Performance metrics were deployed in the seven control areas, where they are used to determine if the planned efforts are achieving the desired outcome. There are numerous performance metrics discovered from the interviewees and document study; the task(challenge) lies in deploying the correct once.

Time

A customized version of the Last Planner was used to schedule the design in the different stages. There were different approaches and interpretations of how to measure progress were used, the main ones being milestones, reviews, and the MMI approach. The approach chosen is dependent on the stage of the design.

Cost

The cost was determined by work break down structure of the design, with the number of hours for the task determined by organizational standards and employees, then corrected using a factor based on Law of large numbers, determining the design budget. Then the actual hours spent on tasks against planned hours become the leading performance metric to determine the cost.

Quality

Six main approaches used to control the quality of design, review system, comment/issues system, root cause analysis, clash control, request for information, and risk matrix. Their application is dependent on the phase of design and the organization in question.

ICE meetings

ICE meetings where used identify, coordinate, integrate information, and content. The meetings were evaluated qualitatively through questionnaires and quantitively through PPC of the tasks in the meeting, percent participants, and percent of changes.

Project production management

PPM provides the processes needed to push the project towards their intended targets. This was mainly evaluated through the performance metrics, percent complete of deliverables, and PPC of weekly work plans.

6.2 RS2- Challenges to Current Approach

The following chapter will conclude the findings from Chapter 4.2 and Chapter 5.2.

Challenges to current design performance measurement system

Getting project managers and design managers to use the new performance measurement system, and the process was a recurring problem. The technology threshold and time consumption were the main reason for this resistance from the interviews.

Challenges to Current approach to Performance Metrics

Keeping the performance metrics up to date was considered highly challenging; taking time from other well-established management tasks. Finding controllable factors that had a clear cause-effect relationship on the performance metric was another problem. Also, when the production in design is at a standstill, few controllable factors may help the design managers.

Time

What the progress of the design where was a consistent challenge**,** especially in the earlier design phases. Knowing the progress of deliverables between start and finish was another problem.

Cost

Changes in scope resulting in rework were one of the primary reasons for the design exceeding its limits. A challenge for consultants arises when estimating a task with no experience-data. For the contractors, one of the challenges related to cost was ensuring that the hours were spent on the right task at that time.

Quality

For the designers, one of the challenges was that they did not get substantial feedback on the tasks performed. The quality controls did not provide enough feedback or never reached the designers. For the contractor, the challenge was ensuring that the design was buildable, coordinated, and that the documentation was unambiguous.

ICE Meeting

Interviewees found it time-consuming to prepare productive ICE meetings. The need for high participant representation makes alignment of schedules difficult and expensive. Commitments and decisions made in the meeting are not kept.

Project production management

Changes in base conditions and scope creeps can make the metrics non-representative. There is a need for a better way to handle the data and a structured way to work with the performance metrics. The performance metrics need to be adapted to stay relevant.

Unwanted behavior

Consultants and contractors expressed that they have experienced and conducted unwanted behavior due to performance metrics. Two main reasons being the unfair contractual basis and non-representative performance metrics.

6.3 RS3- Improvements of the Current Approach

The following chapter will conclude the findings from Chapter 4.3 and Chapter 5.3

Improvements of the design performance measurement system

The consultants and contractors were in a period of choosing a new system or implementing a new one. This was done to have a common platform, easy access, and entering of information and to get out performance metrics. To counter the problems regarding implementation, include the people doing the work in the development and have a gradual implementation. Continually improve performance measurement system.

Improvements to the current approach to performance metrics

Move away from manual data entry in spreadsheets to automated performance metrics where it is reasonable. Know the actual cost and opportunity cost of assembling data. Let the people doing the work experiment with the metrics, as it ensures empowerment and creates better metrics.

Time

Create a standard way of breaking down the deliverables and report the progress, which works with automated performance metrics. Develop the BIM models with MMI adapted for data retrieval and performance metrics.

Cost

Find the most qualified to determining the length of the task, when historical data is not present. Have the cost controller examine the work, ask relevant questions, and know the cost committed against each cost target.

Quality

Change the reviewers' job from approving deliverables to providing the feedback that ensures the most approval through the entire review process. Use Deming's "Plan-Do-Study-Act" cycle for continuous improvement. Have a systematic way of identifying identify controllable factors for quality.

ICE Meeting

ICE meeting needs to be implemented into the project strategic process. Preparation is the key to successful ICE meetings. Involving the participants in the planning is an effective way of overall improving the meeting.

Project production management

Delegating the processes of keeping the performance metric up to date can free up essential time for the manager (e.g., to the BIM-coordinator). Implement performance metrics early to ensure acceptance and more valid trend data. Develop the performance metrics in conjunction with the controllable factors.

