Delft University of Technology

DIGITIZING PROJECT PORTFOLIO MANAGEMENT IN THE ARCHITECTURE, ENGINEERING & CONSTRUCTION INDUSTRY

THE APPLICATION OF DATA & ANALYTICS FOR EVIDENCE-BASED DECISION-MAKING

Master thesis submitted to Delft University of Technology in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in Management of Technology

Faculty of Technology, Policy and Management

By

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PREFACE

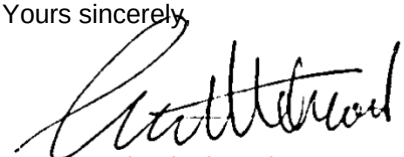
This master thesis was written to obtain the master's degree in Management of Technology at the Faculty of Technology, Policy and Management at the Delft University of Technology. The thesis report describes the research and development of a conceptual framework for Project Portfolio Management in the Architecture, Engineering and Construction industry, using Data & Analytics.

During the first year of the master's programme, the technology, innovation, and organisation theme attracted my attention including courses in leadership and technology management, business process management and technology, and inter- and intra-organisation decision-making. After an Exchange programme in Sweden at the Royal Institute of Technology I was intrigued by the research field of Project Management and R&D Management. Especially Project Portfolio Management, attracted my attention due to the strong ties between strategy and innovation. I see Project Portfolio Management as the way strategy is being translated into execution. Project portfolio Management is a valuable organisational capability and interests in the field is growing in all different types of industries.

Besides, I wanted to get introduced in the world of consultancy related to Engineering and Construction and wanted to extend my knowledge in Digitalization, Big Data, Data Management and Analytics. After I discovered that the Architecture, Engineering and Construction industry did not have empirically established frameworks for Project Portfolio Management using Data & Analytics, I responded to a vacancy for an internship in the Global Data & Analytics team at Arcadis. Within Arcadis, I set up a case study to investigate the possibilities of Project Portfolio Management, using Data & Analytics.

It is my hope that you enjoy reading this graduation master thesis.

Yours sincerely,



C.J. (Coen) Wittebrood

EXECUTIVE SUMMARY

This master thesis research has the aim to investigate how Data & Analytics enhance monitoring, reporting and control in project portfolio management practices to improve portfolio decision-making in the Architecture, Engineering and Construction (AEC) industry. Adequately and regularly reconsidering the project portfolio, with interdependencies towards the internal and external complex and rapidly changing environment, has shown to be a determinant for being successful in creating competitive advantage and securing the future of organisations that are project-based. Especially in the information technology (IT) field, rapid technological changes aim for dynamic organisational capabilities. This is reflected by the demand for digitized project portfolio management (PPM) using Data & Analytics. Projects are creating an increasingly growing amount of data and becoming more data driven. The main goals for introducing more formal PPM are: to achieve the highest financial value of the project portfolio, to balance the different types of projects in the portfolio, to limit the number of projects to fit with organisational capacity and to ensure that the portfolio reflects the company's corporate and business strategies. Businesses in the architecture engineering and construction (AEC) industry are forced to work more efficiently, to save money and to be more productive, this altogether with limited budgets. Project portfolio management practices facilitate repeatable success, help allocate resources optimally, improves time to market and leads to cost savings.

Although literature in the academic research field of project and project portfolio management describe different frameworks for PPM, there is a lack of context and practice. Information regarding comprehensive PPM frameworks that incorporate organisational, technological, and environmental factors found through empirical research are missing. Moreover, industry specific factors are missing as frameworks are generic and standardized, existing PPM practices miss adequacy and regularity and are often based on intuition, power, opinion, and leadership. To enhance competitive advantage within the AEC industry, a comprehensive approach in PPM is investigated with a focus on digitization and Data & Analytics.

