The Effects of Digital Tools on Management Practices in the AEC Industry:

A Cross-Country Qualitative Analysis

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TU Delft

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By

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Preface

This thesis represents the culmination of my master programme in Construction Management and Engineering at Delft University of Technology. The title of the thesis is self-explanatory, as it digs into the effects digital tools have on management practices in the Architecture, Engineering, and Construction industry. Throughout the development of this study, numerous challenges emerged since this represented my first time conducting research on such a high academic level. The nature of the research as well as the look for a relevant subject led me to a constant reflective and reflexive state of mind, which further improved my own understanding of proper research by itself.

Readers who are interested in the gap in the literature as well as the value and originality of the thesis, can find this in the first Chapter. Further and detailed information is provided in the literature review in Chapter 2. Readers who are especially interested in the methodology, which is the heart of the thesis, can be referred to Chapter 3. The Discussion in Chapter 5 brings everything together, and thus readers who are looking for the answers to the research questions can directly skip to this Chapter.

I would like to thank all the people who were directly or indirectly involved in this process. I got to learn many interesting, fundamental, and not always discussed things about the construction industry. The participants from this study resulted a major support, by setting time with me even with their busy schedules. I am very grateful for your help and wish you nothing but the best success. You know who you are. Last but not least, a special and big thank you to my two supervisors Erik-Jan and Paul. Your insights during this journey were incredibly valuable to me and I deeply appreciate the friendly and off-topic conversations that we had. Your guidance, encouragement, and intelligence assisted me in ways I cannot seem to describe. To paraphrase you: “sometimes a brilliant idea takes longer to develop”, and this master thesis is the clear example of such a powerful statement.

Jaime Nicolás Castellanos
Delft, July 2024

Abstract

The past decade has witnessed a major breakthrough in technological advancements due to numerous factors, including the COVID-19 pandemic. The literature has shown a growing interest in digital tools in the Architecture, Engineering, and Construction (AEC) industry. Various technologies have been developed to monitor construction processes, reduce costs, manage safety hazards, increase efficiency, enhance performance, improve productivity, and facilitate coordination and communication. So far, most studies have focused on specific digital tools, on how these affect performance, or firms' resistance to change. However, far less attention has been paid on how these digital tools are shaping management practices in the AEC industry. This study aims to explore this gap in the literature. 9 semi-structured interviews were conducted with experts in the field from different countries leading in technological solutions. Through an abductive approach and the grounded theory method, this qualitative study identifies three variables that mediate the relationship between digital tools and management practices: *efficiency*, *effectiveness*, and *experience*. Furthermore, *resistance to change* works as a moderating variable between these two concepts. Based on this, three new management practices are created and added to the model originally developed by Bloom and Van Reenen (2007). (1) *Efficient target setting* is defined as a strategy comprised of an adequate optimiser based on important considerations that seeks to accelerate the fulfilment of targets in a construction project. (2) *Effective monitoring* is the collection of data comprised of the facilitator and the inhibitor that determine the degree to which the monitoring of a construction project is successful. And (3) *perceptual assessment* is the evaluation of objective and subjective human performance measurements. The findings suggest that the sole existence of trendy digital technologies does not translate to performance improvement within an organisation, rather, careful evaluation of these is recommended. Additionally, the successful implementation of digital tools in a construction firm implicates a modified organisational structure that promotes digital transformation. Further research could strengthen the results through quantitative methods.

Limitations of the study: First, only 9 participants were interviewed due to time constraints, although their quality was remarkable. Second, the participants were intended to be from countries where management practices have already been studied, since these are contingent on the firm's environment. But the difficulty to recruit high quality individuals and the fact that some countries do not have access to LinkedIn (e.g. China), made this difficult to achieve. And third, management practices are a broad subject, which made it challenging to discuss about each of their 18 key indicators during the interviews. Because of this, the results show a general understanding of how digital tools are shaping management practices in the AEC industry.

Keywords: *construction industry, digital tools, management practices.*

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1. Introduction

This chapter serves as an introduction of the study. It starts with a description of the research background in section 1.1, followed by the problem definition, the emerging questions, and the objectives of the study in section 1.2. Finally, section 1.3 emphasises the value of the study and its limitations. Also, a brief outline of the thesis is provided at the end of this section.

1.1. Research Background

Recently, the literature has shown a growing interest in *digital tools* in the Architecture, Engineering, and Construction (AEC) industry. Various technologies have been developed to constantly monitor construction processes, reduce costs, manage safety hazards, increase efficiency, enhance performance, improve productivity, and facilitate coordination and communication (Chen et al., 2022; Loosemore, 2014). Such is the case with Building Information Modelling (BIM), which has had a positive impact on productivity, collaboration, return on investment (ROI), and customer-client relationships in several cases (Azhar, 2011). Likewise, Artificial Intelligence (AI) technologies like robotics or machine learning are used in construction to optimise processes of design, predict the behaviour of structures and increase productivity (Egwim et al., 2023). Other technologies like Virtual Reality (VR) can generate 3D visualisations from complex data and facilitate construction processes (Chen et al., 2022). In general, digital construction tools reduce the inherent complexities of large-scale infrastructure projects through the optimisation of resources, performance enhancement, and timely delivery improvement, which has a direct impact on the allocated budget (Abdullahi et al., 2023). **So far**, most studies have focused on specific digital tools, on how these affect performance, or firms' resistance to change. For example, in a literature review by Demirkesen and Tezel (2022), they identified and ranked the main challenges of digital transformation, with resistance to change at the top of the list. Contrarily, Chen et al. (2022) determined that most technologies implemented in the AEC industry result in an increase of work efficiency. **However**, far less attention has been paid on how these digital tools are shaping *management practices* in the AEC industry. The emergence and implementation of new technologies implicate an organisational change, since organisational factors and business processes of construction firms can hinder communication, collaboration, and effective digitalisation (Prebanić & Vukomanović, 2021). Given that digitalisation of construction processes is still in its infancy (Pan & Zhang, 2023; Agarwal et al., 2016), the AEC industry is seeking inspiration from industries that encountered similar challenges in the early stages of digitalisation, like the manufacturing industry (Blampain et al., 2023).

Bloom and Van Reenen (2007) developed a scoring framework that specifically targets core operational management practices which have an impact on performance of manufacturing firms across the globe. This framework consists of 18 key practices divided into targets, monitoring, and incentives, and can determine whether a company has 'good management'. But the availability of new digital technologies, market competition, and customer behaviour are changing these traditional practices, making companies that do leverage technology more appealing (Verhoef et al., 2021). The AEC industry is not an exception,

for which innovation and digitalisation of the current processes have become an interesting and necessary topic lately. In fact, the lack of these in project management practices has led to a decrease in productivity (Jahanger et al., 2021). Nevertheless, digital tools must be implemented conscientiously, since a new organisational strategy will be formed (Bhattacharya & Momaya, 2021). To adapt to the growing use of advanced technologies, Tian et al. (2023) define digital transformation practices as "sequential changes beginning with digital technologies and management, and then transformed into expected organisation performance outcomes through a set of digital actions (p. 2)." Hence, digital tools and management practices must be approached in parallel for a smooth and successful transition into digital transformation of the AEC industry.

1.2. Problem Definition, Research Questions and Objectives

This section covers the research problem in subsection 1.2.1, the research aims and questions in subsection 1.2.2, and the objectives of the study in subsection 1.2.3.

1.2.1. Problem definition

To address the inherent complexities of large-scale infrastructure projects, various digital tools have been developed or improved over the past decade (Abdullahi et al., 2023). These tools are rapidly adapting the AEC industry into a similar version of *Industry 4.0*, where digital processes are an essential part of a firm's system (Soto et al., 2019). But the successful implementation of these digital tools in construction firms also implicates a paradigm shift in business models (Prebanić & Vukomanović, 2021). To quantify whether a firm possesses "good or bad" management practices, Bloom et al. (2012) introduced 18 key management practices. Their model is a remarkable approach and arguably the best proxy in the literature to measure management practices since the authors developed it via a double-blind survey methodology, which was executed on more than 10,000 organisations over a decade across different industries and countries. This gave place to "one of the first large internationally comparable management datasets (Bloom et al., 2012, p. 13)". Yet, this model has some limitations. It does not consider digitalisation, it disregards finance, pricing, marketing, opening and closing decisions, and innovation. Moreover, the model revolves around the manufacturing industry and thus, cannot perfectly be transferred to the AEC industry. Furthermore, in the recent strategic management literature, researchers have focused on the impact digital transformation has on performance (Tian et al., 2023), on specific digital tools (e.g. Mahmudnia et al., 2022), or on firm's resistance to change (e.g. Demirkesen & Tezel, 2022). However, far less attention has been paid on how these digital tools are shaping management practices. The increasing usage of digital technologies in the AEC industry to facilitate processes makes this subject even more relevant.

1.2.2. Research aims and questions

To address the gap in the literature and provide construction firms with guidance regarding the implementation of digital tools, the aim of this study is to explore the way in which digital technologies are shaping management practices in the AEC industry, which leads to the formulation of the following research question:

RQ: *How are digital tools shaping management practices in the AEC industry?*

To accurately answer the research question, this study also aims to investigate the definition of both concepts: digital tools and management practices. Moreover, it aims to investigate the purpose of implementing digital tools in the AEC industry and to explore the relationship between the two concepts. Hence, the following sub-questions are proposed:

SQ1: *What are management practices?*

SQ2: *What are digital tools?*

SQ3: *What is the purpose of implementing digital tools in the AEC industry?*

SQ4: *How are management practices and digital tools related?*

The answers to these sub-questions will strengthen and facilitate the main purpose of this study. An overview of the research focus, questions, and methods is shown below in *Figure 1*.

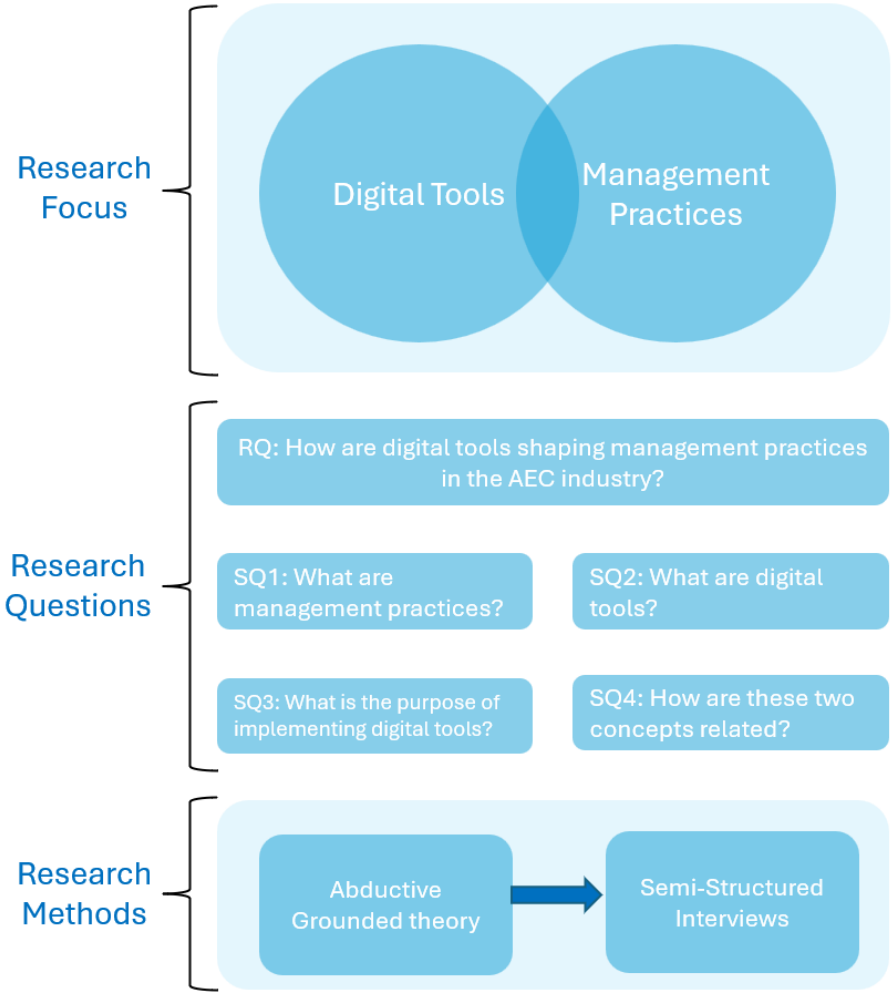

Figure 1: *Research Focus, Questions, and Methods*

1.2.3. Objectives of the study

Given the gap in the literature, the aims, and the research questions presented to deal with this problem, the objectives of this study are:

- To clearly define both concepts (i.e. digital tools and management practices) and evaluate their relationship with the AEC industry.
- To thoroughly evaluate the literature on the management practices framework proposed by Bloom et al. (2012).
- To investigate the literature on digital tools in the AEC industry.
- To investigate the purpose of implementing digital tools in the AEC industry.
- To explore the relationship between digital tools and management practices.
- To explore how digital tools are shaping management practices in the AEC industry through an appropriate research methodology.
- To explore the alignment between the current literature and empirical data.
- To provide recommendations to practitioners who wish to adopt new technologies, since this also implicates a change in management practices.

1.3. Research Value, Limitations, and Outline

This section covers the value of the research in subsection 1.3.1, the scope and limitations of the study in subsection 1.3.2, and a brief outline of the thesis in subsection 1.3.3.

1.3.1. Research value and significance

The value of this study lies in the lack of research in the literature regarding digital tools and management practices simultaneously. Research on digital transformation practices is still quite novel in the strategic and operations management field, and thus has not been sufficiently studied, let alone in the AEC industry (Tian et al., 2023; Pan & Zhang, 2023). The collection of empirical data with reference to how digital tools are shaping management practices can provide a better understanding of the current state of the industry in terms of digitalisation. With the increasing demand for digitalisation in several industries, it is particularly important to conduct research on the subject, so construction firms can make better judgements when optimising their current processes or when implementing digital technologies for the first time. Furthermore, it could potentially increase the industry's profitability, productivity, performance, efficiency, and survivability in the market. Hence, the resulting framework of this study is intended to provide recommendations and guide companies in the AEC industry who are interested in improving their existing procedures.

The past decade has witnessed a major breakthrough in technological advancements due to many factors including the COVID-19 pandemic (Sepasgozar et al., 2023). The adaptation of traditional processes into digital ones has gained more attention in the recent years but research is still insufficient. While the manufacturing industry has experienced significant improvements, the AEC industry is still in its infancy and has faced some difficulties such as the lack of standardisation or resistance to change (Demirkesen & Tezel, 2022). Besides its contribution to the body of knowledge in Construction Management and Engineering, this thesis could eventually serve as the foundation for similar studies in the future.

1.3.2. Study scope and limitations

The study of management practices is focused mostly on manufacturing firms across nations, and although it can easily be translated into areas with shared similarities, this study is limited to projects in the AEC industry. Furthermore, the AEC industry has its own complexities for which specific digital tools have been developed, and so the scope of this study lies in the change management practices has encountered given the growing digitalisation of the AEC industry in particular. Besides, three limitations worth considering are related to time constraints, access, and the extent of the topic. However, to mitigate these limitations exhaustive research on methodology methods was conducted to prevent subjective results that might not be representative in the AEC industry. Additionally, support and suggestions from the thesis committee resulted significantly valuable and enhanced the quality of the research. The limitations are described in detail in Chapter 3.

1.3.3. Structural outline

This thesis report comprehends six chapters and is divided as follows. Chapter 1 introduced the research problem, the gap in the literature, the research questions, aims, objectives, and the scope of the study. Chapter 2 provides an exhaustive literature review of the two main concepts: *management practices* and *digital tools*. Chapter 3 introduces the research methodology, which includes the design of the research, the limitations, as well as the ethical considerations of the study. Chapter 4 unveils the empirical results obtained from the research. The discussion in Chapter 5 interprets the results and their practical and theoretical implications. Finally, Chapter 6 concludes the study with a summary of the research and its main findings. In addition, this chapter provides recommendations and proposes new topics for further research based on the main findings.

2. Literature Review

This chapter works as the foundation of the thesis by diving into an in-depth literature review of the two main concepts that form part of this thesis. Section 2.1 explores the latest research on management practices. Section 2.2 examines the literature on digital tools and how these relate to management practices in the AEC industry. Finally, section 2.3 briefly summarises both concepts and concludes the chapter. Here, a theoretical conceptual framework is built based on the key points of the literature.

2.1. Management Practices

This section covers the literature on management practices. Subsection 2.1.1 covers the definition and measurement of the term based on the literature. Subsection 2.1.2 focuses on targets. Subsection 2.1.3 describes monitoring. Subsection 2.1.4 analyses the third component of management practices, incentives. Finally, subsection 2.1.5 discusses the critical reception of the model proposed by Bloom et al. (2012).

2.1.1. Definition and measurement

According to Investopedia, strategic management is "the management of an organisation's resources to achieve its goals and objectives (Kenton, 2023)". Now more than ever, strategic management is of the utmost importance due to the competitive environment different firms face. However, strategic management does not offer a one-size-fits-all model, given that firms specialise in a variety of areas. For example, Apple probably has different goals and objectives than McDonald's, and thus it organises its resources in a dissimilar way. Besides, Apple is a technology company interested in the development of smart devices and further technological advancements, whereas McDonald's is a fast-food chain restaurant which is more interested in delivering quality and affordable food. Nonetheless, both companies are well-known globally and are used as examples in business studies owing to their massive success.

There are some similarities amongst companies that are said to be 'well managed', which involve the organisational structure of the company itself, the business culture, and the skills of employees (Kenton, 2023). These factors coupled with an analysis of the market can influence whether a company achieves its goals. However, it has been difficult to measure what are 'good or bad' management practices, especially since the term 'management practices' has not been clearly defined. On the other hand, the strategies to optimise the management of manufacturing firms have been widely researched in the literature. Clegg and colleagues (2011) offer a fundamental primer of management and organisation, both in theory and practice. They start with the definition of managing practices as the actions managers do to help an organisation achieve its goals. To efficiently manage an organisation though, these managers must have a thorough understanding of the different management theories that are embedded in a certain way in the organisation. They do not need to 'reinvent the wheel', rather they need to use these theories as an educated guess to best predict the successful management of a company. For this same reason, other academics have stated that given the variety of practices and their relationship with performance, good management is contingent on the context.