Unwanted behavior

Do not use the performance measurement system to pinpoint blame, use it for improving the processes and the understanding of it. Be forthcoming and explain why it is being used and how it will work. Ensure that everyone economically benefits from the project.

Circle of Alignment for Performance Metrics

As a concrete action to answer the research question three, the framework CAPM was developed, consisting of three models to improve the way we develop project performance measurement systems. They are based on renowned academic models, and the challenges form results and elements of the discussion. The models are meant to work with the existing practice of VDC and the VDC certification program from CIFE Stanford.

<u>Countering metrics model</u>: Ensures a more holistic approach to the development of performance metrics by finding what might be unwantedly sacrificed in pursuit of the metric and countering it with its own metrics.

<u>Performance metrics Johari window model:</u> Helps identify the power dynamics and business strategies of the participants and the employees' interpretation of the performance metrics. This is done by identifying the organizations performance metrics of the participants and their alignment to the project performance metrics. The model is giving the project manager a better basis to develop performance metrics and countering metrics.

<u>Development of project performance measurement system</u>: Presents the proposed steps needed to develop good project performance measurement system. It's based on Andersen and Fagerhaug (2002) approached, fused with the VDC management with metric system and the improvement model already presented.

The models have been revived by professor Bjørn Andersen and Ph.D. Kai Haakon Kristensen, as an attempt to "test" the models. Both emphasize that the models were good and point out areas for improvement and recommendation for future work.

The models concretize the process around VDC metrics, where it gives the project members an understanding of what they as a collection of organizations need to do to create valuable buildings.

6.4 Future Work

The author discovered in his work areas of performance metrics that need further attention. The areas present challenges and uncertainty related to the use of performance metrics.

- Find the effect of volatility for efficiency in the design phase over time and how to act upon it when setting targets.
- How and should contracts facilitate the implementation of performance metrics.
- How and should performance metrics change with the contract strategy.
- Which performance metric can and should be automated.

The CAPM framework should be tested, finding areas that might be unclear for the participants and need further development. As the models are meant to adapt to each project or organization, it will be interesting to see what area they desire to use and why. When testing the models on projects or within an organization, there are some questions the participants should try to answer:

- Does the model work with its current approach to performance metrics?
- Are the participants willing to align how they will produce, measure production, and progress?
- Does the model develop metrics that measure the intended concept?
- Are the participants willing to contribute?
- Is the model easy to understand for the participants?
- What is the additional cost required to calculate these measures?
- Does the model develop a balanced of leading and lagging metrics and qualitative and quantitative metrics?
- Do the participants agree on how to measure the value they are creating for the owner?

Bibliograhy

AHMAD, S. B. S., SVALESTUEN, F., ANDERSEN, B. & TORP, O. 2016. A Review of Performance Measurement for Successful Concurrent Construction. *Procedia - Social and Behavioral Sciences,* 226**,** 447-454.

ALARCON, L. F. & ASHLEY, D. B. 1996. Modeling project performance for decision making. *Journal of Construction Engineering and Management,* 122**,** 265-273.

ANDERSEN, B. & FAGERHAUG, T. 2002. *Performance Measurment Explained* Milwaukee Wisconsin, ASQ Quality Press.

ATKINSON, A. A., WATERHOUSE, J. H. & WELLS, R. B. 1997. A stakeholder approach to strategic performance measurement. *MIT Sloan Management Review,* 38**,** 25.

BALLARD, G. Positive vs negative iteration in design. Proceedings Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, Brighton, UK, 2000a. 17-19.

BALLARD, G., HAMMOND, J. & NICKERSON, R. Production control principles. Proceedings of the 17th annual conference of the International Group for Lean Construction, 2009. 489-500.

BALLARD, G. & TOMMELEIN, I. 2016. Current process benchmark for the last planner system. *Lean Construction Journal,* 89**,** 57-89.

BALLARD, H. G. 2000b. *The last planner system of production control.* University of Birmingham.

BARNES, P. & DAVIES, N. 2014. *BIM in Principle and in Practis,* London, ICE publishing.

BASSIONI, H. A., PRICE, A. D. & HASSAN, T. M. 2004. Performance measurement in construction. *Journal of management in engineering,* 20**,** 42-50.

BIMFORUM.ORG. 2018. *Level of Development (LOD) Specification* [Online]. Available: https://bimforum.org/lod/#_ftn2 [Accessed 19.11 2018].

BITITCI, U. S., CARRIE, A. S. & MCDEVITT, L. 1997. Integrated performance measurement systems: a development guide. *International journal of operations & production management,* 17**,** 522-534.

BLUMBERG, B., COOPER, D. R. & SCHINDLER, P. 2011. *Business research methods,* London, McGraw-Hill Higher Education.

BOWEN, G. A. 2009. Document Analysis as a Qualitative Research Method. *Qualitative Research Journal*.