The main research question in this thesis research is: *"How does a PPM framework for monitoring, reporting and control look like to improve project portfolio decision-making practices in the AEC industry, using Data & Analytics?"*. To answer this question the concept of triangulation is used in this research as project portfolio management falls under social sciences. Different research methods are combined to build the chain of evidence. The core of the research is based on extensive literature review to build an academic foundation. Then via interviews and the use of a case firm in the AEC industry, using mainly document analysis, the theories from literature are adapted and transformed to develop the conceptual framework for PPM. Portfolio performance and success factors that are industry specific are integrated in the framework. And Data & Analytics needs, and methods are elaborated to fit the framework. As the conceptual framework is theoretic, influencing factors on the implementation of the framework in practice are identified.

The conceptual framework that is developed is built on the three pillars, people, processes, and technology. The people pillar proposes an organizational governance structure that facilitates PPM through establishing an enterprise project management office (EPMO) that acts as general expertise centre and handles large data

flows from the project environment. Moreover, divisional, and regional project management offices absorb the fragmentation of the large AEC firms. The processes pillar incorporates a formalized and well-defined core PPM process that is worked out in detail to enhance practices for selecting, evaluating, and optimizing the project portfolio through 6 phases. These phases are stochastic project forecasting, pre-screening, individual project analysis, screening, optimization, and adjustment. The technology pillar of the framework identifies on a high level how the information technology (IT) structure integrates different databases into a data warehouse that facilitates the executive team, the EPMO, the PMOs and senior level management to work with the required data. The databases incorporate customer relationship management data bases, enterprise resource management data bases, human capital management data bases, sales and business development data base and externally of public databases with macro-economic data and environmental data (e.g. national public data bases, stock exchange data base).

Adherent to the conceptual framework, key success factors (KSFs) for portfolio performance and project success in the AEC industry are found that in the end drive business success. Most important findings are on the portfolio level the individual project performance (>50%), strategic fit based on risk, analytics and aggressiveness, the type of portfolio balancing and optimization methods, and project synergies and interdependencies. On the project level the most important findings are the triple constraint of project management (time, cost and scope), contracting for project delivery and procurement, the knowledge, skills and abilities of the project team, and the location and project management process. These insights do contribute to the academic literature in terms of specifying CSFs that can be translated into selection criteria and eventually KPIs. Moreover, it is found that project performance data is of utmost importance as input for PPM practices. Currently, data is not optimally collected analysed and used, especially improvements can be made with gathering performance data with regards to timing and scheduling. Here EVM methods in project management practices indicate high added value. To enable the AEC industry to use Data & Analytics, data management, which is a prerequisite of creating insights based on data, must grow to higher maturity level. Findings indicate that the whole range from descriptive analytics to prescriptive analytics apply to PPM practices. Most value can be derived through starting with improved descriptive analytics through visualization and dashboarding. This opens the organizational dialogue in the decision-making process. More advanced analytics like time-series analytics can be used in the initial phases of the PPM core process to identify trends and opportunities in the market through macro-economic variables and project characteristics. Other phases can benefit the most from categorization methods and techniques and quantitative modelling methods and optimization techniques.

The developed conceptual framework is theoretic and implementation of the framework in practice is subject to influencing factors. Findings indicate different categories of influencing factors, under which digitalization in the AEC industry, general barriers to PPM, project management and data management maturity, and barriers to Data & Analytics. Some factors are covered through the framework, other factors are refuted with resolutions. The framework is evaluated by expert opinion, and has been received as theoretical and exploratory, but as promisingly applicable to the industry. Future research should make the translation to a standard operating procedure and must test the framework with available data from a number of projects. Besides external data sources and variables must be investigated and connected to different service offerings in the AEC industry.