Donaldson (2001) explains the contingency theory in abstract terms as the effect a variable X has on another variable Y depends on a third variable Z. This translates to organisations as the effect certain characteristic has on organisational effectiveness or performance, which is highly related to the success/failure of a company. In this context, Donaldson (2001) uses the terms organisational effectiveness and performance interchangeably and defines them based on the work of other academics as "the ability of the organisation to attain the goals set by itself, or by its ability to function well as a system, or by its ability to satisfy its stakeholders (p. 6)". Nevertheless, other researchers contradict to some degree that management practices are context dependent by stating that there are in fact best practices overall. Voss (1995) basically states that manufacturing companies with best practices outperform those with worst practices. Practices such as just-in-time manufacturing, total quality management, and Japanese manufacturing are all strategies that have been proven to be better than others. Yet, many companies refuse to take a holistic approach when implementing these, as if one strategy will solve all their problems. In hindsight, the respective literature has identified that to assess 'good' practices within a firm, these should be analysed in clusters rather than individually (Agarwal et al., 2013).

In an attempt to define management practices and determine whether 'best practices' actually exist, Bloom et al. (2012) developed a scoring framework that specifically targets core operational management practices which have an impact on performance of manufacturing firms across the globe (*Table 1*). They defined a well-managed organisation as one that tracks and refines their processes, sets achievable goals, and recognises over and under performers and acts accordingly. Contrarily, a firm with 'bad' management practices is one that fails to monitor performance, has unrealistic targets, and does not address underperformers.

Through an interview-based evaluation, Bloom et al. (2012) listed 18 key management practices that relate to one of three areas: *targets*, *monitoring*, or *incentives*. Each of these practices are indicators ranked from 1 (worst) to 5 (best), in order to determine whether a company has 'good management'. The average management practice score of manufacturing firms across countries can be found in *Figure 2*. The first key area, *targets*, refers to whether an organisation is setting realistic targets and if it is tracking its outcomes. In case these targets are not met, the organisation might need to modify the previously set targets or plan a new strategy to meet these targets based on the reason why it failed to do so in the first place. *Monitoring* refers to what can companies do to improve what happens inside a firm based on its current structure. This key area serves as a feedback loop for companies, which is significantly important in a dynamic market. Finally, the third key area, *incentives,* focuses on the quality of the personnel by constantly reviewing their performance and how this impacts the organisation. Here, a company either promotes, rewards, hires, retrains, or fires its employees in the worst-case scenario.

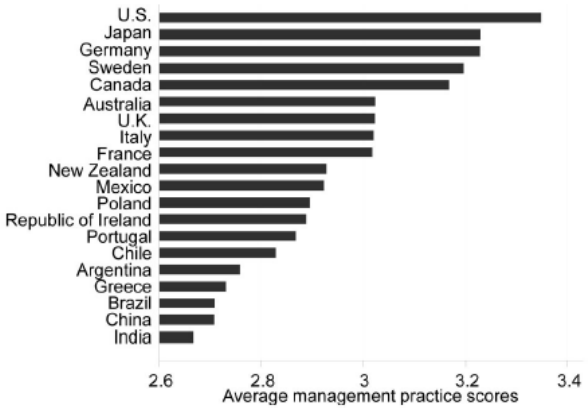

Figure 2: *Average Management Practice Scores in Manufacturing firms from different countries. Sample size: 9,079 (from Bloom et al., 2012)*

Nevertheless, the authors found three major limitations to their study. First, some management practices might depend on the firm's nature, and therefore, the model might not be translatable to some sectors. Second, other types of management like leadership were not included due to its difficulty to quantify. And third, the change of practices over time caused by external factors such as technological advancements, might modify the model. However, this model is a remarkable approach and arguably the best proxy in the literature to measure management practices since the authors developed it via a double-blind survey methodology. This approach was executed on more than 10,000 organisations over a decade across different industries and countries, and to guarantee its accuracy they used open-ended questions. This gave place to "one of the first large internationally comparable management datasets (Bloom et al., 2012, p. 13)".

The model was originally developed by McKinsey & Company (Bloom et al., 2012), which is an American company considered as one of the most prestigious firms (if not the most) in the management consulting industry ("McKinsey & Company", 2024). The purpose was to measure the quality of firms' management based on the consultants' experience and hence, it focuses on the aspects that affect a firm's performance. Still, the literature lacks a unified definition of the term (Grous, 2009) and debates whether 'good or bad' management practices can be accurately measured with such a standard method. However vague, quality management practices have been broadly researched over the years, and it seems to follow a pattern. Lakhal et al. (2006) for example, categorised ten general practices such as employee training, improvement of quality system, or information and analysis; and analysed their relationship with financial performance, operational performance, and product quality through a path analysis method (statistical analysis) with a sample of 133 manufacturing firms from Tunisia. Similarly, Patyal and Koilakuntla (2017) studied 262 manufacturing firms in India and found a positive relationship between quality management practices and performance.

Table 1: *Management Practice Dimensions (from Bloom et al., 2012)*

Categories	Score from 1 to 5 based on:
(1) Introduction of modern manufacturing techniques	What aspects of manufacturing have been formally introduced, including just-in-time delivery from suppliers, automation, flexible manpower, support systems, attitudes, and behavior?
(2) Rationale for introduction of modern manufacturing techniques	Were modern manufacturing techniques adopted just because others were using them, or are they linked to meeting business objectives like reducing costs and improving quality?
(3) Process problem documentation	Are process improvements made only when problems arise, or are they actively sought out for continuous improvement as part of normal business processes?
(4) Performance tracking	Is tracking ad hoc and incomplete, or is performance continually tracked and communicated to all staff?
(5) Performance review	Is performance reviewed infrequently and only on a success/failure scale, or is performance reviewed continually with an expectation of continuous improvement?
(6) Performance dialogue	In review/performance conversations, to what extent are the purpose, data, agenda, and follow-up steps (like coaching) clear to all parties?
(7) Consequence management	To what extent does failure to achieve agreed objectives carry consequences, which can include retraining or reassignment to other jobs?
(8) Target balance	Are the goals exclusively financial, or is there a balance of financial and nonfinancial targets?
(9) Target interconnection	Are goals based on accounting value, or are they based on shareholder value in a way that works through business units and ultimately is connected to individual performance expectations?
(10) Target time horizon	Does top management focus mainly on the short term, or does it visualize short-term targets as a "staircase" toward the main focus on long-term goals?
(11) Target stretching	Are goals too easy to achieve, especially for some "sacred cow" areas of the firm, or are goals demanding but attainable for all parts of the firm?
(12) Performance clarity	Are performance measures ill-defined, poorly understood, and private, or are they well-defined, clearly communicated, and made public?
(13) Managing human capital	To what extent are senior managers evaluated and held accountable for attracting, retaining, and developing talent throughout the organization?
(14) Rewarding high performance	To what extent are people in the firm rewarded equally irrespective of performance level, or is performance clearly related to accountability and rewards?
(15) Removing poor performers	Are poor performers rarely removed, or are they retrained and/or moved into different roles or out of the company as soon as the weakness is identified?
(16) Promoting high performers	Are people promoted mainly on the basis of tenure, or does the firm actively identify, develop, and promote its top performers?
(17) Attracting human capital	Do competitors offer stronger reasons for talented people to join their companies, or does a firm provide a wide range of reasons to encourage talented people to join?
(18) Retaining human capital	Does the firm do relatively little to retain top talent, or does it do whatever it takes to retain top talent when they look likely to leave?

2.1.2. Targets management

The average management score of a manufacturing firm is ranked from 1 (worst) to 5 (best) through all the 18 key management practice dimensions, and it serves as an indicator for a company's quality of management effectiveness. Since *Table 1* can come across as overwhelming due to the amount of information it contains, the practices are divided into three different tables based on each category

comprising the model to ensure its understanding. The first cluster, *targets*, encompasses the items between 8-12 from *Table 1*, which can be seen in *Table 2*.

Table 2: *First Cluster of Management Practices: Targets (adapted from Bloom et al., 2012)*

Cluster: *targets*	**Score measurement**
Target balance	Are the goals exclusively financial, or is there a balance of financial and nonfinancial targets?
Target interconnection	Are goals based on accounting value, or are they based on shareholder value in a way that works through business units and ultimately is connected to individual performance expectations?
Target time horizon	Does top management focus mainly on the short term, or does it visualise short-term targets as a "staircase" toward the main focus on long-term goals?
Target stretching	Are goals too easy to achieve, especially for some "sacred cow" areas of the firm, or are goals demanding but attainable for all parts of the firm?
Performance clarity	Are performance measures ill-defined, poorly understood, and private, or are they well-defined, clearly communicated, and made public?

2.1.3. Monitoring management

The second cluster to determine whether a manufacturing firm is well managed is *monitoring*. This involves items 1-6 from *Table 1* and can be seen separately in *Table 3*.

Table 3: *Second Cluster of Management Practices: Monitoring (adapted from Bloom et al., 2012)*

Cluster: *monitoring*	**Score measurement**
Introduction of modern manufacturing techniques	What aspects of manufacturing have been formally introduced, including just-in-time delivery from suppliers, automation, flexible manpower, support systems, attitudes, and behaviour?
Rationale for introduction of modern manufacturing techniques	Were modern manufacturing techniques adopted just because others were using them, or are they linked to meeting business objectives like reducing costs and improving quality?
Process problem documentation	Are process improvements made only when problems arise, or are they actively sought out for continuous improvement as part of normal business processes?
Performance tracking	Is tracking ad hoc and incomplete, or is performance continually tracked and communicated to all staff?
Performance review	Is performance reviewed infrequently and only on a success/failure scale, or is performance reviewed continually with an expectation of continuous improvement?
Performance dialogue	In review/performance conversations, to what extent are the purpose, data, agenda, and follow-up steps (like coaching) clear to all parties?

2.1.4. Incentives management

Finally, the third cluster is *incentives,* which entails the items 7 and 13-18 from *Table 1*, which can be seen in *Table 4*.

Table 4: *Third Cluster of Management Practices: Incentives (adapted from Bloom et al., 2012)*

Cluster: incentives	**Score measurement**
Consequence management	To what extent does failure to achieve agreed objectives carry consequences, which can include retraining or reassignment to other jobs?
Managing human capital	To what extent are senior managers evaluated and held accountable for attracting, retaining, and developing talent throughout the organisation?
Rewarding high performance	To what extent are people in the firm rewarded equally irrespective of performance level, or is performance clearly related to accountability and rewards?
Removing poor performers	Are poor performers rarely removed, or are they retrained and/or moved into different roles or out of the company as soon as the weakness is identified?
Promoting high performers	Are people promoted mainly on the basis of tenure, or does the firm actively identify, develop, and promote its top performers?
Attracting human capital	Do competitors offer stronger reasons for talented people to join their companies, or does a firm provide a wide range of reasons to encourage talented people to join?
Retaining human capital	Does the firm do relatively little to retain top talent, or does it do whatever it takes to retain top talent when they look likely to leave?

2.1.5. Critical reception of the model

Besides the aspects presented in the model of Bloom et al. (2012), other scholars of the strategic management literature argue that it is incomplete. Nemlioglu and Mallick (2017) complemented the use of managerial practices with innovation activities such as investment in R&D. They found that firms that not only possess good management practices, but also focus on higher innovation activities, tend to outperform those that do not. Additionally, these firms tend to survive longer in time even during crises. This phenomenon is clearly visible in the AEC industry for example. Construction firms that invested in digital technologies early to improve their processes can now outperform those that did not, while the firms that refused to adapt have less efficient processes (Chen et al., 2022).

However, whether management practices can result in higher firm's performance has been debated in the past literature. Chavez et al. (2012) found that the rate of change in a particular industry is more important than supply chain management practices to determine a firm's performance. In contrast, Brito and Sauan (2016) found empirical data that supports that management practices can indeed increase performance. Furthermore, they found that firms that exhibit a high level in one practice tend to show a higher result in other practices. Similarly, Cornwell et al. (2021) peer-reviewed and extended the previous work of Bender et al. (2018) and found remarkable coincidences. Both articles documented that more structured management practices positively affect organisational performance in German firms, which led to

retaining higher quality workforce, and thus increase productivity. In addition, both studies found that employees from organisations with higher levels of management practices receive higher salaries. However, Cornwell et al. (2021) noticed that the same did not apply to Brazil, and thus concluded that structured management practices are contingent on the local context.

To provide external validity, an earlier study published by Agarwal et al. (2013) investigated the association between management practices score and firm productivity and performance. They focused their study based on the previous work of Bloom and Van Reenen (2007), in which they had already developed the 18 key management practice dimensions. Through an empirical analysis of 152 medium and large manufacturing firms (+50 employees) located in New Zealand, Agarwal et al. (2013) found a strong relationship between management practices score and firm productivity. But contrarily to Bloom and Van Reenen (2007), they could not find a positive relationship with return on investment. Nevertheless, they validated the scoring tool given that for other characteristics such as firm size, education of managers, and product market competition found similar results. Furthermore, they concluded that some practices are more universal while others follow the contingency theory. Yet, the scoring tool proves to be an accurate measurement of management practices.

The work of Bloom et al. (2012) has been widely used by researchers because it offers a systematic measure of management practices in hospitals, schools, manufacturing, and retail firms across nations. Given its relationship with organisational performance, data has been gathered from governments, universities, and healthcare facilities. The fact that this interview-based survey tool collects high quality data and mitigates biases at the same time, led Scur et al. (2021) to develop the World Management Survey (WMS). Unlike other measurements like the Management and Organizational Practices Survey (MOPS) – which has a partnership with the US Census Bureau –, the WMS can compare management scores across countries.

However, the WMS presents some caveats. Although it includes several key performance indicators to differentiate 'good' from 'bad' practices, it disregards aspects such as finance, pricing, marketing, opening and closing decisions, and innovation as mentioned earlier (Scur et al., 2021). Additionally, certain industries might need more specific management practices or might not need to measure one in particular. Furthermore, the survey is culturally biased towards Anglo-Saxon organisations, even though the authors indicate that based on the data gathered over time, they followed a methodological approach to decrease this effect. In general terms, they claim that for the most part, the survey does not affect the relationship between management practices and performance. *Table 5* below summarises its caveats.

Table 5: *Main Caveats of the WMS model*

Caveats	Explanation
Neglect	Disregards finance, pricing, marketing, opening and closing decisions, and innovation.
Context-dependent	Different models for different industries.
Cultural	Culturally biased towards Anglo-Saxon organisations.

Given that the model has been peer-reviewed and validated by several authors, the fact that it was originally developed by one of the most prestigious firms in the management consulting industry, and that contrarily to other management models, it can compare management scores across countries, the framework by Bloom et al. (2012) will be used for this research. Although it is not perfect and it has some limitations, the model has been proven to be sufficiently accurate when measuring a firm's performance.

2.2. Digital Tools

This section focuses on digital tools. Subsection 2.2.1 covers the basics of digital transformation and its implications in the construction sector. Subsection 2.2.2 explores the most common and useful digital tools used in the AEC industry. Finally, subsection 2.2.3 links the relationship between digital tools and management practices and manifests the gaps in the research.

2.2.1. Digital transformation and Construction 4.0

The Neolithic Revolution marked a relevant turning point in history, where the human dynamics switched from hunters and gatherers to a settled agriculture (North & Thomas, 1977). Fast forward to the XVIII century, and the Industrial Revolution takes place, where innovative manufacturing processes replaced handmade production processes ("Industrial Revolution", 2024). These two periods have been accurately compared due to the significant improvement in the quality of life and the global economy, both caused by a transition of processes (North & Thomas, 1977). In modern times, a similar transition is occurring, that of digital transformation.

To understand this modern transition, Verhoef et al. (2021) exhaustively reviewed the multidisciplinary literature on the subject from 2000 to 2018 and identified three main phases of digital transformation through thematic analysis: *digitisation*, *digitalisation*, and *digital transformation*. *Table 6* below summarises each phase.

Table 6: *The Three Phases of Digital Transformation*

Phases	Definition	Example
Digitisation	The conversion of analog information into digital information (Verhoef et al., 2021).	Digital documentation
Digitalisation	The implementation of digital technologies to alter and optimise the current processes (Verhoef et al., 2021).	Online communication channels
Digital transformation	A company-wide transformation of processes and strategies through digital technologies (Verhoef et al., 2021).	Digital business models

The same authors (Verhoef et al., 2021) pinpointed three external factors pushing for digital transformation in companies and emphasised the need for this transition. First, the emergence and *availability of digital technologies* in the market such as artificial intelligence (AI), Internet of things (IoT), or robots. The exponential growth in the number of new digital options is transitioning all kinds of businesses into digital ones. Second, the *market competition* is rewarding digital companies while taking out of business less digitalised businesses. Such is the case with Booking.com, which is changing the hospitality industry. And third, *customer behaviour* is adapting to this transition, which has a considerable impact on different businesses. For example, Amazon offers an online purchasing store, which is more appealing to its users due to its practicality and comfortableness when shopping. In light of these factors, Verhoef et al. (2021) highlight that "if firms cannot adapt to these changes, they become less attractive to customers, and are likely to be replaced by firms that do leverage such technologies (p. 891)".

Based on a clearer view of what exactly are the digital transformation phases and the external factors pushing this transition, Verhoef et al. (2021) suggest four crucial aspects firms need to take into consideration so they can successfully adapt. Regarding *digital resources*, they mention that firms logically require digital assets to have a competitive position in the market. Firms also need to be competent enough to show agility when using these digital resources to maintain their position and enhance their added value. Moreover, firms must have a digital networking ability, where they can form partnerships with similar digital firms to create value. Also, firms need to be capable enough to analyse big data. Regarding, their *organisational structure*, it is worth considering having separate business units that focus on the analysis of digital technologies. To foster digital agility, a flexible structure is recommended as opposed of a top-down hierarchy one, but without ignoring different digital areas such as the IT department and other high-skilled human resources. Regarding *digital growth strategies*, it usually depends on digital platforms, but Verhoef et al. (2021) explain it based on the Ansoff matrix, comprised of market penetration, product development, market development, and diversification. Finally, firms must measure their *metrics and goals* based on their key performance indicators (KPIs) such as ROI, growth, user experience, profitability, and efficiency.