BROWN, M. G. 1996. *Keeping score: Using the right metrics to drive world-class performance*, Amacom.

BROWN, M. G. 2007. *Beyond the balanced scorecard: Improving business intelligence with analytics*, CRC press.

CHAN, A. P. & CHAN, A. P. 2004. Key performance indicators for measuring construction success. *Benchmarking: an international journal,* 11**,** 203-221.

CHRISTENSEN, C. M. & BEVER, D. 2014. *The Capitalist's Dilemma* [Online]. hbr.org. Available: https://hbr.org/2014/06/the-capitalists-dilemma [Accessed 08.05.19].

CIFE 2017. Type of Metrics.

DRUCKER, P. F. 2008. *Managment Revised Edition* New york.

DUMAS, M., LA ROSA, M., MENDLING, J. & REIJERS, H. A. 2013. *Fundamentals of business process management*, Springer.

ECCLES, R. G. 1991. The performance measurement manifesto. *Harvard business review,* 69**,** 131-137.
EMMITT, S. 2013. *Collaborative Design Management,* London, Routledge.
EMMITT, S. 2017. *Design Management,* New York Taylor & Francis.
ENGEBØ, A. 2018. *RE: Introduction to method*
EYNON, J. 2013. *The Design Manager's Handbook,* Chichester, Wiley-Blackwell.
FISCHER, M. 2017. Instructions for ICE Session on Metrics [PowerPoint slides] California.

FISCHER, M., ASHCRAFT, H., REED, D. & KHANZODE, A. 2017. *Integrating Project Delivery,* New Jersey, John Wiley and Sons, Inc.
FLØISBONN, H. W., SKEIE, G., UPPSTAD, B., MARKUSSEN, B. & SUNESEN, S. 2018. MMI – Modell Modenhets Indeks.
HAPONAVA, T. & AL-JIBOURI, S. 2012. Proposed system for measuring project performance using process-based key performance indicators. *Journal of Management in Engineering,* 28**,** 140-149.
HJELSETH, E. 2017. BIM = Informajonsledelse. University of Oslo.
HJELSETH, E. 2018. *RE: Litt generelt om forskningsmetoder.*
HUDSON, D. N. 1997. *Benchmarking construction project execution.* University of Texas at Austin.
HUGHES, W. & GRAY, C. 2007. *Building Design Management*, Butterworth-Heinemann.
HUSSEIN, B. 2016. *Veien til suksess,* Bergen, Fagbokforlaget.
JACOBSEN, D. I. 2005. *Dokumentstudier, og innholdanalyse og narrative analyse* [Online]. UIO. Available: https://www.uio.no/studier/emner/jus/afin/FINF4002/v09/undervisningsmateriale/metodeforelesning3_tranvik.pdf [Accessed].
KAGIOGLOU, M., COOPER, R. & AOUAD, G. 2001. Performance management in construction: a conceptual framework. *Construction Management and Economics,* 19**,** 85-95.
KAPLAN, R. S. & NORTON, D. P. 2001. Transforming the balanced scorecard from performance measurement to strategic management: Part I. *Accounting horizons,* 15**,** 87-104.
KAPLAN, R. S. & NORTON, D. P. 2007. Using the balanced scorecard as a strategic management system. *Harvard Business Review,* 85**,** 150-161+194.
KAUFMAN, J. 2012. *The Personal MBA: Master the Art of Business*, Portfolio.
KENTON, W. 2018. *Law of large Numbers* [Online]. www.investopedia.com. Available: https://www.investopedia.com/terms/l/lawoflargenumbers.asp [Accessed 17.06.19 2019].
KESTLE, L. & LONDON, K. Towards the development of a conceptual design management model for remote sites. IGLC 2002: proceedings: 10th Conference of the International Group for Lean Construction, 2002. International Group on Lean Construction, 1-14.
KNOTTEN, V. & SVALESTUEN, F. 2014. *Implementing Virtual Design and Construction(VDC) in Veidekke - using simple metrics to improve the design management process*.
KNOTTEN, V., SVALESTUEN, F., HANSEN, G. K. & LÆDRE, O. 2015. Design management in the building process-a review of current literature. *Procedia Economics and Finance,* 21**,** 120-127.
KRISTENSEN, K. H. 2013. *Building design managemnt* Doctoral thesis, Norwegian University of Science and Technology.