ACKNOWLEDGEMENTS

I would like to express my deep and sincere gratitude to my thesis supervisor dr. ir. Z. (Zenlin) Roosenboom-Kwee for giving me the motivation and invaluable guidance throughout my research. Her involvement and constructive comments have been very supportive from the initiation phase including my proposal to my final thesis report. Our biweekly meetings challenged me and helped me. I also want to express my gratitude to my chair professor, prof. dr. ir. M.F.W.H.A. (Marijn) Janssen, for the critical look that sharpened the academic style in my thesis and emphasized the integration of digitalization and data and analytics part in my thesis.

Arcadis, and especially the Global Data & Analytics team with my supervisor, Freek Matheij, offered me all the freedom, connections, and information to conduct my research, for which I am very grateful. My experiences and insights gained from the Arcadis internship during my research will stay with me and contribute to discovering my personal knowledge, capabilities, and interests in a very positive way. There still might be career challenges ahead within this company as, at the time of writing, I was offered the opportunity to orient myself for a job within the company.

I did my thesis research and internship during the covid-19 crisis, what made it a special event. After an introduction week at the Arcadis headquarters in Amsterdam, I worked at home for the entire duration of my research. During the first month I moved into my new home and went to live together with my boyfriend. I am proud of the way in which my supervising professors at the Delft University of Technology, my supervisor at Arcadis, and others close to home have adapted to the challenging situation.

The result is a demonstration of good co-operation, which proves possible digitally and remotely. Working at home was sometimes challenging my motivation and concentration but through changing workplaces I managed to stay focused.

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LIST OF ABBREVATIONS

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
CoP	Community of Practice
DA	Data & Analytics
DAMA	Data Management Association
DMAIC	Define, Measure, Analyse, Improve, Control
DMBOK	Data Management Body of Knowledge
ERM	Enterprise Resource Management
ERP	Enterprise Resource Planning
GEC	Global Expertise Centre
GPT	General Purpose Technology
IaaS	Internet as a Service
ICB	IPMA Competence Baseline
ICT	Information Communication Technology
IoT	Internet of Things
IPMA	International Project Management Association
ISO	International Standardization Organisation
IT	Information Technology
KPI	Key Performance Indicator
KSF	Key Success Factor
ML	Machine Learning
NLP	Natural Language Processing
OPM	Organisational Project Management
PaaS	Platform as a Service
PBO	Project Based Organisation
PgM	Programme Management
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMO	Project Management Office
PPM	Project Portfolio Management
PRINCE	Projects in Controlled Environments
PRiSM	Projects Integrating Sustainable Methods
RPA	Robotic Process Automation
SaaS	Software as a Service
SMC	Strategic Management Control
VR	Virtual Reality

1 INTRODUCTION

This chapter introduces the research topic: project portfolio management (PPM). The chapter first describes the research background of PPM and the need for further investigation. Second, research gaps in the PPM field, based on a preliminary literature review, are presented and the problem statement is elaborated. Section three describes the context and scope in more detail. In the fourth section, research objectives and research questions are formulated. And in the fifth section, the thesis outline is represented.

1.1 Research Background

Growth of the organisation is the result of successful projects that are at the foundation of new products, procedures, and services. Both project managers and senior-level managers are important in the hierarchy of project portfolio management as projects are the means of converting strategy into execution (Spalek, 2019). PPM is related to strategic management (see Figure 1) and focuses on doing the right projects (Oltmann, 2008). PMI (2017, p. 3) defines a project portfolio as "*a collection of projects, programmes and other work that is grouped together to facilitate the effective management of that work to meet strategic business objectives*". PPM is the firm's capability to evaluate, select and prioritize projects (Magnusson, 2019). It helps firms achieve their long-term growth objectives and support new product's or service's success. The field of project portfolio management (PPM) is gaining popularity as the world economy is transforming increasingly to project-based work (Jerbrant, 2019). Project management practices are data driven and projects are not organised separately nowadays, but are grouped together to bring more value to the company (Spalek, 2019). Therewith even more data is produced and this data should be analysed to bring value, through cost, resources, schedules and work types (Spalek, 2019). The main goals for introducing more formal project portfolio management are to achieve the highest financial value of the project portfolio, to balance the different types of projects in the portfolio; to limit the number of projects to fit with organisational capacity and to ensure that the portfolio reflects the company's corporate and business strategies (Magnusson, 2019).