Given the increasing use of digital alternatives, a new paradigm shift has resulted across different industries, and hence new terms have emerged. One of them is *Industry 4.0*, which purpose is to explain the Fourth Industrial Revolution based on digital transformation. The term was first proposed by the German Government (Strange & Zucchella, 2017) and is now frequently used to describe "cyber-physical systems (CPS) and dynamic data processes that use massive amounts of data to drive smart machines (Sirkin et al., 2015, p. 1)". Alternatively, Lasi et al. (2014) describe *Industry 4.0* as a project characterised by two development directions, an application-pull and a technology-push. The former refers to a change of operation frameworks given new social, economic, or political demands. According to the authors, this involve short development periods, individualisation on demand, flexibility, decentralisation, and resource efficiency. While the latter refers to new technology being pushed into the market. The most relevant relate to mechanisation and automation, digitalisation and networking, and miniaturisation (Lasi et al., 2014). This Fourth Industrial Revolution is particularly important in the manufacturing industry, which is characterised by the standardisation of processes.

Similarly, the AEC industry is adapting to this trendy revolution to increase efficiency and to maintain their competitive position in the market. Hence, the term *Construction 4.0* has surfaced as the counterpart of *Industry 4.0* to describe the digitalisation and automation of construction processes (Soto et al., 2019). Its purpose is to transition the AEC industry's traditional practices into digital ones, which seeks to increase

the efficiency of processes. The potential improvement in the quality of a project, as well as the reduction of time, waste, and the cost of it, has attracted the attention of several academics. However, unlike in the manufacturing industry, construction projects occur in uncontrolled environments, are difficult to automate given their specificity, and the use of robots is very limited (Soto et al., 2019). Nonetheless, Rivera et al. (2020) state that *Construction 4.0* has three elements at its core: *Lean Construction*, *BIM*, and *Integrated Project Delivery*, each of them acting at a certain project phase. According to the authors, these elements represent the "principles of lossless production and efficient management models, the integration and use of collaborative models, and the relations between the different agents of the project. (p. 695)", respectively. However, the AEC industry is far behind the manufacturing one regarding digitalisation, and thus little is known about its benefits (Demirkesen & Tezel, 2022).

In a study by Oesterreich and Teuteberg (2016), they used a triangulation approach of both qualitative and quantitative methods to answer a number of research questions regarding the implications of *Industry 4.0* in construction. Part of their study involved two systematic reviews, content analysis, and a case study. In the end, they presented the benefits and the challenges of digital transformation in the construction industry from political, economic, social, technological, environmental, and legal perspectives (PESTEL). Their results are summarised below in *Table 7*.

Table 7: *Digital Transformation Implications for the AEC Industry (adapted from Oesterreich and Teuteberg, 2016)*

Benefits	Cost savings, time savings, on-time and on-budget delivery, improving quality, improving collaboration and communication, improving customer relationship, enhancing safety, improving the image of the industry, and improving sustainability.
Challenges	Hesitation to adopt, high implementation cost, organisational and process changes, need for enhanced skills, knowledge management, acceptance, lack of standards and reference architectures, higher requirements for computing equipment, data security and data protection, enhancement of existing communication networks, regulatory compliance, and legal and contractual uncertainty

Despite the need of digital transformation in several businesses and industries (e.g. manufacturing), and the benefits of it, the AEC industry is falling behind. In a more recent study by Demirkesen and Tezel (2022), they exhaustively reviewed the literature and identified the main challenges the AEC industry faces regarding the adoption of digital technologies. Since some of these were similar or overlapping, they formed a list containing 9 challenges. Furthermore, they conducted questionnaires and semi-structured interviews with experts in the field with the purpose of ranking these challenges in order of importance (*Table 8*). They found that the industry is very conservative, and hence *resistance to change* was ranked as the biggest challenge. Through a statistical analysis, they recognised that younger companies (at least in the US) are more open to change than older ones, and they suggest that a change in company culture plus

training aimed at this digital transition could resolve this issue. Other authors like Chan et al. (2019) mention that companies in Hong Kong refuse to accept innovative technologies like BIM because of the time required to learn a new software, which is mostly a behaviour issue. Hemström et al. (2017) instead, suggest that cooperation and communication between the involved parties in a project is key for this digital transition, although innovation still represents an economic risk and further enhances resistance to change. This also relates to the next challenges Demirkesen and Tezel (2022) identified, *unclear benefits and gains* and *cost of implementation*. Construction companies are more worried about the iron triangle components than with innovation, and given the changing dynamics of every project, the industry is *fragmented*, which appeared to be the most difficult challenge to overcome (Demirkesen & Tezel, 2022). Moreover, the *lack of standardisation* in the industry is worth considering since many companies fail to standardise their activities due to management, policy, knowledge, and market barriers (Wang et al., 2016). In addition, high-skilled personnel are fundamental to improve productivity and digital construction processes, and thus the lack of proper *labour force* is one of the biggest challenges for companies to overcome (Demirkesen & Tezel, 2022). The remaining three challenges (*lack of investment in R&D*, *data protection and cybersecurity*, and *legal and contractual problems*) are easier to overcome than the other ones but are highly influenced by company culture, since the construction industry is not usually concerned with them (Demirkesen & Tezel, 2022). Yet, these are of the utmost importance for digital transformation given the increase of digital platforms.

Table 8: *Main Challenges of Construction 4.0 (adapted from Demirkesen & Tezel, 2022)*

Challenge	**Order of importance**
Resistance to change	1
Unclear benefits and gains	2
Cost of implementation	3
Lack of standardisation	4
Fragmented and project-based nature of the industry	5
Lack of labour force	6
Lack of investment in R&D	7
Data protection and cybersecurity	8
Legal and contractual problems	9

Regardless of the potential benefits and the need to push for digital processes as reported by Verhoef et al. (2021), the AEC industry is clearly different in nature. The main challenges all increase resistance to change, and digital transformation seems a very complex subject within the construction context. Nevertheless, the successful implementation of specific digital tools can bring many advantages and support with daily construction processes as will be seen in the next subsection.

2.2.2. Digital tools in the AEC industry

Something can be catalogued as '*digital*' when the data of that something is converted from analog into digital through complex computerised codes of zeroes and ones (Verhoef et al., 2021). In the context of construction, *technology* refers to innovative "tools, machines and modifications of them that are used to achieve a goal, perform a specific function or solve a problem (Sepasgozar & Davis, 2018)". Together, *digital technologies* are part of the digitalisation phase as mentioned by Verhoef et al. (2021) and involve the alteration and optimisation of the current processes within an organisation. Most authors use the terms digital technologies and digital tools interchangeably, since a tool is defined as a piece of equipment that

helps to achieve certain activity (Cambridge Dictionary, n.d.). However, the purpose of implementing a new digital tool is to solve an existing problem or to make certain processes more efficient. Rivera et al. (2020) for example, identified the main problems the AEC industry faces through a literature review to understand how and when digital technologies might be beneficial. They identified the following 12 general issues affecting the industry:

- Cost overruns and delays
- High dependency and low interaction with suppliers
- Ineffective knowledge management
- Focus on classic routine activities
- Extensive regulation limiting innovation
- High diversity of agents leading to fragmentation
- Lack of skilled workers
- Poor financial management
- Poor asset management
- Design changes during construction
- Poor planning and programming
- High accident rate

The emergence of different digital tools has proven to be highly effective during the life cycle of a construction project in a variety of studies. According to Duarte-Vidal et al. (2021), the implementation of digital tools reduces fragmentation in the AEC industry by integrating teams, processes and organisations. Soto et al. (2018) found that digital fabrication of wall structures could increase productivity. Azhar (2011) found that BIM has had a positive impact on productivity, collaboration, return on investment, and customer-client relationships in several cases. Similarly, Wang et al. (2013) found that the combination of digital technologies such as BIM and Augmented Reality (AR), facilitates monitoring and on-site coordination when used together with tracking and laser devices like radio frequency identification (RFID). More recently, Abdullahi et al. (2023) found that the use of digital tools during the execution phase can optimise performance of mega infrastructure projects in Nigeria, and thus reducing project complexity. Another digital tool currently trending is Blockchain technology, which can be useful in the AEC industry to mitigate disputes related to payments, collaboration, and documentation (Mahmudnia et al., 2022). There are thousands of similar studies like the ones exposed above that show the advantages or potential benefits of digital technologies in construction, and thousands more that analyse one technology in particular. The vast amount of information can result overwhelming for construction companies who want to push for digital transformation but do not know where to begin.

In a first attempt to provide a holistic picture of digital technologies, Chen et al. (2022) conducted a systematic review of the different types of technologies that have been applied globally in the AEC industry from 2001-2020. Through databases such as IEEE, Scopus, Web of Science, and Google Scholar, they identified 175 peer-reviewed articles that presented empirical results (i.e. case studies or real-world examples) of the benefits of implementing these tools in the industry. From these articles they found 26 different technologies, with BIM being the most researched one in the construction domain followed by RFID, immersive media (e.g. augmented/virtual reality, gaming), multidimensional modelling (*n*D), and web services. The authors categorised all technologies into five groups based on their functionality, these being (1) data acquisition, (2) data analytics, (3) data visualisation, (4) communication, and (5) design and

construction automation. *Figure 3* below shows the different types of technologies they encountered. Similarly, they illustrated the benefits of implementing these technologies in the AEC industry through a classification of five improvement categories according to the literature. As displayed in *Table 9* below, some tools showed an improvement in more than one category, with work efficiency being cited the most (83%).

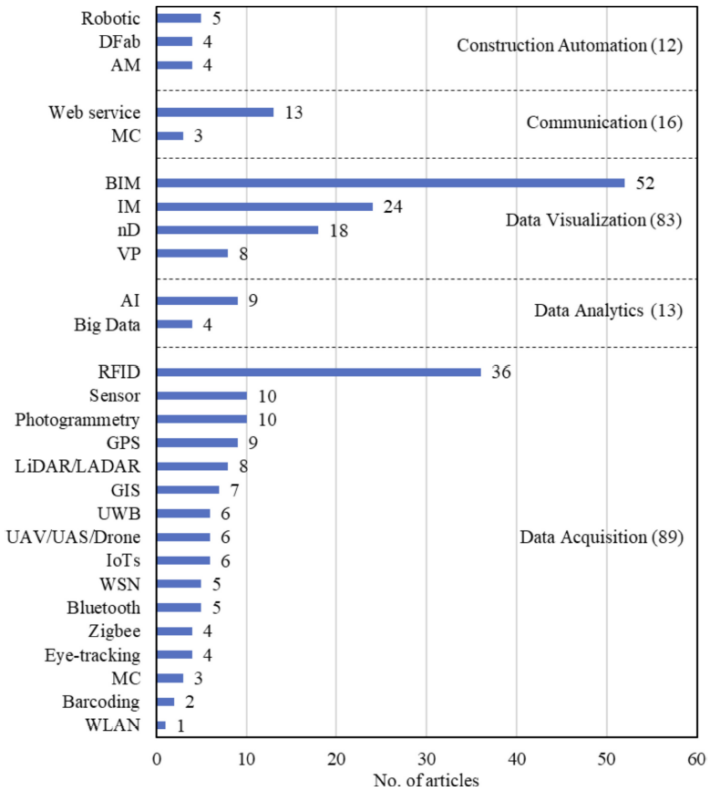

Figure 3: *The Most Used Digital Tools in the AEC Industry (from Chen et al., 2022)*

Table 9: *Benefits of Implementing Digital Technologies (from Chen et al., 2022)*

Category	Technology	Benefits				
		Efficiency	Health and safety	Productivity	Quality	Sustainability
Data acquisition	WLANs	1	–	–	–	–
	Barcoding	2	–	2	2	–
	MC	4	3	3	–	1
	Eye-tracking	1	4	2	–	–
	Zigbee	3	5	1	–	–
	Bluetooth	3	3	1	1	–
	WSNs	3	4	1	–	–
	IoTs	5	6	3	2	–
	UAV/UAS/ drones	5	5	1	3	–
	UWB	6	4	4	–	–
	GIS	7	2	2	2	3
	LiDAR/LADAR	5	5	4	5	–
	GPS	8	4	5	3	1
	Photogrammetry	9	3	4	6	–
	Sensors	3	8	4	2	–
	RFID	33	20	19	16	3
Data analytics	Big data	4	1	1	–	–
	AI/ML	6	5	2	2	–
Data visualisation	VP	7	6	4	2	1
	nD	17	9	10	6	4
	IM	21	12	12	5	1
	BIM	46	19	35	18	9
Communication	Web services	12	4	5	6	2
	MC	4	3	3	1	–
Construction automation	AM	3	1	2	3	2
	Robotic	4	1	3	2	1
	DFab	5	3	3	3	2
Total no. of articles		145	92	86	58	20
Percentage		82.86	52.57	49.14	33.14	11.43

More recently and similar to Chen et al. (2022), Naji et al. (2024) analysed 387 studies (after a thorough screening process) about digital transformation in the construction industry to comprehend the use of digital tools during pre-construction, construction, and facility management regarding buildings (*Figure 4*). Again, they found that BIM was the primary technology used and that other tools are interconnected with BIM at the core. BIM is an integral part of *Construction 4.0* since it can enhance collaboration, decision-making, communication, productivity, safety, and quality throughout all the construction phases (Naji et al., 2024). However, one of the main issues in the construction industry compared to other sectors is the resistance to change, which has resulted in firms' low productivity, lack of collaboration, and poor practices (Li et al., 2019). For this reason, the use of BIM is being pushed in countries like France and Germany due to its increasing popularity and the increasing number of studies in the construction literature, and hence it is expected to be mandatory soon (Pan & Zhang, 2023).

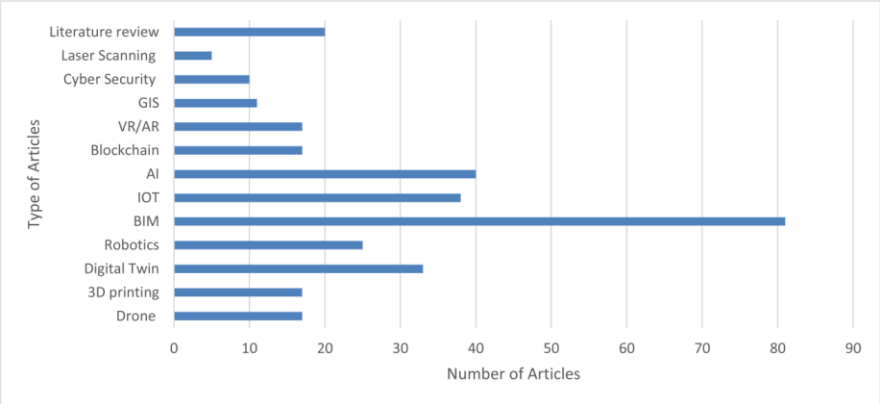

Figure 4: *Number of Articles Published Related to Digital Transformation from 2008-2023 (from Naji et al., 2024)*

According to Pan and Zhang (2023), BIM is revolutionising the AEC industry due to its ability to generate 3D visualisations and integrate solid data of projects throughout the design, construction, and operation and maintenance phase. Therefore, the integration of BIM with other technologies has received considerable attention by scholars and is currently under investigation. An example is the potential integration of BIM with AI tools (*Figure 5*), which could facilitate the retrieval of information and project analysis and might result in even higher efficiency and collaboration (Pan & Zhang, 2023). Another strategic technology that is currently being researched is Digital Twin, which connects a physical model with a digital one and analyses real world behaviour (Pan & Zhang, 2023). Unlike VR/AR, Digital Twin can accurately integrate data from the physical model into the digital one in a timely fashion (Feng et al., 2021). However, the construction industry is still in its infancy regarding digital tools and as such, a great deal of experimentation is required.

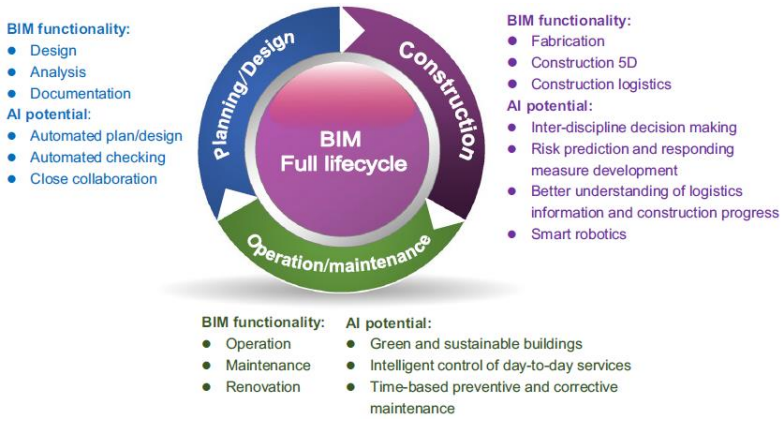

Figure 5: *Integration of BIM and AI in Projects (from Pan & Zhang, 2023)*

Furthermore, in the paper by Rivera et al. (2020) they identified 47 technologies from the *Industry 4.0* and the current or potential benefits these could have in the AEC industry. After a thorough literature review, the authors used a deductive approach to develop a technological-methodological framework comprised of the life cycle of a construction project and its relationship with three technological scenarios, these being physical domain/automation, simulation and modelling, and digitalisation and virtualisation. They grouped each technology into these scenarios and showed the potential impact these digital tools could have on each phase of the project ranked on a scale from 1 to 3 as shown in *Figure 6*. To accomplish this, they parted from three philosophies or management methodologies that have proven to be essential in *Construction 4.0* according to Rivera et al. (2020). These are (1) *Lean Construction* which is focused on constant improvement and waste reduction, (2) *BIM* which incorporates a digital model with management variables like time and cost, and (3) *Integrated Project Delivery*, which facilitates stakeholder collaboration through a multi-part contract. Aside from these management methodologies, Karmakar and Delhi (2021) also consider *Digital Twin* to be fundamental for a successful digital transformation, since it can store precise data of a project in a common digital platform. The framework by Rivera et al. (2020) revealed that apart from BIM, product-lifecycle-management technology demonstrates a high effect throughout the whole project. This technology is characterised for reducing fragmentation in the AEC industry by the integration of all construction phases. However, the construction industry is one of the most polluting in the world, and so far, little attention has been paid on the positive effect digital tools could have on sustainability and circular economy (Lu et al., 2024).