KRISTENSEN, K. H., ANDERSEN, B. & TORP, O. 2013. Performance measurement in the building design process: A tool for building design managers. *Journal of Design Research,* 11**,** 148-167.
KUENG, P. 2000. Process performance measurement system: a tool to support process-based organizations. *Total Quality Management,* 11**,** 67-85.
KUNZ, J. & FISCHER, M. J. C. F. I. F. E., STANFORD UNIVERSITY, STANFORD, CALIFORNIA, UNITED STATES 2012. Virtual design and construction: themes, case studies and implementation suggestions.
KVALE, S. & BRINKMANN, S. 2009. *Interview: Learing the Craft of qualiative research interviewing,* USA, SAGA Publication.
LAM, E. W. M., CHAN, A. P. C. & CHAN, D. W. M. 2007. Benchmarking the performance of design-build projects: Development of project success index. *Benchmarking,* 14**,** 624-638.
LUFT, J. & INGHAM, H. 1961. The johari window. *Human relations training news,* 5**,** 6-7.
MOHAMMED, M. A. & HASSANAIN, M. A. 2010. Towards improvement in facilities operation and maintenance through feedback to the design team. *The Built & Human Environment Review,* 3**,** 72-87.
NEELY, A., MILLS, J., PLATTS, K., GREGORY, M. & RICHARDS, H. 1996. Performance measurement system design: should process based approaches be adopted? *International journal of production economics,* 46**,** 423-431.
NEELY, A. D., ADAMS, C. & KENNERLEY, M. 2002. *The performance prism: The scorecard for measuring and managing business success*, Prentice Hall Financial Times London.
OGUNLANA, S. O. 2008. Critical COMs of success in large-scale construction projects: Evidence from Thailand construction industry. *International Journal of Project Management,* 26**,** 420-430.
PATTY, R. M. & DENTON, M. A. 2010. *The End of Project Overruns: Lean and Beyond for Engineering, Procurement and Construction* Florida, Universal-Publishers.
PILLAI, A. S., JOSHI, A. & RAO, K. S. 2002. Performance measurement of R&D projects in a multi-project, concurrent engineering environment. *International Journal of Project Management,* 20**,** 165-177.
ROBINSON, H. S., ANUMBA, C. J., CARILLO, P. M. & AL-GHASSANI, A. M. 2005. Business performance measurement practices in construction engineering organisations. *Measuring Business Excellence,* 9**,** 13-22.
SAMSET, K. 1998. *Project management in a highuncertainty situation.* Ph.D. Dissertation, Norwegian University of Science and Technology.
SCHIEMANN, W. & LINGLE, J. H. 1999. *Bullseye!: hitting your strategic targets through high-impact measurement*, Simon and Schuster.
SCHNEIDERMAN, A. M. 1999. Why balanced scorecards fail. *Journal of strategic performance measurement,* 2**,** 6-11.
SPITZER, D. R. 2007. *Transforming Performance Measurement: Rethinking the Way We Measure and Drive Organizational Success,* USA, American Management Association.
STREULE, T., MISERINI, N., BARTLOMÉ, O., KLIPPEL, M. & DE SOTO, B. G. 2016. Implementation of scrum in the construction industry. *Procedia engineering,* 164**,** 269-276.
SWINK, M., TALLURI, S. & PANDEJPONG, T. 2006. Faster, better, cheaper: A study of NPD project efficiency and performance tradeoffs. *Journal of Operations Management,* 24**,** 542-562.