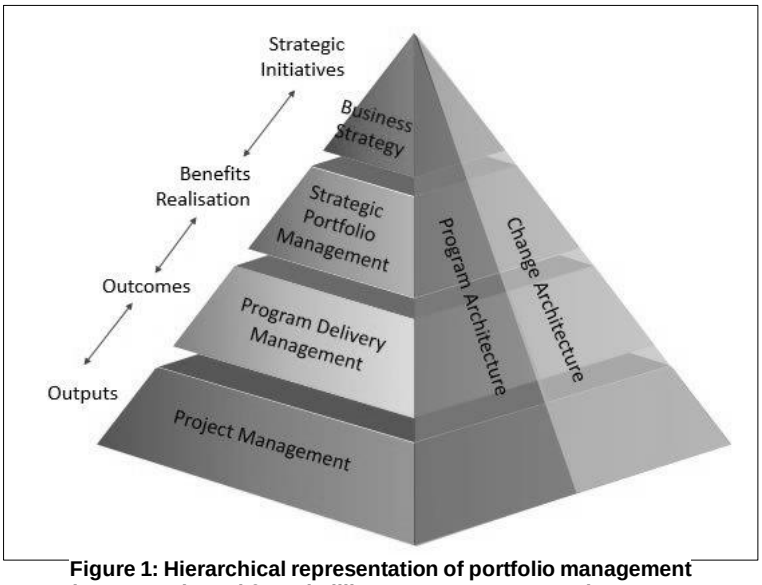

Figure 1: Hierarchical representation of portfolio management (Source: adapted from (Williams & Parr, 2004, p. 12)

Adequately and regularly reconsidering the project portfolio, with interdependencies towards the internal and external complex and rapidly changing environment, has shown to be a determinant for being successful in creating competitive advantage and securing the future of organisations that are project-based (Martinsuo & Lehtonen, 2007; Cooper & Edgett, 2008; Spieth & Lerch, 2014). Especially in the information technology (IT) field, rapid technological changes aim for dynamic organisational capabilities. This is reflected by the demand for adaptable PPM processes (Bredillet, Tywoniak, & Tootoonchy, 2017; Biedenbach, 2012; Calderini, et al., 2005).

Besides the focus on financial performance and risk assurance, project portfolio management now focuses more on organisational, technological, and environmental factors. System thinking and holistic approaches that offer room for experimentation are preferable. But these approaches to PPM are *context* specific and need guidance in *practice* (Spalek, 2019; Biedenbach, 2012; Müller, Martinusuo, & Blomquist, 2008; Teller, Unger, Kock, & Gemünden, 2012; Zika-Viktorssona, Sundström, & Engwall, 206). The context in which PPM is executed depends on organisational complexity (Blomquist & Müller, 2006; Teller, Unger, Kock, & Gemünden, 2012), the degree of innovativeness (Spalek, 2019), contextual dynamics and the organisational (governance) and managerial context (Jerbrant, 2019; Zika-Viktorssona, Sundström, & Engwall, 206; Müller, Martinusuo, & Blomquist, 2008). Moreover, the organisational complexity, the industry and the firm are thus important to include as contextual factors (Teller, Unger, Kock, & Gemünden, 2012). Besides that, uncertainty, change and risks are found both internally and externally (Müller, Martinusuo, & Blomquist, 2008).

1.2 Research Gaps and Problem Statement

Project-based organisations (PBO) have an organisational form that is necessary in the making of temporary systems for the project's performance (Jerbrant, 2019). To make PBOs work, they need to be structured to create synergy between projects, programmes, and portfolios. This is related to the organisation's resources and capabilities (Jerbrant, 2019). Important criteria that are applied in setting up new PPM processes are relevance, efficacy, efficiency and sustainability & impact (Picciotto, 2019).