	Technology		Conceptualisation CON	Criteria Design CDE	Detailed design DDE	Implementation Documents IMP	Coordination DCO	Construction CON	Operation and Maintenance OPE	Demolition or Renovation D/R
Physical Domain / Automation	Additive Manufacturing	AM	1	1	1	1	1	3	1	3
	Cyber-Physical systems	CPS	1	2	3	3	3	3	3	2
	Digital Signage	DSi	1	1	1	1	1	3	3	2
	Embedded system	ES	1	1	1	1	1	3	2	2
	Human-Computer Interaction	HCI	1	3	2	2	2	3	2	2
	Internet of Things	IoT	1	1	1	1	1	3	3	2
	Mass Customization	MCu	3	3	3	2	1	1	2	2
	Modularity	M	1	1	1	2	2	3	2	2
	3D scanner	3DS	1	1	1	1	2	3	2	2
	Off-site Construction	OSC	1	2	1	1	2	3	1	2
	Product-Lifecycle-Management	PLM	3	3	3	3	3	3	3	3
	Radio Frequency Identification	RFI	1	1	1	1	1	3	2	2
	Robotics	R	1	1	1	1	2	3	2	2
	Self-sustainability and Self-sufficiency	SS	1	1	2	1	1	1	3	1
	Sensors	S	1	1	1	1	1	2	3	2
	Supply Chain Management	SCM	1	1	1	1	1	3	3	2
	Unmanned Aerial Vehicle	UAV	1	1	1	1	1	3	2	2
	Wearable Technology	WT	1	1	1	1	1	3	3	2
Simulation and Modelling	Simulations models and tools	SMT	1	2	3	2	3	3	3	2
	Artificial Intelligence	AI	1	3	3	2	3	3	3	2
	Machine Learning	ML	2	3	3	2	3	3	3	2
	Data mining	DM	2	3	3	2	3	3	3	2
	Neural Networks	NNs	1	3	3	2	3	3	3	1
	Predictive maintenance	PM	2	3	1	1	2	1	3	3
	Improve Asset Utilization	IAU	1	2	1	1	1	1	3	2
	Big Data analytics	DBA	2	3	3	1	2	3	3	1
	Augmented Reality	AR	1	2	3	1	3	3	2	2
	Virtual Reality	VR	1	3	3	1	3	3	2	2
	Mixed Reality	MR	1	2	3	1	3	3	2	2
	Building Information Modelling	BIM	3	3	3	3	3	3	3	3
	Photogrammetry	Ph	1	2	3	1	2	3	2	1
	Geographic Information System	GIS	2	3	3	2	2	2	2	1
Digitalisation and Virtualisation	5G	5G	1	1	1	2	1	3	3	1
	Mobile Applications	APPs	1	2	1	3	2	3	3	2
	Mobile Computing	MCo	1	1	1	1	2	3	3	2
	Industrial Internet	II	1	1	3	2	1	3	3	1
	Social Media	SM	2	2	2	2	3	3	2	2
	Automated regulation checking and Audits	ARCA	1	2	3	3	3	2	2	1
	Big Data	BD	2	3	2	2	2	2	3	2
	Blockchain	B	1	2	3	3	3	2	3	1
	Cloud Computing	CC	1	2	1	3	2	2	3	1
	Common Data Environment	CDE	2	2	2	3	3	2	3	2
	Cybersecurity	C	1	2	2	3	3	3	3	2
	Data Sharing	DSh	2	3	3	1	1	1	3	2
	Deep Learning	DL	1	2	3	2	3	2	2	1
	Digital twin	DT	1	2	3	3	3	3	3	2
	Edge computing	EC	1	1	1	1	2	3	3	2

3	High potential effect
2	medium potential effect
1	Low potential effect

Figure 6: *Expected Impact of Technologies in the Life Cycle of a Construction Project (from Rivera et al., 2020)*

2.2.3. Relationship between digital tools and management practices

The availability of new technologies, market competition, and the shift in customer behaviour as described by Verhoef et al. (2021), are the external factors pushing for digital transformation in several businesses, especially in the manufacturing industry. The current strategic management literature is researching the influence digital transformation has on performance. For example, Tian et al. (2023) found that digital transformation practices have a positive effect on workforce productivity, physical asset efficiency, and working capital efficiency, which are all aspects of operational efficiency. Based on their findings, they propose three important managerial implications worth considering. First, manufacturing firms must recognise digitalisation as an important strategic orientation. Second, firms must prioritise investment in digitalisation to increase efficiency in the long-term. And third, firms should adjust their digitalisation depending on the external environment, given that a highly competitive environment weakens operational efficiency. Although more research is missing, digitalisation is certainly changing the traditional management practices defined by Bloom et al (2012), which are mostly focused on manufacturing firms.

The AEC industry is not an exception, in fact, digitalisation of construction processes is still in its infancy compared to other industries (Pan & Zhang, 2023; Agarwal et al., 2016). Consequently, it is seeking inspiration from these industries which encountered similar challenges in the early stages of digitalisation (Blampain et al., 2023). Both digitalisation and innovation in the AEC industry are particularly important since the lack of these in project management practices has led to a decrease in productivity (Jahanger et al., 2021). However, Prebanić and Vukomanović (2021) found that organisational factors and business processes of construction firms can hinder communication, collaboration, and effective digitalisation.

Through an integrative review methodology, Bhattacharya and Momaya (2021) developed a strategy framework to facilitate a sustainable digital transformation in the AEC industry. They mention that the prevailing processes and managerial practices in an organisation are affected by the alteration of patterns of activity and vice versa. Thus, a new organisational strategy is required in the context of digital transformation. Their strategy framework was constructed based on three pillars. Firstly, this transition must be simple, flexible, agile, and actionable; and must be guided by an interdisciplinary capability centre. This strategist centre should focus on the main objectives, risk management, team coordination, as well as on the implementation of digital tools through what-if solutions. Secondly, the strategy must consider the dynamic capabilities of the organisation. This pillar refers to the routines and processes within the organisation which will change and shape the business model. And thirdly, digital transformation must consider the management of a careful confluence of change and continuity forces. On the one hand, they found through questionnaires that the main drivers of *change* were similar to those exposed by Verhoef et al. (2021), these being the need for competitiveness, industry trends worldwide, and the emergence of new digital tools. On the other hand, *continuity forces* are related to an organisation's resistance to change, primarily company culture, the current processes and networks, and the existing standard operating procedures. Their resulting framework is shown in *Figure 7*. Additionally, Bhattacharya and Momaya (2021) analysed the digital tools that have a significant impact on productivity in the AEC industry and found similar results to Naji et al. (2024), with BIM, AR, Machine Learning, and Drones/Sensors at the top of the list.

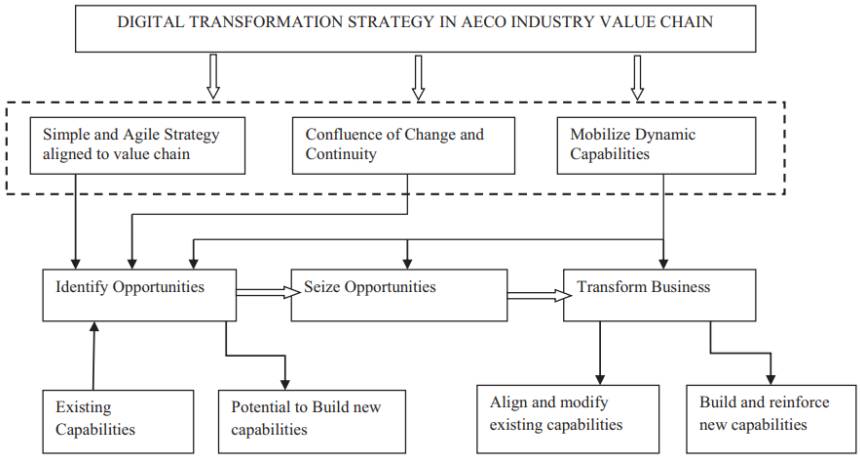

Figure 7: *Strategy Framework of Digital Transformation (from Bhattacharya & Momaya, 2021)*

As a result of an imminent digital transformation in the AEC industry, construction firms must adapt in order to maintain their competitive position (Verhoef et al., 2021). More specifically, they need to adapt in four areas, strategic/environmental, product/service, process management, and organisational, which are all aspect of business management adaptability (Zhang et al., 2021). Likewise, Bugarčić and Slavković (2023) suggest that digital transformation implies a change in planning, organising, management, and control processes. In addition, they found that the implementation of digital tools in the construction sector is imperative to improve project management effectiveness, which can be reflected in the creation of new business models and the awareness of employees. For example, Tetik et al. (2019) developed a new technology-based operations management practice called Direct Digital Construction (DDC) to "improve construction operations management in supply chains and firms' processes (p. 12)". Basically, DDC derives from DDM, or Direct Digital Manufacturing, and uses the concepts of BIM and Virtual Design and Construction (VDC) to add value and increase efficiency of a project throughout its lifecycle. To achieve this, Tetik et al. (2019) suggest increasing the level of detail during the design phase. Albeit time-consuming, it could have a significant impact on the construction and maintenance phase due to less on-site improvisation and undocumented changes in the digital model. However, how *digital tools* are shaping the *management practices* originally proposed by Bloom et al. (2012) has not been researched before, let alone in the AEC industry.

2.3. Conclusion of the Literature Review

To determine the best practices in manufacturing firms, Bloom et al. (2012) developed a scoring framework comprised of 18 key management practices divided in three clusters: targets, monitoring, and incentives. Furthermore, they defined a well-managed organisation as one that tracks and refines their processes, sets achievable goals, and recognises over and under performers and acts accordingly. In contrast, a firm with 'bad' management practices fails to monitor performance, has unrealistic targets, and does not address underperformers. This model has been analysed and critiqued by several authors such as Agarwal et al. (2013), Brito and Sauan (2016), Bender (2018), and Cornwell et al. (2021). Unlike other measurements, the WMS can compare management scores across countries. However, Scur et al. (2021) identified three main caveats of the model. First, it disregards aspects such as finance, pricing,

marketing, opening and closing decisions, and innovation. Second, certain industries might need more specific management practices or might not need to measure one in particular. And third, the survey is culturally biased towards Anglo-Saxon organisations. Nonetheless, it is considered the best international approach to measure performance within an organisation.

On the other hand, the AEC industry is adapting to the Fourth Industrial Revolution to increase efficiency and to maintain their competitive position in the market. However, the AEC industry is far behind the manufacturing one regarding digitalisation, and thus little is known about its benefits (Demirkesen & Tezel, 2022). To show this, Demirkesen and Tezel (2022), exhaustively reviewed the literature and identified 9 main challenges the AEC industry faces regarding the adoption of digital technologies. Moreover, they ranked each challenge on order of importance and found that *resistance to change* is the most important one. Digital tools in the AEC industry are generally used to achieve a goal, solve a problem, alter, and optimise the current processes of an organisation (Sepasgozar & Davis, 2018; Verhoef et al., 2021).

A theoretical conceptual framework is constructed based on the research question and the current literature (*Figure 8*). The independent variable is *digital tools*. This is the variable that is not influenced by other variables and was manipulated during the study to explore its effects on the dependent variable, *management practices*. However, this study was limited to the AEC industry, therefore only the relevant literature was used to find the other variables.

According to the systematic review from Chen et al. (2022), the main benefit resulting from the implementation of digital tools in the AEC industry is an increase in work efficiency. Likewise, Pan and Zhang (2023) mention that the combination of digital tools such as BIM with AI has the potential to increase efficiency. Tian et al. (2023) found that digital transformation practices have a positive effect on workforce productivity, physical asset efficiency, and working capital efficiency, which are all aspects of operational efficiency. Tetik et al. (2019) invented a new operational management practice called DDC which uses the concepts of BIM, VDC, and DDM to add value and increase efficiency of a project throughout its lifecycle. Oesterreich and Teuteberg (2016) pinpointed various benefits of the implementation of digital tools such as cost and time savings, improved collaboration and communication, or on-budget delivery, which can also be considered as elements of efficiency. There are numerous other examples of digital tools that have proven to increase efficiency since the counterpart of *Industry 4.0*, i.e. *Construction 4.0*, describes the digitalisation and automation of construction processes (Soto et al., 2019). Hence, the mediator variable between digital tools and management practices is *increase in efficiency*.

In contrast, the moderator variable that affects the relationship between digital tools and management practices is *resistance to change*. Oesterreich and Teuteberg (2016) mention that some of the biggest challenges the AEC faces regarding digital transformation are hesitation to adopt, high implementation cost, organisational and process changes, and acceptance, which all relate to resistance to change. Similarly, Demirkesen and Tezel (2022) found in their study that the top challenge to adopt digital technologies is resistance to change, followed by unclear benefits and gains and the cost of implementation. Li et al. (2019) also mentions that the resistance to change hinders the implementation of distributed ledger technologies like Blockchain. In fact, several academics that study digital transformation agree that resistance to change is quite ingrained in the AEC industry. Regarding the control variables shown in *Figure 8*, *academic background*, *years of experience*, and *digital advancement*; these were used as parameters for the sampling strategy and are described in detail in Chapter 3.

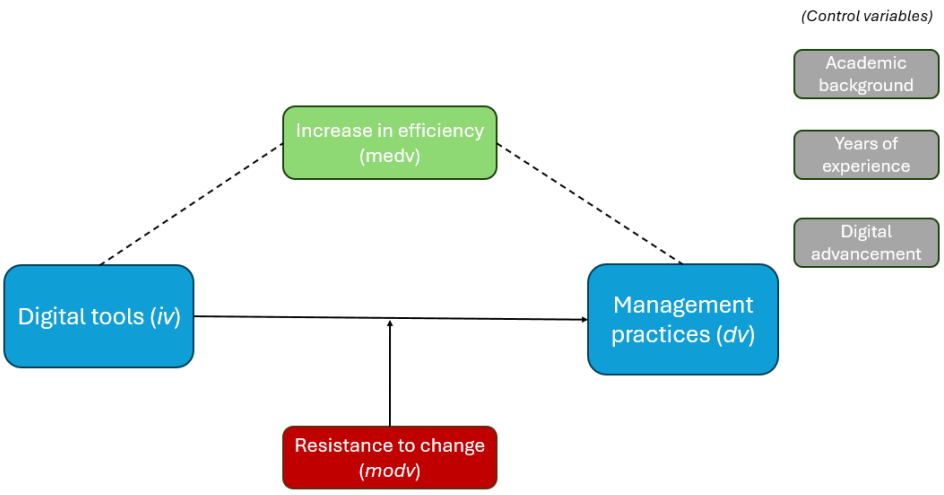

Figure 8: *Theoretical Conceptual Framework*

3. Methodology

This chapter elaborates on the design of the research in section 3.1 followed by the research procedures and techniques in section 3.2. After this, the limitations of the research are described in section 3.3. Subsequently, section 3.4 comments on important ethical considerations of this study.

3.1. Design of the Research

This section follows the Research Onion proposed by Saunders et al. (2023) to describe under which criteria the research was conducted. This methodology strategy was originally designed for business studies; however, it is suitable in this context due to the social nature of the research topic and its ability to provide a comprehensive view of the research questions and ensure consistent results that can be replicated later in future studies (Melnikovas, 2018). The Research Onion is divided into layers and goes from the outer layer to the inner layer of research methodology. This organisation allows an accurate view of the researcher's line of reasoning to answer the research question through an appropriate method.

Subsection 3.1.1 describes its philosophy. Subsection 3.1.2 explains the approach of the research. Subsection 3.1.3 focuses on the methodological choice. Subsection 3.1.4 elaborates on the research strategy and finally, subsection 3.1.5 specifies the time horizon of the research.

3.1.1. Research philosophy

According to Saunders et al. (2023) there are three common research assumptions: ontology, epistemology, and axiology. This study parted from an **ontological** research assumption where it focused on the nature of reality and what is the world like. Given the purpose of this research this ontological assumption followed an **objectivist** philosophy dimension, meaning that it emphasised that the existence of social actors does not influence reality. In this case, the assumption comes from the fact that the introduction of digital tools in the AEC industry would affect management practices objectively. The effect it produces is not influenced by the existence of the participants or the researcher. Furthermore, Saunders et al. (2023) identify two types of research paradigms: the regulation perspective and the radical change perspective. The nature of this research followed a **regulation perspective**, where organisational affairs are understood and suggestions are made to regulate them rather than to challenge the already existing system. In this context, the introduction of digital tools in the AEC industry is shaping management practices in a certain way which needs exactly that, regulation in order to improve the current organisational position. Burrell and Morgan (1979) assert that this research paradigm organisation would fall into the **functionalist** category. This paradigm, characterised by the objectivist and regulation dimension, aims to generate recommendations for improvement based on logical explanations of the present frameworks (Saunders et al., 2023).

All things considered, this research was guided by the **critical realism** philosophy. According to Saunders et al. (2023) this philosophy is characterised by the things people "see and experience in terms of the underlying structures of reality that shape the observable events (pp. 148-149)". Put differently, reality is external and autonomous, and it is comprised of both empirical observation and the actual events that might not have been observed. Regarding this thesis topic, the introduction of digital tools in the AEC industry has been widely researched. However, this alone does not offer the whole picture of how these

are shaping management practices. Practical and theoretical evidence are both imperative to provide a more accurate clarification of the social world, and the research philosophy mentioned above is the most appropriate to provide an explanation of the underlying causes and mechanisms that are shaping management practices, especially since this thesis focuses on how things have changed over time. Moreover, unlike other research philosophies, critical realism considers how different socio-cultural backgrounds and experiences might affect reality and will try to minimise these through objectivity to prevent possible research biases (Saunders et al., 2023).

3.1.2. Research approach

There are mainly three research approaches: deductive, inductive, and abductive. Research that follows a deductive approach develops new hypotheses based on the literature and collects new data to test these theories. The inductive approach does the opposite, it collects data to understand a phenomenon and develops a new theory based on the data already collected (Saunders et al., 2023). This thesis followed an **abductive** research approach, which interacts between the other two approaches. In essence, the abductive approach moves 'back and forth' between the theory and the empirical data to identify patterns and generate or modify an existing hypothesis or proposition. In fact, the fictional character Sherlock Holmes created by Sir Arthur Conan Doyle uses this type of scientific approach to solve crimes rather than the 'science of deduction' (Saunders et al., 2023).