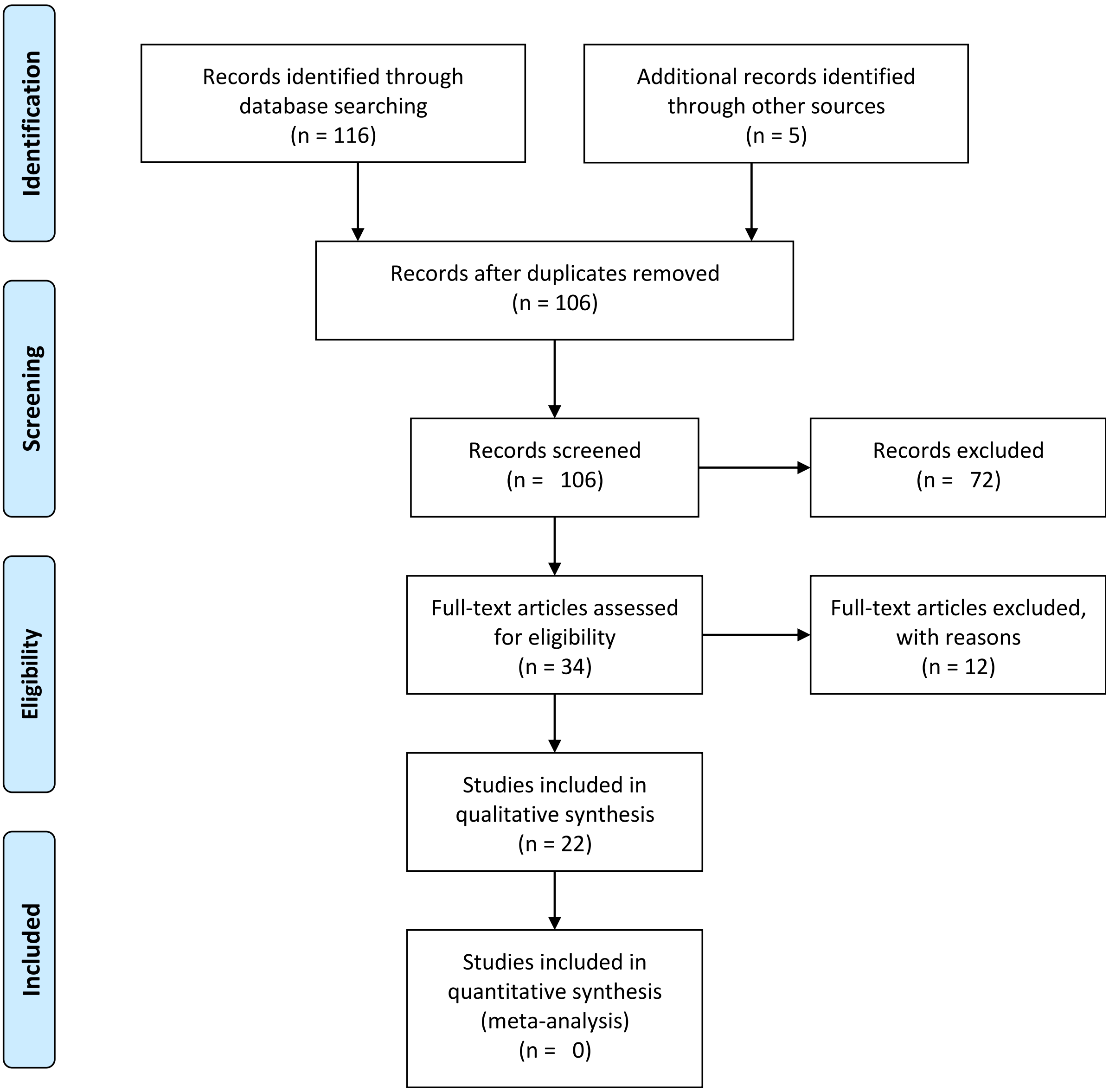
TAKIM, R. & AKINTOYE, A. Performance indicators for successful construction project performance. 18th Annual ARCOM Conference, 2002. 545-555.
TATICCHI, P., TONELLI, F. & CAGNAZZO, L. 2010. Performance measurement and management: a literature review and a research agenda. *Measuring business excellence,* 14**,** 4-18.
VAN LOOY, A. & SHAFAGATOVA, A. 2016. Business process performance measurement: a structured literature review of indicators, measures and metrics. *SpringerPlus,* 5.
VENUGOPAL, M. 2019. *Avoid Costly Mistakes and Improve Construction Project Management with BIM 360 Insight* [Online]. connect.bim360.autodesk.com. Available: https://connect.bim360.autodesk.com/bim-360-insight-construction-project-management [Accessed].
WILLIAMS, T. 2018. *Busy But Not Productive* [Online]. linkedin.com. Available: https://www.linkedin.com/pulse/busy-productive-tim-williams/ [Accessed 26.04.19].
WOMACK, J. P. & JONES, D. T. 1996. Beyond Toyota: how to root out waste and pursue perfection. *Harvard business review,* 74**,** 140-158.
YIN, R. 2014. *Case study reserach, design and method*, Saga Publication, inc

Appendix

List of attachments:

Attachment 1: PRISMA 2009 Flow Diagram

PRISMA 2009 Flow Diagram



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Attachment 2: Overview of the search results

#	Searches	Scopus	Web of science	Oria
#1	TITLE-ABS-KEY ("Performance indicators" OR "Performance metrics" OR "Performance measures" OR "Key performance indicators" OR "Efficiency measurements" OR "Project performance" OR "Process indicator" OR "Process performance" OR "Metrics")	421,477	179,341	5,273,556
#2	TITLE-ABS-KEY (Design AND construction)	265,050	136,407	3,180,613
#3	TITLE-ABS-KEY ("Design management*" OR "Design manager" OR "design project management")	2,435	1,356	90,665
#4	#1AND #2	2,934	1,373	202,028
#5	#3 AND #4	25	8	4404
#6	VDC OR “Virtual design and construction” AND #1	19	9	1334
#7	VDC OR “Virtual design and construction” AND #3	3	0	100
#8	VDC OR “Virtual design and construction” AND #4	11	3	400
#9	BIM OR “Building information modeling” AND #1	248	109	5033
#10	BIM OR “Building information modeling” AND #3	59	24	1112
#11	BIM OR “Building information modeling” AND #4	124	40	3182

Attachment 3: Interview Guide

For the reader: The interview is semi-structured; its presentation here is not representative of how the flow of the interview where. An answer to a question usually answered more of the question than the original question. The information presented behind the question is possible areas for follow-up questions.