Based on literature review, the main problem with PPM has to do with the lack of *practice* and *context* which is related to the organisational level and the industry level (Spalek, 2019; Biedenbach, 2012; Müller, Martinusuo, & Blomquist, 2008; Teller, Unger, Kock, & Gemünden, 2012; Zika-Viktorssona, Sundström, & Engwall, 206). Regarding this problem, four specific gaps in literature are identified.

First, rational approaches based on finance are applied in PPM to contribute to the strategic objectives of the organisation. But innovation projects are often executed to go beyond these financial strategic objectives and question the status quo (Aithal & Aithal, 2019; Nguyen et al., 2018; Schilling, 2008; Sergeeva & Zanello, 2018; Sicotte et al., 2015; Spalek, 2019a; Spieth & Lerch, 2014). Second, existing frameworks focus on the internal business environment regarding resources but overlook external parties, causing limited insight in project interdependencies and limited control over resources (Jerbrant, 2003; Schilling, 2008; Spalek, 2019a). Third, PPM frameworks assume full awareness of all possible influential factors from the internal and external environment.

But projects are often not well defined, challenging, limited with information for decision-making and the environment needs often to be studied and is poorly known (Tonnqvist, 2018; Spalek, 2019). Fourth, PPM research indicates that it is assumed that project information is embedded in criteria and routines aligned with the corporate strategy. But portfolio managers are not well informed, and criteria and routines do thus not solve the multi-project problems (Shao, 2018; Simons, 2016; Spalek, 2019b).

Quote from interviews:

"*Theory of project, programme, portfolio management is good, but the practice is very bad*."

- Global Director, Project & Programme Management, Retail & Banking, UK, 03-06-20 -

Thus the problems regarding context and practice in PPM that are being addressed in this thesis are the establishment of routines and practices, the identification of industry specific project portfolio selection criteria, the enhancement of (internal and external) information flow for portfolio decision-making, and strengthening the focus on strategic objectives instead of financial matter in PPM. This is done through an in-depth case study in a PBO consultancy firm in the AEC industry.

1.3 Research Context and Scope

Consultancy and advisory organisations in the Architecture, Engineering and Construction (AEC) industry deliver services incorporating control, governance, design, R&D, re-arrangement, and non-routine use (Selstad, 1990). The focus is on the creation and collection of information and new technologies, data interpretation and the evaluation and implementation of strategies for new technologies are endorsed in the AEC industry. The AEC industry, is known for adopting new processes and innovations slowly, cost and time-overrun are rule rather than the exception while financial returns are often relatively low (Agarwal, 2016; Jerbrant, 2019). Firms in the AEC industry are mostly project-based organisations (PBO).

Practises in the field of PPM are often uncoordinated, lacking risk management maturity and are less innovative. Besides, monitoring, reporting and control is behind. (Agarwal, 2016; Jerbrant, 2019; Bilal, et al., 2016). Recent investigation in the principles of movement showed four trends to remain competitive (Meisels, 2019). First, cost pressures drive the AEC industry to plan, manage and execute projects better. Second, digital technologies change the way the AEC industry operates. Third, new partnership models and project, programme and portfolio structures are required. Fourth, the AEC industry is deploying smart technologies to continue transforming (Meisels, 2019). This all stimulates industry leaders to develop new vision, missions and strategies and map a digital roadmap or blueprint. The AEC industry should restructure the business model and operational processes to react to a changing market and catch the opportunities that innovation and technology provide (Meisels, 2019).