Within this thesis' context, the abductive approach (also called retroduction) was the most suitable to explain how are digital tools in the AEC industry shaping the already existing management practices. In general terms, the academic literature facilitates the observation of certain phenomenon while the collection of data identifies and explains the mechanisms that are challenging the literature. This way, a new framework can be developed through an iterative process between the literature and the empirical data, which can be tested later in future studies (usually by a deductive approach). According to Kovács and Spens (2005), in order to develop new scientific knowledge through abduction, creativity and intuition are imperative to escape from the limitations of the other two research approaches, and just like Sherlock Holmes, an intuitive leap rather than a logical procedure describes the research conducted in this thesis.

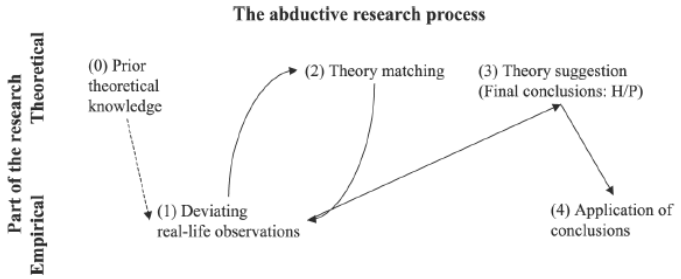

Figure 9: *The Abductive Research Process (from Kovács & Spens, 2005)*

3.1.3. Methodological choice

It is important to mention that this study is **exploratory** due to its focus on the 'What' and the 'How' of a certain phenomenon, i.e. the research questions given the gap in the literature. According to Saunders et al. (2023) the methodological choice frequently refers to a quantitative, qualitative, or mixed methods study depending on the kind of data collected. Since this study was not interested in numerical data to answer the 'What' and the 'How' of the research questions, it followed a **qualitative** analysis. For an accurate collection of data, quickly building rapport and trust with the participants and asking for

clarification when needed was of the utmost importance, while also steering the conversation into the researcher's interests.

3.1.4. Research strategy

Of all the research strategies available in the social sciences, **grounded theory** was the most appropriate strategy for this context. In this case, an objectivist philosophy was considered to discover and explain an external reality based on both the theory and the data provided by social actors (participants). Bryant and Charmaz (2007) consider grounded theory to be an iterative process in which the potential theoretical explanations of the results are analysed. For this reason, an abductive approach was reasonable. Moreover, this is an emergent research strategy, and as such required the researcher to be competent, reflexive, and to have some degree of theoretical sensitivity (Saunders et al., 2023) while analysing the findings in order to create new conceptual possibilities grounded in the data.

3.1.5. Time horizon

Due to time constraints the research was **cross-sectional**, meaning that the study of how digital tools are shaping management practices in the AEC industry was conducted at a particular point in time. Although the study focused on 'what' and 'how' something has changed over time, the interviews and the screening process were designed in such a way that the participants were able to positively contribute to the research.

3.2. Research Procedures and Techniques

Following the Research Onion by Saunders et al. (2023), this section elaborates on the research procedures and techniques. Based on the objective philosophy of the research described above, appropriate methods are chosen to answer the research question, which are contingent on observation of the already existing system (as defined earlier by critical realism). Subsection 3.2.1 elaborates on the sampling strategy and access. Subsection 3.2.2 describes the data collection method. Finally, subsection 3.2.3 discusses how the data was analysed.

3.2.1. Sampling strategy and access

To get accurate results the sampling strategy heavily relied on the quality of its participants, and thus followed a non-probability sampling procedure. More specifically, a **purposive sampling procedure** which is characterised for selecting information-rich cases as opposed to statistically representative cases (Saunders et al., 2023). Additionally, the type of sampling procedure was **homogeneous**, meaning that the participants presented similar characteristics in terms of work experience, academic background, and digital advancement.

To ensure this, access to appropriate participants was necessary. Saunders et al. (2023) describe three main characteristics of access: type, nature, and level. For the purpose of this research, the participants were contacted through an **internet-mediated** type of access, in this case LinkedIn. One of the advantages of this social network is that it was relatively easy to find suitable candidates based on their qualifications. Moreover, an **individual person** nature was used to gain access to these subjects, meaning that organisational access was not required; the subjects were contacted directly. Finally, the level of access was **cognitive**, were the participants granted consent to participate in the study. The message used to recruit intended participants is shown below.

"Dear [participant's name],

I hope this message finds you well. My name is [researcher's name], and I am a master student at TU Delft (The Netherlands). I am conducting a research study on Digital Construction Management as part of my thesis. I am writing to invite you to participate in this study. Based on your background and expertise, your insights would be incredibly valuable to my research. This would entail an online interview that will last 45-60 min and could be scheduled at your convenience. Your participation would be greatly appreciated for the success of my research and obtainment of my master's degree in Construction Management & Engineering. Please let me know if you can participate, in which case I will send you a consent form explaining the details.

Sincerely,

[Researcher's name]

[Researcher's student email address]"

Furthermore, the screening process to recruit subjects was assessed based on three criteria: academic background, years of experience, and digital advancement. First, the **academic background** required to participate in this study was narrowed to the AEC industry, i.e. either architects, (civil) engineers, or construction managers who specialised in digital solutions. If the subjects had a degree in these or similar areas, they were considered. Although some people that work in the AEC industry do not possess these degrees, the prior training as problem solvers was prioritised. Second, the **years of experience** was examined. At least 5 years of experience in the industry was indispensable, where subjects with further experience were given preference. This was fundamental given the goal of the study, which was to examine how something has changed throughout time. Evidently, more experienced subjects were able to provide better answers, but were more difficult to recruit due to their busy schedules. And third, the **digital advancement**. This last element referred to the technological development present in the country of the participant. To get a broader picture of the issue at hand, this study was not limited to one country, and thus, a cross-country qualitative analysis was conducted. Since management practices scores are comparable across nations by the WMS, it makes sense to conduct the research in multiple countries. While digital advancement varies from company to company across the globe, more developed countries where given preference to avoid a lack of awareness of digital tools in the AEC industry.

To find participants who could meet these requirements, the social network LinkedIn was used. LinkedIn allows its users to join groups of people with similar professional interests and 'connect' with them. In this case, engagement with groups concerned about digital solutions in the AEC industry were considered. While many people were contacted, in the end only **9** of them decided to take part in the study. However, given the strict participation requirements, the quality of the participants was remarkably satisfactory, with some of them having worked in over 100 construction projects, others being involved in lean construction, others being involved in research of digital tools, and some having worked in multi-million and multi-billion (currency) projects. Therefore, extra subjects would have not affected the validity of the results. *Tables 10*, *11*, and *12* below show some characteristics of the subjects while maintaining their identity confidential.

Table 10: *Academic Level of Participants*

Academic level	Number of participants
Bachelor	1
Master	5
PhD (ongoing or obtained)	3

Table 11: *Years of Experience in the Field*

Years of experience	Number of participants
5-10	1
11-15	2
16-20	4
21+	2

Table 12: *Countries Where Participants Have Worked*

Countries
USA
England
Ireland
The Netherlands
Mauritius
UAE
Saudi Arabia
Brazil

3.2.2. Data collection

To collect the data, **semi-structured interviews** with a thematic format were conducted. The questions for the interviews were planned in advance and had an open-ended structure. These types of interviews have shown to be a proper technique given that they serve as controlled conversations were the interviewees answer preset open-ended questions that are skewed towards the interviewer's interests (Jamshed, 2014). The interview guide is shown in *Appendix A*. Given that management practices are divided into *targets*, *monitoring*, and *incentives*, the questions basically addressed how digital tools have changed these in the AEC industry, and as such, the interview questions were divided among these three themes (*targets*, *monitoring*, and *incentives*). The follow-up questions depended on the conversation, at times these involved specific items of targets, monitoring, or incentives, and at other times these were concerned about a certain technology. At no point were the research questions asked nor personal opinions, experiences, or assumptions given. The intention of the researcher was to get quality information by asking relevant questions that could support the study and occasionally rephrasing some for further clarification.

The interviews were conducted on a **one-to-one** basis between the researcher and the interviewee and were held **online** through Microsoft Teams (student account of MS Teams provided by TU Delft). Before each interview the interviewees were directly asked if they give consent to record the meeting. To relax

the participants and ensure the quality of the data provided, the first 5 minutes was focused on building rapport and trust by sharing personal information about the researcher and explaining data confidentiality matters. Subsequently, a couple of broad questions about the participants were asked regarding themselves and the construction industry to smoothly transition the conversation into the main themes (see *Appendix A*). Incidentally, the interview questions were not shared with the participants before each interview to prevent any biases.

Once the interviews were completed, the researcher gave a brief explanation of the purpose of the research and answered emerging inquiries from the interviewees. The transcripts were automatically generated by Microsoft Teams but were revised and edited by the researcher where necessary (data cleaning) based on the recordings. The recordings and transcripts of the interviews were stored confidentially and were not shared with anyone. Finally, these revised transcripts were sent back to the respective interviewees. The duration of each interview is shown below in *Table 13*.

Table 13: *Duration of the Interviews*

Number of interview	Duration
Interview 1	54 min
Interview 2	50 min
Interview 3	48 min
Interview 4	51 min
Interview 5	50 min
Interview 6	51 min
Interview 7	1h 41 min
Interview 8	57 min
Interview 9	47 min

3.2.3. Data analysis

Given the philosophy and design of the research, the **grounded theory method** was used to analyse the data. There are many academics on the subject of grounded theory and they all have differing views on the correct approach. However, they all share the same foundations. Corbin and Strauss (1990) argue that the main goal of grounded theory is not to generalise the results to a wider population, the focus is on the representativeness of its concepts. This way a theoretical explanation can be provided based on a particular phenomenon. Charmaz (2014) insists that where the research question addresses social processes or factors that shape a phenomenon, the grounded theory method is suitable. Since the main research question of this study does exactly that, this method was the most appropriate.

First, after each interview the generated transcripts were modified were needed (data cleaning). The recordings of the interviews were used to accurately do this. This helped to familiarise with the data, reflect on it, and to improve the quality of the succeeding interview as new questions and interests emerged. Second, the transcripts were introduced into *Atlas.ti* and line-by-line coding began. The coding process was done in accordance with Braun and Clarke (2006), where the data is reduced and grouped into subthemes. However, once the *initial coding* process was completed, *axial coding* followed. Basically, the existing codes were grouped together into clusters that derived from the literature, in this case, the management practice clusters: *targets*, *monitoring*, and *incentives*. An additional category named *miscellaneous* was created to add other codes that although interesting, did not belong to the aforementioned clusters. Unlike with reflective thematic analysis, a paramount part of the grounded

theory method is a constant comparative analysis, where the data is carefully analysed and divided into categories (Braun & Clarke, 2020; Corbin & Strauss, 1990; Tie et al., 2019). And third, *selective coding* ensued, where subcategories were created from the core categories and only the codes that helped to answer the research question were considered, while the rest were disregarded. The paper by Pas et al. (2019) served as an example to correctly analyse the data, where second and third order constructs were created. This was an iterative, pondering, and time-consuming process which successfully led to answer the research question of this thesis through new theory development. An overview of the whole methodology is shown below in *Figure 10*.

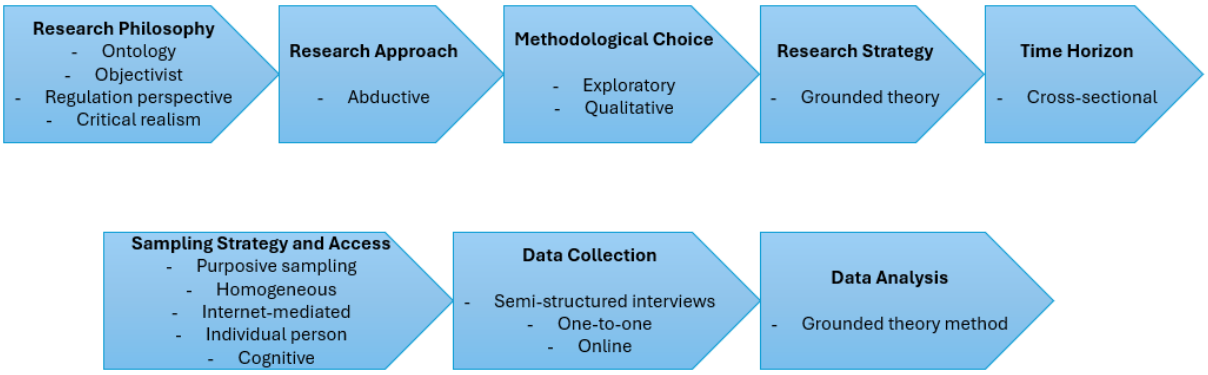

Figure 10: *Overview of the Research Methodology*

3.3. Study Limitations

There are three main limitations regarding this research:

- Ideally, the participants were intended to be from countries where management practices have been studied, since these are contingent on the firm's environment. However, given the limited time, the difficulty to recruit high quality participants, and the fact that some countries do not have access to LinkedIn (e.g. China), made this difficult to achieve. Nevertheless, the strict sampling procedure helped to mitigate this problem.
- Initially 10 participants were expected to be part of this study. Due to time constraints and the lack of response from the desired participants, only 9 were interviewed. The literature varies regarding the appropriate sample size required in qualitative research, the answer mostly being 'it depends'. According to one of the most cited articles about sample size in qualitative research, code saturation is reached after 9 in-depth interviews (not to be mistaken with semi-structured interviews), meaning that no new information will be provided by more interviewees, but that 16-24 in-depth interviews could improve the understanding of the data (Hennink et al., 2016). On a systematic review of 23 articles, outside of grounded theory, Hennink and Kaiser (2022) found that after 9-17 interviews saturation was reached, especially with homogeneous samples. Regarding grounded theory studies, the sample size is more flexible, and saturation depends on the researcher's judgment (Robinson, 2013). Given the quality of the participants and the duration of each interview, the representativeness of the sample seems appropriate. It Is believed that a larger

sample would have not drastically affected the results nor the emerging grounded theory, although further research is suggested.

- Finally, the interviews were quite long as shown in *Table 13*. However, management practices are a broad subject, which made it challenging to discuss about each of their 18 key indicators during the interviews. Because of this, the results show a general understanding of how digital tools are shaping management practices in the AEC industry. Albeit valid, further research is recommended to tackle specific indicators of management practices.

3.4. Ethical Considerations

Since the data for this master thesis was collected from human subjects in the form of semi-structured interviews, approval from TU Delft's Human Research Ethics Committee was necessary prior to contacting the participants. Given the nature of the research, three documents were submitted to the committee: a checklist for human research, a data management plan, and the informed consent form for participants. These documents described the purpose of the research, the collection method, and the risks associated with the research, as well as any mitigation measures. Once the committee approved the research, the potential participants were contacted.

People who met the sampling requirements to be part of this research were contacted through the researcher's personal LinkedIn account. The information on this account was filled transparently and did not share any false, misleading, or unnecessary data about the researcher. When the subjects were contacted, the principles of integrity, fairness, and open-mindedness were considered. As such, all the subjects contacted (even the ones that did not participate in the study) were treated respectfully and at no point were they pressured, caused any sort of discomfort or psychological harm. Participation was completely voluntary.

In addition, to get consent from the participants the informed consent forms were sent to them before the interview. This form stipulates that the researcher will not share any personal information (e.g. names, age, unrelated subjects) or sensitive data that could have been said intentionally or unintentionally by the interviewees and that did not assist the purpose of this master thesis (see *Appendix B*). Further, verbal consent from the participants was asked at the beginning of the online meetings in order to record the interviews. These meetings were held online through Microsoft Teams using the researcher's student account provided by TU Delft. The resulting transcripts of these interviews were revised and sent back to the participants to get additional consent on using the data they provided. These recordings and transcripts were not shared with anyone and were destroyed once the master thesis was uploaded to TU Delft's repository. Finally, the information that forms part of this research such as quotes from the subjects was treated confidentially to protect their identity, and thus, it does not let the readers directly identify them since they were anonymised.

4. Results

This chapter presents the findings of the research. As described in the methodology in Chapter 3, the **grounded theory method** was used to analyse the data resulting from semi-structured interviews. Hence, this chapter is divided into four sections that make reference to the literature, which is the second step of the grounded theory method also known as *axial coding*. From these, 2nd and 3rd order constructs were formed in a similar way that with thematic analysis, and that ensured an accurate and objective answer to the research question. This third step of the grounded theory method is also known as *selective coding*. As a result, this chapter is divided into the main components of management practices, targets in section 4.1, monitoring in section 4.2, and incentives in section 4.3. An additional category named miscellaneous in section 4.4 comprehends the results that also affected management practices but is not part of targets, monitoring, or incentives. The 1st order constructs, which are part of the first step of the grounded theory method also known as *initial coding*, can be found in *Appendix C*, *D*, *E*, and *F*, respectively.

4.1. Targets

Two 2nd order constructs were identified regarding the way in which digital tools are shaping targets in the AEC industry (*Table 14*). *Optimiser* refers to the technologies used in a project that can optimise the fulfilment and control of the initial targets, whereas *considerations* refer to the careful assessment of technologies that could potentially optimise target setting based on their added value. Together, they formed the 3rd order construct ***efficient target setting***, which is a strategy comprised of an adequate *optimiser* based on important *considerations* that seeks to accelerate the fulfilment of targets in a construction project.