Short introduction:

Ole Herman Haugstvedt, writing a Master thesis at the Department of Civil and Environmental Engineering for NTNU, about how to measure productivity in design in projects that contain BIM.

- Have you read the research question beforehand? If not -> Present
- The interview goes from general topics to more precise questions.
- It is possible to answer later, email, or telephone.
- It lasts about 45 min – 1 time
- The interview is fully anonymous: name, organization, project, and all other identifiers will be removed from the thesis.
- If you allow me, the interview will be transcribed. The recording stays only on my phone and deleted when the master is finished.
- If LinkedIn profile not conclusive -> which project are they working on and position
- Ask question specific to their project. Phases? How it is going?

Project managers and design managers

General

- What areas control the design phase? Cost, time, quality.
- Which has priority?
- What changes the priority?

Time

- How do you go about creating a schedule of the design phase?
- How do you measure the progress of deliverables?
- Do you use pull planning when breaking down the deliverables?
- What is the most usual hindering to declare a task healthy? Weekly look head plan.

Quality

- How do you measure quality in design?
- What controls are in place?

Cost

- How do you go about determining budgeted design?
- How do you define the number of hours for the different tasks?
- How is this measured? Are the hours register on an activity or project?
- Are the employs aware of the number of hours they can use?

ICE

- How do you feel about ICE meetings?
- What is most challenging?
- What is different now from when you started with ICE?

Metric

- Are there metrics that have become standard in projects? Which, Why,
- Which metric you think is best for the customer overall?
- What current metrics are you using? Quality, time, cost, ICE, PPM and BIM
- What are the controllable factors? Quality, time, cost, ICE, PPM and BIM
- What do you use the metrics for? Decision making, improvement process, control.
- How do you decide on the targets?
- Do you use limits/thresholds?
- When are the metrics presented (used)? ICE meeting, Frequency, time-period.
- Which tools do you use? Data collection, development, presentation
- How is the data collected? Who is responsible
- How is the data kept up to date?
- How is data storage?
- Who has access to the data?
- What happens with the data after a project is completed?

Do you feel the metrics work as intended?

- How do you feel about metrics on an induvial level?
- Has any metrics removed/stopped during a project, if so, why? What could have been done to prevent it?
- Do you benchmark metrics? Internal, externally, international.
- Are performance levels on projects taken back to improve your own performance?
- Is the result from metrics used by the owner for tenders later?
- Have your organization established a core team to facilitate the implementation VDC/performance measurement system?

Is there any undesired behavior because of any metrics? Example, Why.

- Are there conflicting metrics? How do you prevent conflicting metrics?
- How changes the productivity of design over time?
- How does one respond to the volatility at the start of the project? Do you wait a moment before the metrics take effect? Does this change the target of a metric change over time?
- Some metric is more important than the other, do you therefore rank/weight different metrics? Is the process of rank done in private?
- How do you ensure consistency, if people change/work on different projects, and they do not know the differences in "same" measures? Number of crashes
- When a performance increasing action/idea is created, does it become standard for the owner to request it? Contractual level?
- Does the increased performance result in a higher hourly rate?
- The goal of increased performance is to stay relevant and win tenders, but Increased performance reduces the number of hours spent on projects?
- How do you keep the number of sold hours up or increasing and at the same time increase productivity?

Designs/BIM coordinators

How do you get tasks in a typical work week?

- What level detail is a task given to you?
- Do you feel that you know what is expected of you?

Do you know how your productivity is measured?

- How are the numbers of hours you can spend on a task decided? Do you have an impact on that decision?
- When asked of the number of hours a task takes, do you have a method of coming up with the answer?
- Do you know the metrics that are used on the project? Which?
- What type of metrics are you subject to on projects?
- Are you responsible for any of the metrics? Which
- Do you see the result of metrics?
- Which metric works to best measure for your work?
- How do you feel about metrics on an induvial level?
- Which metric you think is best for the customer overall?
- Do you feel the metrics work as intended?
- Is there any undesired behavior because of any metrics? Example, Why.
- Are there conflicting metrics? Organization, project.

What do you feel is that limits your productivity the most? What the cause

- Do you get feedback on your work? When, How
- Is there a plan for improving your work during a project?
- Do you know what the company strategy/ vision is?
- How do you feel the metric you subject to reflect the company strategy/ vision?
- Do you share good solutions/ ideas with in the organization (e.g., scripts)? How
- When a performance increasing action/idea is created, does it become standard for the owner to request it?
- Does the increased performance result in a higher hourly rate?
- The goal of increased performance is to stay relevant and win tenders, but Increased performance reduces the number of hours spent on projects. What do you think about this

How does MMI/LOD impact the way you work?

- Is it done on objects, models, or sections?
- Do you personally feel it helps you do your job better?
- The object libraries have LOD different, how does this work with MMI/LOD
- Does clash control a reflection of the quality?