Literature points out that the AEC industry is less digitalized compared to other industries (Agarwal, 2016; Jerbrant, 2019; Bilal, et al., 2016). Organisations are aware that digitization helps their business but changing the organisation and implementing tools and technologies and ways of work needs advice and direction. The same holds for the PPM processes in the AEC industry. As the transition towards a digitalized organisation

should be non-invasive, change and development starts at the project level. In later stadium programme management and portfolio management should be organised digitally as well. The transformation then reaches business unit level and finally corporate level (Wollersheim, 2019).

Several characteristics of Data & Analytics, such as discovery, interpretation, communication, pattern recognition and enhanced evidence-based decision-making can offer solutions for PPM practices (Spalek, 2019). Data & Analytics enhance retrieving useful information from data. Moreover, Data & Analytics enables project portfolio management practices to focus outside the triple constraints of project, programme, and portfolio management and encompasses the business needs and activities of the organisation internally externally. Therefore, Data & Analytics helps combining input from business analytics and project management metrics and analytics. A combination of business intelligence measures and metrics needs to be combined with historical data, real-time data, and strategic key performance indicators (KPIs). Planning data and controlling data can be integrated, like schedules, budgets, specifications, resources, and work performance. New approaches in Data & Analytics are data visualization, process simulation, text and voice analysis, media analytics and other techniques. (Spalek, 2019)

1.4 Research Goal and Research Questions

The research goal is to extend and sharpen academic literature in the PPM field, specifically on PPM decision-making processes in the AEC industry using Data & Analytics. Therefore, the objective is to develop a conceptual framework for Digitized PPM in the AEC industry using Data & Analytics. This conceptual framework is an analytical tool for project portfolio practices with context specific indicators for the AEC industry. The framework is an abstract representation that synthesizes the research's empirical findings in directing the collection of project data as input for project portfolio decision-making based on the application of the organizational learning and strategic management theories in combination with findings from the IT field. With this framework, analysis on the current state of the organisations project portfolio is performed and actions for improvement regarding the execution of new projects are recommended through the framework. To achieve this, the framework covers the elements people, processes, and technology. To achieve the objective, a main research question and four sub questions have been devised that give direction throughout the research.

The main research question has been devised as:

RQ: *"How does a PPM framework for monitoring, reporting and control look like to improve project portfolio decision-making practices in the AEC industry, using Data & Analytics?"*

As the study will be performed in the AEC industry, all sub questions refer to it. First, the current state of the PPM frameworks must be investigated, therefore the first question is devised as:

***SQ1**: "What are the characteristics that are crucial for a PPM framework?*

Second, industry specific context and practice must be added to the framework. The second question is devised as:

***SQ2**: "What financial and non-financial project factors determine the success of a project portfolio?"*

The third part is to specific input for the PPM framework to be developed. Therefore, the third sub question is:

***SQ3**: "How can Data & Analytics be applied for decision-making in PPM practices in the AEC project environment?*

The fourth part is to factors in the AEC industry that influence the application of Data & Analytics to assess the potential of the framework, therefore the fifth question is:

***SQ4**: "What factors influence the application of Data & Analytics in PPM in the AEC industry?"*

1.5 Thesis Outline

The content of the thesis consists of three parts (see Figure 2), the first part is theory building on PPM frameworks, the second part is building the framework with Data & Analytics and the third part is the delivery of the framework, the validation and the follow-up. In the second chapter, research methodologies are extensively described. In the third chapter the concept of PPM and characteristics of a PPM framework are introduced. Project, programmes, and portfolios are distinguished, and management implications linked with the project portfolio are considered. The fourth chapter describes characteristics of project portfolio performance, and successful projects. The fifth chapter elaborates on Data & Analytics for PPM. Big data and technology are briefly introduced as starting point, and Data & Analytics and methods are described. Project data and analytics are identified to use in the PPM framework. The sixth chapter describes influencing factors on the application of the framework for digitizing PPM. Digitalization and trends and opportunities are explained project and portfolio analysis methods and techniques. In Chapter 7 the discussion and conclusion tie together all findings and answer the main research question. The conceptual framework for PPM using Data & Analytics is delivered and validated, recommendations for future research and managerial and practical implications are provided.