Unlike with the manufacturing industry, the respondents agreed that the AEC industry mainly focuses on the delivery of a project within time, budget, scope, and the required quality. Several technologies have been developed and adapted to the AEC industry to improve the initial processes that have a significant impact on target setting. For example, the participants identified Artificial Intelligence technologies like ChatGPT as a helpful tool, especially during the design phase or for report writing as illustrated by the following quote:

"*You can ask for the program again* [about AI], *it's just the first draft of the program, but you are not starting from scratch, so it buys you time. If you have a report that's like with no sensitive information.*" (Participant C, May 2024)

Digital tools are not drastically changing the main targets a construction project has, since the main goal has always been to build a physical model mostly made of concrete, steel, and wood. However, these tools are being used to support and optimise the entire process. The daily tasks that once were difficult to achieve, no longer represent a challenge as proven by the following quote:

"*I'm not sure if it changes our targets, but it made our projects possible, like to meet our deadlines, for example to do quality, especially this clash detection things that the coordination sessions were previously very hard and now it's just easy someone is putting everything together and then it can achieve the quality and we can meet our timeline with these things.*" (Participant D, May 2024)

Table 14: *Efficient Target Setting Construct*

Raw data	2nd order construct	3rd order construct
"*Let's go back to the two softwares that I talk about right, like Primavera and MS Project you can create a schedule as detailed as it needs to be, manage your cost, manage your time,* […] *and you know, we can do a lot of work. I mean, you can basically manage all three sides of the triangle with one software.*" (Participant E, June 2024) "[About AI] *You can quickly describe a project and say: 'give me a list of risks and put them in the table and suggest techniques to mitigate those risks.' It will be a generic answer, but it's a very good start.*" (Participant C, May 2024)	*Optimiser*: refers to the technologies used in a project that can optimise the fulfilment and control of the initial targets.	***Efficient target setting***: a strategy comprised of an adequate *optimiser* based on important *considerations* that seeks to accelerate the fulfilment of targets in a construction project.
"*I do think models are good. I do think robots are good. I do think in the construction is good, but the question here is does it drive down the cost and time? If it costs me more money to do offsite construction than onsite construction, why would I do that? No one asks that question.*" (Participant G, June 2024) "*I think the first thing is, before bringing the technology, the company to understand what they wanna have, what they want, what they need to have. So oh, I like the virtual reality, but do I need it? I think that's not about the technology, is understanding what do I need to solve or what should I have.*" (Participant F, June 2024)	*Considerations*: the careful assessment of technologies that could potentially optimise target setting based on their added value.	

Furthermore, the participants emphasised the importance of digital technologies to achieve their targets and to successfully deliver a project in time, with an increase in efficiency being repeated the most amongst the interviewees. This was especially true for larger-scale projects. For example, one participant talked about an ongoing mega project:

"*We have insights here in* […] *our company, showing that three years back and these days we multiplied the revenue 5 times or 4.7, almost five times. We increased the efficiency of things three or four times. Efficiency means, for instance, the amount of hour that the model or the draftsman is consuming to do the same drawing three years back. Using the technology is faster than you five times.*" (Participant I, June 2024)

However, the participants mentioned that to successfully implement technologies, these must be carefully assessed. Some tools are trendy in the AEC industry, but that does not automatically mean that they will be beneficial. The following quote for example, mentions the importance of having a R&D department:

"*I believe personally that the Research and Development Department is very important.* […] *Those people should be there just to study what is in the market, what is the forecast of the market and the technology,* […] *how we adapt to what is our position in the future, and so on. So I think that is very important, that someone who's not busy with a project* […] *just thinks about this.* […] *Then you can keep your competitive position.*" (Participant D, May 2024)

Moreover, the lack of standardisation in the industry represents a big challenge, which makes it difficult to use the same technology every time. Uncertainty was described by the participants as an obstacle, and thus, technologies need to adapt depending on the circumstance. One participant said:

"*I've worked on about like 100 projects over my career. Every project is different. It's not like you're building a car* […] *or you're producing 500 cars, and you need to know where you can be efficient. Every project is different in building. One minute you've got problem in underground, next minute you've got a problem overground, next minute you've got a problem with your neighbours next door, you've got a problem with a politician.*" (Participant B, May 2024)

All the participants agreed that technology is expensive and that it does not replace basic human capabilities. The implementation of new digital tools is not meant to teach the user how to properly control the targets in a project. For example, one participant said that scheduling softwares do not teach how to set targets:

"*Even like as I mentioned before, software like Microsoft Project is based on common knowledge […] it used to lead you to believe that, like you have a good understanding of scheduling and to source allocations.* […] *There's basically like a huge gap in people's understanding.*" (Participant A, May 2024)

Therefore, ***efficient target setting*** in a construction project highly depends on technology that acts as an *optimiser* based on important *considerations*. By considering these two constructs grounded in the data, the fulfilment of targets can be hastened.

4.2. Monitoring

Two 2nd order constructs were identified regarding the way in which digital tools are shaping monitoring in the AEC industry (*Table 15*). The *facilitator* refers to the digital strategies that facilitate the monitoring of a construction project. In contrast, the *inhibitor* refers to the digital strategies that would be detrimental to a construction project. Together, they formed the 3rd order construct ***effective monitoring***, defined as the collection of data comprised of the *facilitator* and the *inhibitor* that determine the degree to which the monitoring of a construction project is successful.

A variety of technologies were identified by the participants as been useful for the correct monitoring of a project. This cluster of management practices resulted the most affected by digital tools, as it is an important aspect of project management. From all the technologies, BIM was mentioned as being the most beneficial for its ability to detect clashes during the entire project. However, physical monitoring of the project was still necessary, where other technologies come into place:

"*But then when it gets down to construction and it's so massive, and then maybe it's hard to get a process because in construction you can't verify just by opening your computer, you need to go down on site. And*

the bigger the site then you need more technology to this verification faster, and those big projects I've worked, they use laser scan to do the verification and was the best workflow I've seen." (Participant C, May 2024)

Table 15: *Effective Monitoring Construct*

Raw data	2nd order construct	3rd order construct
"*Revit, Revizto, and also Bluebeam.* […] *But those are more softwares, I wouldn't say online tools, but they are also digital tools that facilitate communication and reflection, weekly reviews especially.*" (Participant D, May 2024) "*Some of these silly activities or repetitive activities that you need to have like strapped to repeat it like macro, or something so you don't need to have a specialist or coders or programmers, you just need somebody to deal with ChatGPT to put the requirements and you have the code. Just you need somebody to understand how or where to put the code to get the result. This is one of the good things where we will benefit from these days.*" (Participant I, June 2024)	*Facilitator*: refers to the digital strategies that facilitate the monitoring of a construction project.	***Effective monitoring***: the collection of data comprised of the *facilitator* and the *inhibitor* that determine the degree to which the monitoring of a construction project is successful.
"*So now what you did, you took all the documents, all the plans that you had in your project with all the versions, you throw it into your machine and you ask it questions, they'll give you the answer of the data that it has. Have you improved your processes? No. Have you improved your performance? No.*" (Participant G, June 2024) "*If we look at BIM at a very small scale, that is a tool for collaboration and for clash detection and it is really effective and efficient. But when you take it beyond that to expand it to 4D and 5D, now it starts to break down.*" (Participant H, June 2024)	*Inhibitor*: refers to the digital strategies that would be detrimental to a construction project.	

Besides the common technologies such as BIM, laser scan, or VR that were mentioned by the participants, cloud computing software showed to be particularly important for the AEC industry. Although it was not developed to improve construction processes, all the participants said this is highly beneficial to monitor the project. Amongst the technologies discussed, Microsoft Teams and Sharepoint were repeated the most. One participant for example, mentioned how cloud computing softwares have changed the way in which they monitor a project nowadays:

"*I remember, you know, the first project that I worked on, let's say a lot of the correspondence and daily, you know, transmittals were sent and received on email. But recently I think a lot of organisations are moving away from that. And they're using cloud based softwares to, you know, to make sure everything is safe. You know, everybody can access it rather than working on something off of your desktop. What if somebody doesn't show up to work? What if somebody is sick? You know, somebody else should be able to have access to all that project history.*" (Participant E, June 2024)

Similarly, a different participant commented on cloud computing software reliance given the vast amount of information that a project requires:

"*So, for me personally it improved. I remember the first projects I've done. It was most of the things we were just talking in meetings. We do these meetings notes and we do everything from the meeting notes and then it's difficult to trace and a lot of emails and so on and then you lose a lot of information, a lot of agreements and so on.*" (Participant D, May 2024)

However, the participants also mentioned that some tools that have been developed lately are not required. Although interesting, they are expensive and implicate a learning process which takes time that could have been spent on another project. All the participants mentioned that technologies do not replace processes, in fact, some can be detrimental to the project which is why many construction companies fail. A general point on the subject can be illustrated by the following quote:

"*First, there needs to be realised the need and understanding, and company culture; and then processes need to be defined, and then you can bring more and more technology. But you can't just like bring stuff tomorrow and say 'well this is our new way of working', if probably this software is going to be underutilised or utilised incorrectly.*" (Participant A, May 2024)

Comparably, the constant monitoring of a project through high technology was mentioned by participants to be unnecessary. Hence, most of them used simple softwares like Microsoft Excel to track the project. Therefore, ***effective monitoring*** depends on the technologies that support the project, which are evaluated based on whether they act as a *facilitator* or as an *inhibitor*. The following quote summarises this point:

"*So we're going to do reality capture to check the progress. I'm like, why do we need to check your progress unless you're bad at planning* […]*, do you understand the problem there? It's a band aid.* […] *A lot of technology that we've put into* […] *as project controls are just a reactive to bad management.* […] *If you have actually a good Takt and last planner planning, and people know what they're doing, you should catch these things on your weekly work plan.* […] *You can't use technology to solve bad planning and bad processes.*" (Participant G, June 2024)

4.3. Incentives

Two 2nd order constructs were identified regarding how digital tools are shaping incentives in the AEC industry (*Table 16*). The first one, *objectivity*, is the common human performance measurements influenced by facts. The second one, *subjectivity*, refers to the common human performance measurements influenced by feelings, senses, and opinions. Together, they formed the 3rd order construct

perceptual assessment, which is the evaluation of both *objective* and *subjective* human performance measurements, which allows a company to assess their personnel.

Table 16: *Perceptual Assessment Construct*

Raw data	2nd order construct	3rd order construct
"*There are some digital tools to monitor the team members to see what they are doing, like for example, even in GitHub you can see that when you assign tasks to the programmers. There are other digital tools, but we don't use them. I assess people based on their performance in accomplishing the tasks given.*" (Participant H, June 2024) "*Just make sure they turn on time. Do the job and go home. And we have Face ID.* […] *So, in terms of workers performance on-site we have Face Detection ID. So, they come on-site, they put their face on a face detection, and they will know what time they came on-site and what time they left on-site.*" (Participant B, May 2024)	*Objectivity*: common human performance measurements influenced by facts.	***Perceptual assessment***: the evaluation of *objective* and *subjective* human performance measurements, which allows a company to assess their personnel.
"*My experience as an employee, not as a manager or as someone that's promoting people is that the companies try to access what's people capabilities, but I think it's very empirical and it's very down to feelings and it's not down to numbers.*" (Participant C, May 2024) "*We are humans, so you should always look at the soft side and the hard side. So it's not like you're dealing with a machine.* […] *I always say, OK, if you have your performance, you have to get it on two things, soft skills* […] *and hard skills.*" (Participant D, May 2024)	*Subjectivity*: common human performance measurements influenced by feelings, senses, and opinions.	

The incentives category was the least affected by digital tools in the AEC industry. All the participants mentioned that the completion of tasks was the only way in which they could evaluate human performance, which is something that has not changed much despite technological advancements. For example:

"*So I think by the deliverables, right? You have a set of deliverables in the beginning of a project and you measure against those deliverables. Again, things might change as a project progresses, but you take that into consideration. But I would say deliverables is a tangible, it's something tangible that you can measure progress against.*" (Participant E, June 2024)

Another participant mentioned that in construction, it is relatively easy to track human performance. Consequently, digital tools are currently scarce:

"*There are things that change with technology and things that don't change with technology, and fundamentally construction right now is: you have a human being, goes in, and does some installation. Over time we have a human being plus a robot doing the work. But even if we have a robot or a human being, you can still measure productivity the same way.*" (Participant G, June 2024)

Nonetheless, some digital technologies are still used to measure human performance. For instance, to attract new people or to promote themselves, social media reputation was identified by participants to be key. Moreover, they used to track performance with pen and paper and now they use technologies such as GitHub, Face ID or Microsoft Excel as shown in *Table 16*. Also, the easy access to basic tools to provide feedback was mentioned by the participants to be relevant to track human performance. This is called *objectivity*. Based on these objective measures, people get promoted, removed, or are retained in the company. In addition, *subjectivity* was identified to be equally important when assessing human performance. For example, one participant mentioned a way to encourage incentivisation in a company:

"*I think* […] *apart from money it's job satisfaction, right? So, you want them to be happy, and by giving them interesting projects or challenging projects, you keep people happy.*" (Participant B, May 2024)

But again, participants recognised the lack of technologies to measure incentivisation:

"*Technology like those online meetings and those things.* […] *It's about technology too, but we don't have any. Like no any other digital tool that reminds me that I need to talk with one to another or something like that. Or push the button if you are happy or something. No, we don't use that. The technology uses, those that support our closer communication, but not any specific technology developed to like, fulfil and complain their motivation.*" (Participant F, June 2024)

One participant who specialised in digital transformation in mega projects said that the AEC industry is still in its early stages as opposed to other industries, and constant trial and error is still necessary to achieve digital transformation:

"*We have experimented that last year but using another technology which we put, but we failed. We failed to do that but we tried to have like a helmet. Include the chat on it to detect the movement of the labourers and the yard performance. But we found that it wasn't giving us the proper data that we aimed, to get random data. So you can't detect the efficiency that the labour had* […] *working from place A to place B for drinking water. We don't know what was exactly the work that have been done in this space. So we didn't get any insight from this way. So, we decided to have the facial recognition for the next year.*" (Participant I, June 2024)

Therefore, ***perceptual assessment*** is constructed. Digital technologies are slowly shaping incentives but the *subjective* part of it is still quite significant for the AEC industry. One participant for example suggested the implementation of online personality tests, but this was only an idea. The following quote illustrates the current *subjective* approach:

"*So we share some cooking or sports, is part of the experience. So we try to, those that have children, how they interact with children, so it change some tips and talk with them. It's understanding each employee and each one as individuals and understanding the context they are currently. I think those are things that are important, just not about professional skills, but also about what made them feel good.*" (Participant F, June 2024)

4.4. Miscellaneous

The miscellaneous category was formed by the codes that did not form part of targets, monitoring, or incentives, but still affected management practices based on the digital tools developed for the AEC industry. Here, ***resistance*** was identified as the 2nd order construct which is defined as the unwillingness to adopt digital solutions in the AEC industry (*Table 17*). Although the interview questions did not directly assess resistance to adopt new technologies, all the participants mentioned this to be a challenge and to influence digital transformation in the AEC industry. The reasons varied, some were related to the cost of new digital tools, others to a lack of time, others to the resistance to learn how to use a new tool. In the case of AI for example, some participants expressed that their biggest concern was sharing confidential information with an external company (e.g. OpenAI). But in general, more than one participant said that resistance is mainly due to a behaviour issue:

"*But yeah, I would say that people want to change. No, they want THE change, but they don't want TO change.*" (Participant C, May 2024)

While some participants emphasised the importance of understanding construction processes before adding new technology, others mentioned that even with tools that have been proven to be beneficial, people still do not make an effort to adapt. Albeit resistance is not a part of management practices, the participants showed that this is intrinsically shaping them. The following quote summarises this category:

"*We do innovation events and we do regular meetings with the teams for opening their mind up and to tell them, OK, look, this is happening outside your, you know, your project and so on, and that's what we can do.* […] *Then they start thinking about it a bit better and yeah, but it's not always successful. So, we got tools that we couldn't adapt.*" (Participant D, May 2024)

Table 17: *Resistance Construct*

Raw data	2nd order construct
"*So, you also open the door to all your data to be vulnerable, and then you're giving all the data to OpenAI or any other AI company. And so, it's a risk. You have the risk of people misuse that.*" (Participant C, May 2024) "*On a $100 million project you'll be wasting $2,000,000 on just doing that* [investing in new technology]. *Does that improve your work? No, it doesn't, it gives you the illusion you're making progress. A lot of these things give you Illusion, but not progress, and for whatever reason people are OK with illusion.*" (Participant G, June 2024) "[About research on new technologies] *But I would say that like the project managers, or the leadership of those companies, is not aware of those publications. […] They focus on business development instead of like internal doable programs.*" (Participant A, May 2024) "[About new digital tools in the industry] *When you look at research papers, research articles, you will see that there are huge changes, but in actual construction projects there are no changes at all.*" (Participant H, June 2024)	***Resistance***: unwillingness to adopt digital solutions in the AEC industry for a variety of reasons.

5. Discussion

This chapter matches the literature with the results for theory development. Section 5.1 interprets the meanings of the results obtained through the semi-structured interviews. In this section, a new conceptual framework is proposed based on the evidence. Section 5.2 discusses the implications this research has on the AEC industry. Finally, section 5.3 addresses the main research question and the sub-questions of the study, hence fulfilling its purpose.

5.1. Interpretation of the Results

Three 3rd order constructs were formed from the results, one for each management practice cluster. In addition, resistance was shown as a prevalent challenge in the AEC industry and is therefore worth considering. Regarding *targets*, ***efficient target setting*** was constructed. Overall, efficiency should not come as a surprise since several authors have identified it as the main benefit of implementing digital tools in the AEC industry (e.g. Chen et al., 2022; Tian et al., 2023; Oesterreich & Teuteberg, 2016), but efficient target setting is more specific. Tetik et al. (2019) for example, invented a new operational management practice called Direct Digital Construction or DDC, which focused on the easier achievement of a firm's goals by spending a considerable amount of time drafting the design through an increment in the level of detail. Several technologies were mentioned by the authors to increase efficiency of outdated processes, such as BIM, AI, and cloud collaboration softwares, especially during target setting. However, many of these tools do not prove to be effective. In fact, the participants interviewed mentioned that although research on digital tools usually shows positive results, the reality is different. They mentioned that some companies invest thousands of euros/dollars/pounds in new technologies, and by the time they evaluate their progress, they do not encounter a significant improvement in terms of cost, time, or quality. This seemed to be especially true during the monitoring phase, and thus ***effective monitoring*** was constructed. The literature, however, refers mostly to effective processes or modified organisational structures that promote digital transformation, rather than measuring the effectiveness of digital tools during monitoring. For example, Zhang et al. (2021) mentioned that construction firms need to adapt in four areas to effectively adopt digital solutions, these being strategic/environmental, product/service, process management, and organisational, which are all aspect of business management adaptability. Equivalently, other authors suggest that digital transformation implies a change in planning, organising, management, and control processes (Bugarčić & Slavković, 2023), and that project management effectiveness depends on the creation of new business models and the awareness of employees. Fundamentally, the empirical results showed that the effectiveness of digital tools and their effect on management practices is worth considering, as it is not explicitly declared in the literature. Conversely, ***perceptual assessment*** was found to be equally important from the participants perspective, which is something usually dismissed in the literature of digital technologies in the AEC industry. Evidently, human performance is a major aspect in the construction sector and cannot be easily replaced by technology. All the participants (without exception) emphasised the scarce technologies available that can assess human performance and consequently take action in the form of promotions, rewards, or punishments. There is extensive literature regarding leadership and soft skills in the AEC industry, but certainly not regarding digital tools. Nonetheless, some authors like Demirkesen & Tezel (2022) suggest that a shift in company culture is salient to promote digital transformation in the industry. Whereas the last construct, ***resistance***, seemed to be in

line with the literature (e.g. Hemström et al., 2017; Chan et al., 2019), with reasons varying from the cost/time to implement a new digital tool, to learning how to use it. Based on the results, *Table 18* below shows a summary of the interpretation of the results. Primarily, three words emerged: *efficiency*, *effectiveness*, and *experience*, which refers to the perceptive aspect of humans.