END

Given this interview, is there anything you would like me to find out? That can help you?

Thank you for participating, if there is anything you can contact me by email and phone.

Attachment 4: Meetings/ICE Performance Metrics and Controllable Factors

<table>
<tr><th colspan="3">Meetings/Integrated Concurrent Engineering</th></tr>
<tr><th>Explanation and Controllable Factors</th><th>Performance Metrics</th><th>Targets</th></tr>
<tr><td rowspan="3">Explanation: Meeting participants gave feedback on their experience of the meeting. This was done through questioners at the beginning and the end of the meeting.

Controllable Factors

Involved the discipline in preparation of meetings (Yes/No)

Meeting plan and process guide created (Yes/No)

Correct facilities (e.g., Big Rom) (Yes/No)

Right participants (%)

Participants has decision making power (e.g., Mandate) (Yes/No)

Updated metrics before meeting (Yes/No)

Updated BIM model before meeting (Yes/No)

Set of enough time to prepare and plan correctly (Yes/No)

Set of enough time to conducted meeting agenda (Yes/No)</td><td>Participants experience % felt that the meeting was correctly prepared</td><td>> 90 %</td></tr>
<tr><td>Participants experience % felt that the meeting achieved the planned outcome</td><td>> 90 %</td></tr>
<tr><td>Participants experience % felt that the meeting was valuable</td><td>> 90%</td></tr>
<tr><td rowspan="2">Explanation: Task set to be completed during the meetings (e.g., decisions, questions)

Controllable Factors

See above

Delegation of the task not completed (Yes/No)

Follow-up of the task not completed (Yes/No)</td><td>% completion of the tasks in the meeting</td><td>90%</td></tr>
<tr><td>% completion of tasks within XX days.</td><td>100%</td></tr>
</table>

Explanation: Right participants present during the meetings **Controllable Factors** Meeting invitation sent well ahead of time (Yes/No) Get commitments for next meeting (Yes/No) Mandatories participation (Yes/No) Involved the discipline in preparation of meetings (Yes/No)	Right participants (%)	80%
Explanation: At the end of the meeting, a To-do list was created, with corresponding delegations. These tasks are meant to be completed until the next meeting. **Controllable Factors** To-do list (Yes/no) Clear delegation of tasks (e.g., To-do list) (Yes/No) Confirmation of understood task by the delegated party (Yes/No) Delegated pulls (Kanban) from the task, explaining information need from meeting participants (Yes/No) Progress follow-up of the To-do list for each discipline with set frequency (e.g., one week before the meeting)	PPC of To-do list from the last meeting, XX days before the meeting	80%
	PPC of the To-do list from the last meeting, at the meeting.	90%
Explanation: Ensure that the right decision is taken (e.g., they stick) **Controllable Factors** Ask the variability of the decision. Involve the client in the early process Metrics are updated before the meeting Participants are prepared for the meeting (e.g., Information needed to make decisions is prepared) Correct facility (e.g., Big room) is there to contribute to decision-making.	% of change on the agreed-upon decision in the meeting	< 10%

Attachment 5: PPM Performance Metrics and Controllable Factors

Project Production Management		
Explanation and Controllable Factors	**Performance Metrics**	**Targets**
Explanation: List of all deliverables in the tender package, with metrics that show the progress of each deliverable. The delivery is broken down into milestones, which represent a percentage of completion. If a delivery has not met their mark, the number of days delayed is presented. **Controllable Factors** Clear scope of work for each millstone (e.g., List of tasks need for each millstone) (Yes/No) Root cause analysis of why deliveries mist their target. (Yes/No) Allocate the need recourses (e.g., what was the previous allocation compared to the current) (Yes/No) Meeting held to resolve the five most pressing issues (e.g., weekly) (Yes/No) Progress follow-up with each discipline with set frequency (Yes/No)	% completion per deliverable Delay of deliverables(days)	100% at latest XX Zero
Explanation: The deliverables have different review phases (e.g., internal control, technical control, interdisciplinary control, etc.). For each, there three stages, not started, incomplete and completed with a target date and contributor. To follow-up on the progression of the review phases, percent of completed is measured. **Controllable Factors** Ensure that the review system is prepared beforehand (Yes/No) Ensure that discipline assign the review task (Yes/No) Progress follow-up (Yes/No)	Not started, incomplete and completed % completion per review phase.	Completed 100 % by the latest XX

Explanation: Number of open and closed review comments (e.g., issues) of each discipline and stakeholders. The latency of response from each discipline and stakeholders. **Controllable Factors** Coordination meetings with disciplines at a set frequency (Yes/No) Duration of the comment being open (Days) Ranking system for the importance of the comments (e.g., minor, moderate, high, critical) (Yes/No) Follow-up of comments, with set frequency (Yes/No)	No. Of Open and No. Of Closed	Closed
	% of review comments addressed.	100% by the latest XX
	Latency comment being open	< 2 day
	Latency for critical being open	< 1 day

Project Production Management		
Explanation and Controllable Factors	**Performance Metrics**	**Targets**
Explanation: Decisions can be used as millstones, where a design decision needs to be taken to proceed (e.g., decision gate). **Controllable Factors** Allocate the need recourses (e.g., what was the previous allocation compared to the current) (Yes/No) Structured comment system and review system (Yes/No) Assignment of the tasks (Yes/No)	% of the tasks done XX days. before a decision gate.	80%
	% of tasks done by decision gate	90 %
	% critical tasks done	100%
	% of change on agreed upon decisions	<5%

Explanation: Before detailed design starts, disciplines dimension/design criteria must be provided. **Controllable Factors** Each discipline breaks down criteria for each section, status of done/not for each criterion. Criteria breakdown has % complete from the (Done/not) for discipline per section.	Each discipline provides dimension criterions within each section (Yes/no)	Yes
	% of the criteria done XX days before a detailed design starts	80%
Explanation: Cost and number of claims due to insufficient design documentation. **Controllable Factors** Interdisciplinary review done in 3D (Yes/No) Clashes of all discipline's models (Yes/No)	No. of claims due to design mistakes	Zero
	Cost of claims due to design mistakes	Zero
Explanation: Cost and number of claims due to insufficient design planning. **Controllable Factors** Schedule deliveries in collaboration with the contractor (Yes/No) Clashes of all discipline's models (Yes/No) 4D simulation of construction (Yes/No)	No. of claims due to design planning	Zero
	Cost of claims due to design planning	Zero
Explanation: Request for information due to conflict in construction between building systems. **Controllable Factors** Including contractor in the development of the design (Yes/No) Clashes of all discipline's models (Yes/No) 4D simulation of construction (Yes/No)	No. RFI's due to conflict in construction	Zero

<table>
<tr><td>Explanation: Stops on-site due to insufficient design planning and/or insufficient design documentation. Not all can be claimed.

Controllable Factors

See above</td><td>No. stops on site due to lacking and/or insufficient engineering deliverables</td><td>Zero</td></tr>
<tr><td rowspan="2">Explanation: Number of registered risk and number of handled risks.

Controllable Factors

Set up a structured risk matrix (Yes/No)

Interdisciplinary risk meetings (Yes/No)</td><td>No. Of handled and Nr. Of registered risk</td><td>Handled</td></tr>
<tr><td>% handled risk</td><td>100%</td></tr>
</table>

Attachment 6: BIM Performance Metrics and Controllable Factors

Building information modeling		
Explanation and Controllable Factors	**Performance Metrics**	**Targets**
Explanation: The target for the MMI levels in different sections, measured up against the actual MMI at the time. **Controllable Factors** Sections are defined and confirmed by each discipline (Yes/No) Clear scope of work for each MMI (E.g. List of tasks need for each level) Automated updating of federated models (Yes/No) Each discipline breaks down the criteria for each section (Yes/No) Establish workflow of entering MMI (Yes/No) Structured review system (Yes/No) Structured comment system (Yes/No)	% of model at a certain MMI at date XX per discipline.	90 -100%
Explanation: MMI at 300 (e.g., ready for interdisciplinary control) for a section before clashes control and then Interdisciplinary meeting. **Controllable Factors** Follow up on Disciplines models at MMI 300 one week before Interdisciplinary meeting. (Yes/No) Completion of MMI 300 per discipline two days before Interdisciplinary meeting. (Yes/No)	% of section at 300 MMI per discipline.	> 90 %

Explanation: MMI at 400 (e.g., production ready) for each section. **Controllable Factors** Number of unsolved clashes (No.) Interdisciplinary meeting at MMI 350 (Yes/No)	Section at 400 MMI by date XX.	> 90 %
Explanation: Control of discipline BIM models, ensure that there are not any clashes between discipline models. **Controllable Factors** Coordinate BIM models with correct coordinates (e.g., MMI100) Create/define the workflow for the Clash control model (Yes/No) Standards that defines what constitutes a clash is (Yes/No) Assignment of the clash (Yes/No)	No. of unsolved clashes	Zero
	No. of unsolved clashes from preceding test	Zero
Explanation: Surveys of the construction site, comparing the design to what has been built. **Controllable Factors** Use of 3D scans (Yes/No) Construction worker can report deviations (e.g., app-based reporting system) (Yes/No) Interdisciplinary clashes control (Yes/No) Interdisciplinary meeting at MMI350 (Yes/No) Interdisciplinary meeting with the contractor (Yes/No) Involvement of contractor in the early phase (Yes/No)	% of correlation between design model and construction	100%

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