Table 18: *Interpretation of the Results*

Management practice cluster	3rd order construct	Interpretation
Targets	***Efficient target setting***: a strategy comprised of an adequate *optimiser* based on important *considerations* that seeks to accelerate the fulfilment of targets in a construction project.	*Efficiency*
Monitoring	***Effective monitoring***: the collection of data comprised of the *facilitator* and the *inhibitor* that determine the degree to which the monitoring of a construction project is successful.	*Effectiveness*
Incentives	***Perceptual assessment***: the evaluation of *objective* and *subjective* human performance measurements, which allows a company to assess their personnel.	*Experience*

In addition, on account of the methodology of the research, a new conceptual framework is developed (*Figure 11*). Initially, the conceptual framework was constructed based on the literature, to show the way in which management practices are affected by digital tools in the AEC industry (*Figure 8* in Chapter 2). This theoretical framework showed that essentially an increase in *efficiency* acted as a mediator variable between the two concepts. However, the results showed that efficiency alone does not represent the full picture. Hence, two more variables are added to the framework through the grounded theory method, *effectiveness* and *experience*. *Resistance* remains as an integral part of the model as a moderator variable.

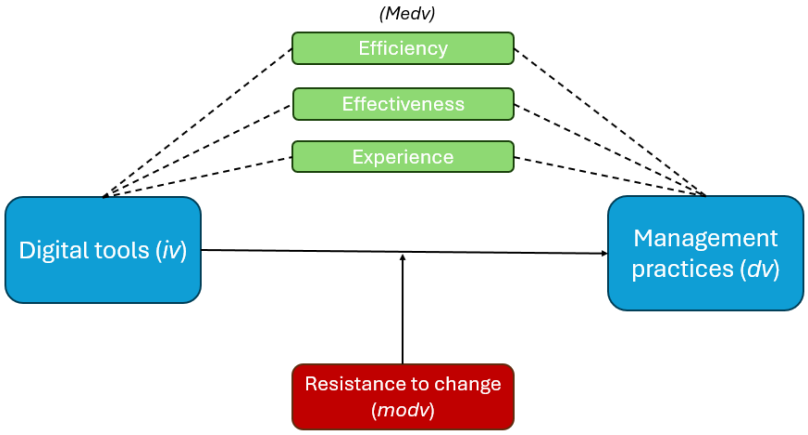

Figure 11: *Grounded Conceptual Framework*

5.2. Practical and Theoretical Implications

According to Bhattacharya and Momaya (2021), the prevailing processes and managerial practices in an organisation are affected by the alteration of patterns of activity and vice versa. Thus, a new organisational strategy is required in the context of digital transformation. In this case, based on the results of this study and the interpretation of them through the grounded theory method, new management practices are created. Although the manufacturing and the AEC industry differ, the evidence provided allow to build new measurements that might also affect other industries. Ideally, the management practice dimensions by Bloom et al. (2012) should be adapted to the construction industry first, where some practices would be added, modified, or eliminated. However, given the nature of the semi-structured interviews conducted and the data gathered, that would imply many assumptions based on non-existent evidence. For now, three new management practices are added to the current model and are showed below divided into the main clusters in *Tables 19*, *20*, and *21*, respectively.

Table 19: *Digital Tools Shaping Targets (adapted and modified from Bloom et al., 2012)*

Cluster: *targets*	**Score measurement**
Target balance	Are the goals exclusively financial, or is there a balance of financial and nonfinancial targets?
Target interconnection	Are goals based on accounting value, or are they based on shareholder value in a way that works through business units and ultimately is connected to individual performance expectations?
Target time horizon	Does top management focus mainly on the short term, or does it visualise short-term targets as a "staircase" toward the main focus on long-term goals?
Target stretching	Are goals too easy to achieve, especially for some "sacred cow" areas of the firm, or are goals demanding but attainable for all parts of the firm?
Performance clarity	Are performance measures ill-defined, poorly understood, and private, or are they well-defined, clearly communicated, and made public?
Efficient target setting	Do the digital tools implemented increase the efficiency of goal achievement? Are these tools constantly evaluated?

The three new management practices represent the three 3rd order constructs from the data, ***efficient target setting***, ***effective monitoring***, and ***perceptual assessment***. Next to each other, questions are provided so companies can assess them and measure their overall performance. Much like the previous framework, practices are scored from 1 (worst) to 5 (best) to determine whether a firm has 'good' or 'bad' management. The main difference is that these three new practices consider digitalisation. Given that the research conducted was a cross-country qualitative analysis, this adaptation can still retain their principal characteristic, which is an international comparable management practice framework. Additionally, some of the caveats pinpointed by Scur et al. (2021) have been addressed, such as the lack of innovation and to some degree, the culturally biased model. The questions to measure the score of a company on these three new practices were developed based on the 2nd order constructs identified in the data, and thus, the proposed model shows validity since it is backed on empirical evidence. For example, in the *targets* cluster, the two questions generated relate to the *optimiser* and its *considerations*.

Table 20: *Digital Tools Shaping Monitoring (adapted and modified from Bloom et al., 2012)*

Cluster: *monitoring*	**Score measurement**
Introduction of modern manufacturing techniques	What aspects of manufacturing have been formally introduced, including just-in-time delivery from suppliers, automation, flexible manpower, support systems, attitudes, and behaviour?
Rationale for introduction of modern manufacturing techniques	Were modern manufacturing techniques adopted just because others were using them, or are they linked to meeting business objectives like reducing costs and improving quality?
Process problem documentation	Are process improvements made only when problems arise, or are they actively sought out for continuous improvement as part of normal business processes?
Performance tracking	Is tracking ad hoc and incomplete, or is performance continually tracked and communicated to all staff?
Performance review	Is performance reviewed infrequently and only on a success/failure scale, or is performance reviewed continually with an expectation of continuous improvement?
Performance dialogue	In review/performance conversations, to what extent are the purpose, data, agenda, and follow-up steps (like coaching) clear to all parties?
Effective monitoring	Are the digital strategies used to monitor the progress effective? Do these correlate to an increase in performance or are these detrimental to the business processes?

In practical terms, the findings manifest that the existence of new or trendy digital technologies does not translate to performance improvement within a construction company. The AEC industry is currently facing many changes and several challenges, and although digital transformation is expected, careful assessment of technologies is yet required, especially in the early stages of digitalisation. This study found that efficiency, effectiveness, and experience are to be considered for a successful transition into digital processes. However, resistance to change for a variety of reasons is still prevalent in the industry, mostly

because of a lack of resources or unwillingness to change, which is associated with human behaviour. Research on particular digital technologies or the benefits of these is quite broad but scant regarding the organisational changes and all the considerations involved. Construction firms are encouraged to use this study as it can support them with technology implementation and the managerial implications this would entail. According to Jahanger et al. (2021), both digitalisation and innovation in the AEC industry are particularly important since the lack of these in project management practices has led to a decrease in productivity. But, as uncovered in this research, the three mediating variables must be examined first.

Based on the literature and the findings of this research, it is recommended that construction companies restructure their organisation in such a way that it further promotes digital transformation. To accomplish this, the creation of a 'digital department' that only focuses on the analysis of technological solutions is encouraged. This idea of re-organisation is in line with academics such as Verhoef et al. (2021) and in line with the answers from the participants, who considered this as a crucial aspect for a successful transition. In fact, some of the participants mentioned that they recently developed such a digital department and have experienced good results when implementing (or developing) digital technologies.

According to Bhattacharya and Momaya (2021), this 'digital department' (or strategist centre) must be simple, flexible, agile, and actionable; and must be guided by an interdisciplinary capability centre. It should focus on the main objectives, risk management, team coordination, as well as on the implementation of digital tools through what-if solutions. Moreover, it must consider the dynamic capabilities of the organisation as well as their purpose, and it must consider the management of a careful confluence of change and continuity forces. Within this department, the focus should additionally be on the three management practices found in this study. First, ***efficient target setting*** to increase the efficiency of goal achievement via constant evaluation of digital tools. Second, ***effective monitoring*** to assess the effectiveness of digital strategies. And third, ***perceptual assessment*** to combine the aspect of digitalisation with the people working within the company. Given the scarce resources of this last element, it is recommended that the R&D department constantly seeks for new and innovative tools simultaneously. Nonetheless, a big 'chicken or egg' question here is whether the implementation of digital tools implicate a change in management practices or if a change in management practices can promote the implementation of digital solutions. Based on the answers from the participants, first and foremost, construction processes must be prioritised and re-organisational structures developed **before** bringing new technologies. The participants mentioned that some companies do this in reverse and do not see a significant improvement in cost, time, or quality. Hence, the creation of the new management practices is presented and expected to support practitioners with their transition. Although some of the management practices are contingent on the environment, the new ones will support all practitioners who wish to push for digital transformation.

Finally, although this research was conducted with construction specialists, other industries such as the manufacturing are fostered to review it. Tian et al. (2023) for example, found that manufacturing firms must recognise digitalisation as an important strategic orientation. They should prioritise investment in digitalisation to increase efficiency in the long-term, and they should adjust their digitalisation depending on the external environment.

Table 21: *Digital Tools Shaping Incentives (adapted and modified from Bloom et al., 2012)*

Cluster: incentives	**Score measurement**
Consequence management	To what extent does failure to achieve agreed objectives carry consequences, which can include retraining or reassignment to other jobs?
Managing human capital	To what extent are senior managers evaluated and held accountable for attracting, retaining, and developing talent throughout the organisation?
Rewarding high performance	To what extent are people in the firm rewarded equally irrespective of performance level, or is performance clearly related to accountability and rewards?
Removing poor performers	Are poor performers rarely removed, or are they retrained and/or moved into different roles or out of the company as soon as the weakness is identified?
Promoting high performers	Are people promoted mainly on the basis of tenure, or does the firm actively identify, develop, and promote its top performers?
Attracting human capital	Do competitors offer stronger reasons for talented people to join their companies, or does a firm provide a wide range of reasons to encourage talented people to join?
Retaining human capital	Does the firm do relatively little to retain top talent, or does it do whatever it takes to retain top talent when they look likely to leave?
Perceptual assessment	Are people evaluated based on both objective and subjective traits? Are digital tools used to document these evaluations and further incentivise them?

5.3. Digital Tools and Management Practices

To conclude with the study, the research questions are answered based on the literature, the results, their interpretations, and their implications. The answers to the four sub-questions are provided below.

SQ1: *What are management practices?*

Management practices are described by Bloom et al. (2012) through their 18 key practices framework (*Table 1*), comprised of targets, monitoring, and incentives. These practices are constructed to measure a firm's performance in the manufacturing industry. Although the authors did not explicitly say 'management practices are defined as…' this model has been peer-reviewed by several authors across the academia. In addition, it is considered the first cross-country and cross-industry dataset built that can measure the quality of management practices in different establishments (World Management Survey, n.d.). As such, this thesis proposes the following definition of management practices:

> *Managerial parameters for which a firm's performance can be assessed, divided into targets, monitoring, and incentives*

SQ2: *What are digital tools?*

Most authors use the terms 'digital technologies' and 'digital tools' interchangeably, since a tool is a piece of equipment that helps to achieve certain activity. Something can be catalogued as '*digital*' when the data of that something is converted from analog into digital through complex computerised codes of zeroes and ones (Verhoef et al., 2021). On the other hand, '*technology*' refers to innovative "tools, machines and modifications of them that are used to achieve a goal, perform a specific function or solve a problem (Sepasgozar & Davis, 2018)". Together, *digital technologies* are part of the digitalisation phase as mentioned by Verhoef et al. (2021) and involve the alteration and optimisation of the current processes within an organisation. As such, the following definition is proposed:

> *Digitally computerised data that can assist with a particular function*

SQ3: *What is the purpose of implementing digital tools in the AEC industry?*

As exposed by authors such as Chen et al. (2022) in their systematic review, the main purpose of implementing a new digital tool is the increase in work efficiency. A variety of authors agree and the theoretical conceptual framework in *Figure 10* was constructed based on this. Other reasons from their review included health and safety, productivity, quality, and sustainability. However, other variables like effectiveness must also be considered, as found from the empirical observations. Hence, the purpose of implementing new digital tools in the AEC industry is:

> *To use effective digital solutions that have a positive impact on work efficiency, productivity, quality, sustainability, and health and safety; and that can eventually improve construction processes with reduced resources*

SQ4: *How are management practices and digital tools related?*

This sub-question can be answered through the grounded conceptual framework in *Figure 11*. Based on the analysis of the results, digital tools interact with management practices through the three mediating variables identified: *efficiency*, *effectiveness*, and *experience*. According to academics, digital transformation implicates a change in organisational processes, and thus new business models need to be developed (e.g. Bugarčić & Slavković, 2023). However, further research is suggested to prove the emerging theory of this thesis. A quantitative deductive approach could significantly strengthen the results of this study by examining the relationship coefficients between the variables identified.

RQ: *How are digital tools shaping management practices in the AEC industry?*

The main research question, how are digital tools shaping management practices, is in part answered through the grounded conceptual framework in *Figure 11*. Three mediator variables were identified from the results: ***efficiency***, ***effectiveness***, and ***experience***. Also, ***resistance*** remained as an integral part of the model as a moderator variable. From these variables, the former 18 key management practices model by Bloom et al. (2012) is modified as shown in the previous section. Three new management practices are added to the model, one for each cluster. These three new management practices are defined based on the 3rd and 2nd order constructs from the data collected. In the first cluster, *targets*, ***efficient target setting***

is added (*Table 19*). Similar to other practices, this practice can be scored from 1 (worst) to 5 (best) according to the following parameter: *do the digital tools implemented increase the efficiency of goal achievement? Are these tools constantly evaluated?* Similarly, for the *monitoring* cluster, ***effective monitoring*** is added as a new practice (*Table 20*). This practice is scored according to the questions: *are the digital strategies used to monitor the progress effective? Do these correlate to an increase in performance or are these detrimental to the business processes?* Finally, ***perceptual assessment*** is added to the third cluster, *incentives* (*Table 21*). This practice is scored based on the questions: *are people evaluated based on both objective and subjective traits? Are digital tools used to document these evaluations and further incentivise them?*

Through the development of these three new practices, the main research question is fully answered. It is worth mentioning that not all digital tools necessarily shape management practices as presented in *Tables 19*, *20*, and *21*. This research shows a general view of a variety of digital technologies that are being currently used in the AEC industry such as BIM, VR/AR, Digital Twin, or IoT, and further research is recommended to explore the impact of a single technology in management practices. However, as shown by the study, a modified organisational structure (and thus, modified management practices) that promotes digital transformation could support the successful implementation of new digital tools in construction firms. Additionally, an extensive cross-country qualitative analysis similar to the one conducted by Bloom et al. (2012) could create a new management practices framework tailored to the AEC industry. Afterwards, a deductive quantitative/qualitative approach could further strengthen the results found in this study to improve the understanding of how digital tools are affecting management practices in the AEC industry and further contribute to digital transformation.

6. Conclusions and Recommendations

This chapter concludes the study. Section 6.1 provides a summary of the main points of the thesis and emphasises the answers to the research questions. Section 6.2 presents important recommendations for practitioners. Finally, section 6.3 comments on further research.

6.1. Conclusions

In this section a summary of the thesis is provided in subsection 6.1.1. Section 6.1.2 covers the answers to the sub-questions of the research and finally, subsection 6.1.3 answers the main research question.

6.1.1. Summary

Recently, the literature has shown a growing interest in *digital tools* in the AEC industry. Various technologies have been developed to constantly monitor construction processes, reduce costs, manage safety hazards, increase efficiency, enhance performance, improve productivity, and facilitate coordination and communication (Chen et al., 2022; Loosemore, 2014). **So far**, most studies have focused on specific digital tools, on how these affect performance, or firms' resistance to change. **However**, far less attention has been paid on how these digital tools are shaping *management practices* in the AEC industry.

Digital tools are rapidly adapting the AEC industry into a similar version of *Industry 4.0*, where digital processes are an essential part of a firm's system (Soto et al., 2019). But the successful implementation of these digital tools in construction firms also implicates a paradigm shift in business models (Prebanić & Vukomanović, 2021). To quantify whether a firm possesses "good or bad" management practices, Bloom et al. (2012) introduced 18 key management practices. Their model is a remarkable approach and arguably the best proxy in the literature to measure management practices since the authors developed it via a double-blind survey methodology, which was executed on more than 10,000 organisations over a decade across different industries and countries. This gave place to "one of the first large internationally comparable management datasets (Bloom et al., 2012, p. 13)". Yet, this model presented some limitations. It did not consider digitalisation, it disregarded finance, pricing, marketing, opening and closing decisions, and innovation. Moreover, the model revolved around the manufacturing industry and was culturally biased towards Anglo-Saxon organisations. The increasing usage of digital technologies in the AEC industry to facilitate processes makes this subject even more relevant.

To address the gap in the literature and provide construction firms with guidance regarding the implementation of digital tools, the aim of this study was to explore the way in which digital technologies are shaping management practices in the AEC industry, so the following research questions were proposed:

RQ: *How are digital tools shaping management practices in the AEC industry?*

SQ1: *What are management practices?*

SQ2: *What are digital tools?*

SQ3: *What is the purpose of implementing digital tools in the AEC industry?*

SQ4: *How are management practices and digital tools related?*

To answer these questions, an abductive research approach was chosen. Essentially, this approach iterates between the literature and the results. To accomplish this, the grounded theory method was used as a strategy to analyse the data. The data was collected through semi-structured interviews from experts in the field, and as such it was a cross-country qualitative analysis. The participants were selected based on three criteria: their academic background, their years of experience, and the technological advancement of their country. They were recruited through LinkedIn, for which ethical concerns were significantly important and strictly adhered to.

Three limitations were identified in this research:

- Ideally, the participants were intended to be from countries where management practices have been studied. However, given the limited time, the difficulty to recruit high quality participants, and the fact that some countries do not have access to LinkedIn (e.g. China), made this difficult to achieve. Nevertheless, the strict sampling procedure helped to mitigate this problem.
- Initially 10 participants were expected to be part of this study. Due to time constraints and the lack of response from the desired participants, only 9 were interviewed. But given the quality of the participants and the duration of each interview, the representativeness of the sample seemed appropriate.
- Management practices are a broad subject, which made it challenging to discuss about each of their 18 key indicators during the interviews. Because of this, the results show a general understanding of how digital tools are shaping management practices in the AEC industry.

The results were divided into four categories: targets, monitoring, incentives, and miscellaneous. The first three categories were the management practice clusters, and the latter was used as an additional category to store codes that still had an effect on them but was not part of management practices. For the first cluster, two 2nd order constructs were formed, optimiser and considerations. Together they formed the 3rd order construct ***efficient target setting***, which was defined as a strategy comprised of an adequate *optimiser* based on important *considerations* that seeks to accelerate the fulfilment of targets in a construction project. For the monitoring cluster the two 2nd order constructs identified were facilitator and inhibitor. Together they formed the 3rd order construct ***effective monitoring***, defined as the collection of data comprised of the *facilitator* and the *inhibitor* that determine the degree to which the monitoring of a construction project is successful. In the third cluster, incentives, the two 2nd order constructs identified were objectivity and subjectivity. Together they formed the 3rd order construct ***perceptual assessment***, defined as the evaluation of *objective* and *subjective* human performance measurements. Finally, in the miscellaneous category, the 2nd order construct ***resistance*** was encountered. From these results, a new grounded conceptual framework was developed to explain the relationship between digital tools and management practices. This framework consisted of three mediating variables: efficiency, effectiveness, and experience, while resistance was used as a moderator variable, exposing the prevalence of it in the AEC industry.

6.1.2. Answers to the sub-questions

SQ1: *What are management practices?*

Managerial parameters for which a firm's performance can be assessed, divided into targets, monitoring, and incentives.

SQ2: *What are digital tools?*

Digitally computerised data that can assist with a particular function.

SQ3: *What is the purpose of implementing digital tools in the AEC industry?*

To use effective digital solutions that have a positive impact on work efficiency, productivity, quality, sustainability, and health and safety; and that can eventually improve construction processes with reduced resources.

SQ4: *How are management practices and digital tools related?*

This sub-question can be answered through the grounded conceptual framework in *Figure 11*. Based on the analysis of the results, digital tools interact with management practices through the three mediating variables identified: *efficiency*, *effectiveness*, and *experience*.

6.1.3. Answer to the main research question

The main research question, how are digital tools shaping management practices, was in part answered through the grounded conceptual framework in *Figure 11*. Three mediator variables were identified from the results: ***efficiency***, ***effectiveness***, and ***experience***. Also, ***resistance*** remained as an integral part of the model as a moderator variable. From these variables, the former 18 key management practices model by Bloom et al. (2012) was modified. Three new management practices were added to the model, one for each cluster. These three new management practices are defined based on the 3rd and 2nd order constructs from the data collected. In the first cluster, *targets*, ***efficient target setting*** was added (*Table 19*). Similar to other practices, this practice can be scored from 1 (worst) to 5 (best) according to the following parameter: *do the digital tools implemented increase the efficiency of goal achievement? Are these tools constantly evaluated?* Similarly, for the *monitoring* cluster, ***effective monitoring*** was added as a new practice (*Table 20*). This practice is scored according to the questions: *are the digital strategies used to monitor the progress effective? Do these correlate to an increase in performance or are these detrimental to the business processes?* Finally, ***perceptual assessment*** was added to the third cluster, *incentives* (*Table 21*). This practice is scored based on the questions: *are people evaluated based on both objective and subjective traits? Are digital tools used to document these evaluations and further incentivise them?* Through the development of these three new practices, the main research question is fully answered.

6.2. Recommendations for Practitioners

According to several authors, a new organisational strategy is required in the context of digital transformation, especially in the AEC industry since it is currently in the early stages of digitalisation. Based on the results from this study, the following recommendations are presented:

- The existence of new or trendy digital technologies does not translate to performance improvement within a construction company, and thus careful evaluation of digital tools is recommended.

- The creation of a 'digital department' that focuses on efficient target setting, effective monitoring, and perceptual assessment can support practitioners with a successful transition.
- Efficiency, effectiveness, and experience are to be considered for a successful transition into digital processes. However, resistance to change for a variety of reasons is still prevalent in the industry. It is then suggested that proper measures are considered to strategically approach this issue within the 'digital department'.
- Construction firms are encouraged to use this study as it can support them with technology implementation and the managerial implications this would entail. Based on the research conducted, it is recommended that greater importance is given to the R&D department within an organisation.
- The number of digital technologies available to incentivise people is scarce. It is recommended to further develop them and implement them responsibly, since in general people do not appreciate being constantly monitored.
- Finally, although this research was conducted with construction specialists, other industries such as the manufacturing are fostered to review it. Tian et al. (2023) for example, found that manufacturing firms must recognise digitalisation as an important strategic orientation. Hence it is recommended that firms prioritise investment in digitalisation to increase efficiency in the long-term.

6.3. Further Research

This thesis followed an abductive research approach. The grounded conceptual framework and the new management practices were developed based on the current existing literature and the results obtained. Further research is suggested to replicate the research aim but with more refined methods. From the analysis of the findings, a quantitative deductive approach is recommended to prove the emerging theory of this thesis. This could significantly strengthen the results of this study by examining the relationship coefficients between the three mediating variables with digital tools and management practices. Moreover, an extensive cross-country qualitative analysis similar to the one conducted by Bloom et al. (2012) with a bigger sample could create a management practices framework tailored to the AEC industry. Afterwards, a deductive quantitative/qualitative approach could further strengthen the results found in this study to improve the understanding of how digital tools are affecting management practices in the AEC industry and further contribute to digital transformation.

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Appendices

Appendix A: Interview Questions Guide

Broad Questions

1. Can you tell me about a recent project you worked on?

2. What went good/wrong?

Targets

3. Did you have set goals for this project? And how did you manage to achieve these goals?

4. Tell me about the technologies that helped you set, control, and achieve these goals.

5. Have these tools changed or improved the way in which you set goals? How?

Monitoring

6. How did you track the progress of the project? Do other projects follow the same tracking method?

7. Tell me about the technologies you used to track the performance of the project.

8. Based on previous projects, can you tell me what changed/improved to track performance?

Incentives

9. Tell me how did you assess human performance on this project?

10. Did you use any technologies to track human performance? Which ones?

11. How has this changed in relation to past projects?

Broad Question

12. How important would you say that it is to implement digital technologies in the AEC industry?

Appendix B: Informed Consent Form

Consent Form Information

You are being invited to participate in a research study titled "The Digital Age and its Effects on Management Practices". This study is being done by Jaime Nicolás Castellanos from the TU Delft for his master's thesis.

The purpose of this research study is to analyse the impact the digital age has had on management practices in the construction industry, and will take you approximately 60 minutes to complete. The data will be used for the graduation project and will be published in the TU Delft repository. We will be asking you to answer some questions based on your expertise and from what you have seen in the industry.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by anonymising yourself and by omitting any data that could be traced back to you. In addition, a transcript of the interview will be shared with you afterwards, which you can check and decide to give your consent so it can be used in this research study. Once the research is completed, all materials including the recordings of the interviews will be destroyed.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. In case you do not feel comfortable with the answer you provided or if you accidentally shared any sensitive information, the question at hand will be omitted. A transcript of the interview will be shared with you afterwards in which you can decide to withdraw your consent to use the data provided for this research, or you can also decide to remove certain elements from it. The data you consent to share might be used in the master's thesis, which will be shared publicly in the TU Delft repository once the research is finalised.

To request more information or to contact the responsible researcher please send an email to jcastellanos@tudelft.nl.

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated 30/04/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves a video-recorded interview followed by a transcript of it, which will be destroyed once the research is finalised.	☐	☐
4. I understand that I will not be compensated for my participation.	☐	☐
5. I understand that the interview will take approximately one hour.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. I understand that taking part in the study involves collecting specific personally identifiable information (PII) such as name, email, and company; and associated personally identifiable research data (PIRD) such as video, audio, gender, and age, with the potential risk of my identity being revealed.	☐	☐
7. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: • Anonymisation of the participants, • Secure data storage with limited access, • Transcription of the interview, • Omission to publish any PII and/or PIRD, • Destruction of all the materials once the research is finalised.	☐	☐
8. I understand that personal information collected about me that can identify me, such as my name, where I work, or where I live, will not be shared beyond the study team.	☐	☐
9. I understand that the (identifiable) personal data I provide will be destroyed once the study is finalised and the master's thesis is published in the TU Delft repository.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for the researcher's master thesis.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
11. I agree that my responses, views, or other input can be quoted anonymously in research outputs.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS, AND REUSE		
12. I give permission for the de-identified data that I provide (as text) to be archived in TU Delft's education repository so it can be used for future research and learning.	☐	☐
13. I understand that access to this repository is open.	☐	☐

Signatures

_____ _____ _____

Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____ _____ _____

Researcher name [printed] Signature Date

Study contact details for further information: jcastellanos@tudelft.nl

Appendix C: Targets Codes

2nd order construct	1st order construct
Optimiser	○ a shared schedule promotes the progress of the project ○ AI can draw a first draft of the project which saves time ○ AI can help with drafting and writing reports ○ AI can improve the quality of tender proposals ○ AI can predict the necessary requirements in a project ○ AI can support designing the model ○ AI gives a good approximation of possible risks ○ AI shows the most potential due to its efficiency ○ AI with BIM can quickly improve the design ○ asta power project as a tool for scheduling ○ better short term planning with SCRUM ○ BIM can assist in controlling the targets ○ BIM helps to control the initial goals ○ BIM is imperative for large projects ○ BIM, tekla, navisworks and the cloud are used during the design ○ blockchain to enhance the contract ○ cash flow software ○ cloud collaboration during the design phase is key ○ digital project life cycle ○ digital tools allow to create a more detailed schedule and control the iron triangle ○ digital tools facilitate meeting the iron triangle components ○ digital tools should support quality control, cost, and monitoring ○ increase in efficiency and ROI due to digital tools ○ investment in digital tools can save you time and money during the project ○ microsoft office, bluebeam, power project P6 are the most used digital tools ○ MS project and click-up as tools to create a schedule ○ SCRUM Team to define the scope and duration of the project ○ sharepoint is used for phase 0 ○ shift to takt planning ○ technology is used to support the already existing processes ○ the 3D model is necessary for larger projects ○ the main goal of lean construction is to reduce waste

2nd order construct	1st order construct
Considerations	○ AI can support the project but is not smarter than people ○ AI does not create an accurate schedule ○ BIM is limited by the type of project

	○ BIM is used only for the design phase ○ communication is more important than technology for target setting ○ construction processes should be optimised before adding technology ○ construction projects vary, which makes it difficult to standardise the process ○ cost constraints prevent from investing in new technologies ○ design and construction phase use different software ○ developing a tool that goes beyond the iron triangle is challenging ○ Digital tools do not teach you how to create an accurate schedule ○ technologies do not replace proper planning ○ technology can enhance communication and daily tasks but not KPIs fulfillment ○ technology does not affect target setting ○ technology does not always add value to the field ○ technology is a double-edged sword ○ technology is good as long as it reduces costs onsite ○ technology is not a priority ○ the AEC industry is adapting digital practices based on other industries ○ the client is not interested in the technologies used ○ the focus must be on building, not on implementing technology ○ the life cycle of a project should be considered before implementing a new technology ○ the R&D department should decide which technologies benefit the company

Appendix D: Monitoring Codes

2nd order construct	1st order construct
Facilitator	○ 24 hour work shifts due to different time zones ○ AI can help with unimportant time consuming tasks ○ AI can search keywords in a report which increases efficiency ○ AI can support BIM to manage risks ○ AI helps to create scripts which is faster ○ AI improves report checking ○ asta power and ms project to track the progress ○ bim 360, sharepoint, power bi, and python to track the progress ○ blue beam and revizto to facilitate communication ○ clash detection is identified early in the process ○ clash detection makes BIM the most promising ○ cloud based software has improved teamwork ○ communication tools have improved how information is shared ○ comparing the model to the real life construction facilitates goal achievement ○ construction activities monitored through videotapes ○ control process to deal with the vast amount of digital information within a team ○ dashboards, primavera and ms office to track the progress rather than AI ○ design and construction phase integration through cloud sharing information ○ digital tool to track the financial component ○ digital tools allow you to work in multiple projects at the same time ○ digital tools are essential to report the progress ○ digital tools bring better alignment between interfaces ○ digital tools for location based plan to bring the team together ○ digital tools help with nonvalue activities ○ dropbox as collaboration tool ○ efficiency is key in the job, and AI is helping with that ○ excel to track KPIs ○ laser scan and the design model are compared and discussed ○ laser scan improves monitoring the progress ○ lean construction improves monitoring the project and thus productivity ○ live environments encourage the tracking of the project ○ mixed reality to check the progress of the construction phase ○ monitoring through an iterative planning software (JIRA) ○ monitoring through live communication tools increases efficiency ○ mostly basic tools such as excel to monitor the progress ○ mostly excel and primavera to monitor the progress ○ ms project and primavera to calculate performance

	○ online collaboration tools facilitate monitoring ○ online communication with the client ○ Power BI ensures better planning in the future ○ Power BI helps to check the deliverables of the team ○ Power BI to compare the model with the construction ○ project management information system to manage the progress ○ robots used to prevent humans from doing dangerous activities in construction ○ shared virtual environments allows to work internationally ○ standard activity report linked to scheduling software ○ technology can help with minor processes ○ technology facilitates remote monitoring ○ time is tracked through a software and meetings are held to discuss the progress overall ○ verity software for laser scan ○ weekly laser scan to track the progress

2nd order construct	1st order construct
Inhibitor	○ 360 camera is interesting yet not necessary ○ besides clash detection and collaboration tools, technology does not add value ○ coordination in the field is different than what technologies say ○ digital technology modifies the process but does not improve it ○ digital tools are only valuable if the process is understood ○ digital tools must fulfill a purpose ○ due to project variance, digital tools should consider different scenarios in construction ○ fancy technology is used due to poor planning and processes ○ for larger projects it is more difficult to implement sophisticated digital tools ○ for smaller projects the client does not care about the 3D model ○ keeping up to date with technology is key ○ lean construction is far more efficient than using technologies ○ measuring onsite productivity is far more important than creating a new digital process ○ on site verification is necessary in construction ○ people don't always adhere to the cloud, which negatively impacts teamwork ○ process before technology ○ processes must be prioritised ○ processes, culture, and practicality must be prioritised before new technologies ○ quality assessment tools like IoT are quite recent ○ resistance to adapt to working live on the cloud

	○ resistance to change can prevent you from improving your processes ○ resistance to follow lean construction ○ resistance to invest in monitoring technologies like Revit ○ resistance to learn a new tool due to time constraints during the project ○ some daily technologies prevent critical thinking ○ technology compensates the lack of building skills ○ technology is not a synonym of efficient tracking ○ time constraints during construction prevent the use of different digital tools ○ trendy monitoring technology does not always bring value ○ willingness to adapt within a company affects monitoring

Appendix E: Incentives Codes

2nd order construct	1st order construct
Objectivity	○ attracting human capital through remote and flexible working hours ○ digital tracking facilitates incentives like more money and less working hours ○ easier to track and reward yearly performance ○ gamify the process of assessing productivity ○ human performance based on adherence to lean construction ○ human performance measured with digital tools based on deliverables ○ human productivity is not affected by technology ○ online company reputation attracts human capital ○ productivity measured in terms of density of work ○ promotions depend on the number of clients brought, which can be measured easier ○ retraining is uncommon but workshops are encouraged ○ surveys to measure job satisfaction ○ the effectiveness of training is assessed based on the completion of tasks later on ○ time constraints prevents the use of trendy digital tools to track human performance ○ training sessions to learn how to use a new tool

2nd order construct	1st order construct
Subjectivity	○ company culture influences how human performance is assessed ○ digital tools for human performance involve giving and receiving feedback ○ digital tools to track human performance are scarce ○ human data gathering software ○ human performance depends on the culture ○ human performance is difficult to measure through a digital tool ○ human performance is evaluated by the manager ○ human performance is very subjective ○ incentivise through self-development ○ job satisfaction incentivises people ○ only communication tools to support human capital ○ people feel uncomfortable when you directly assess them ○ personality tests should be used more often across the team ○ proper human treatment influences retention ○ software can assess feedback faster

Appendix F: Miscellaneous Codes

2nd order construct	1st order construct
Resistance	○ 4D is interesting, yet not necessary ○ a knowledge gap in digital tools bring misuse of these to the AEC industry ○ AI could misuse sensitive information ○ AI must be used with caution ○ basic questions solve real problems, not technology ○ different cultures prevent a unified digital solution ○ digital technology disconnects you from reality ○ digital tools are not problem solvers ○ digital tools can take over some jobs ○ disagreements between the parties hinder technological advancement ○ implementing new tools is expensive ○ implementing new tools is not always successful ○ investment in new digital tools is not a priority ○ leadership prioritise business development rather than implementation of new technologies ○ learning how to use a software is a limitation ○ managers need to expand their technological skills ○ new technologies bring new risks such as a data breach ○ research articles and actual construction show different results ○ resistance to adapt to new technologies ○ the AEC industry is not like the others ○ The cost of new software is a limitation ○ the user interface of a developed digital tool represents a challenge ○ unlike other industries, the AEC requires more people skills ○ vr/ar is used mostly to satisfy the client ○ willingness to learn how to use new tools is necessary in the industry