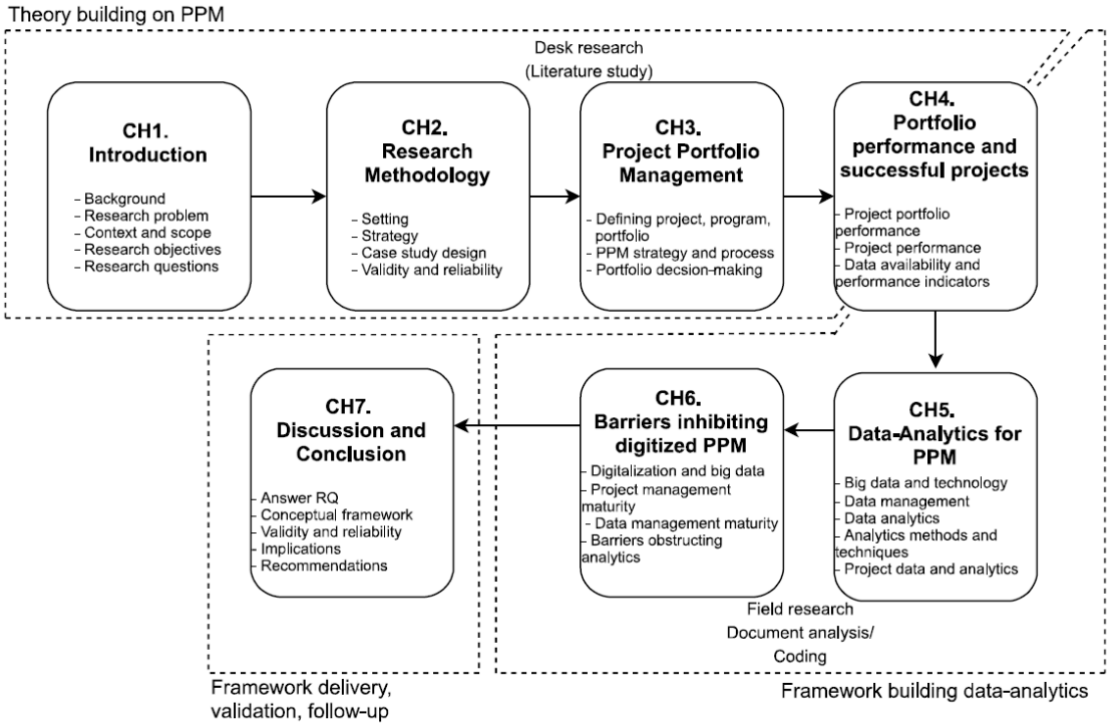

Figure 2: Visualization thesis outline (Source: Author's own analysis)

2 RESEARCH METHODOLOGY

This chapter describes the research methodology. First the research setting is explained as the research is performed during a thesis-internship at an organization. Second, the research strategy and design are elaborated to indicate what type of research is carried out. Third, the literature review method is described in detail. Fourth, the case study set-up is elaborated. In the fifth section, the interview set-up is explained and in the sixth section, the reliability and validity are discussed.

2.1 Research setting

The research is performed within a project-based organisation in the AEC industry. The organisation is a design and consultancy firm for the natural and build assets. Activities within the organisation are split up in two branches, design and consultancy (see Figure 3). Design incorporates architecture and master planning. Consultancy includes cost management, contract solutions, programme management and project management. Both branches share engineering, environmental sciences, and business advisory. Within the organisation, the research is executed in the Global Data & Analytics team as part of the Global Digital Solution and is interlinked with the Global Programme Management Solution, as this solution supports Project, Programme and Portfolio Management services. At Arcadis Project Portfolio Management is replaced by the term Capital Investment Planning, and therefore contributes to the research in terms of networking, documentation, and information sharing.

Quote from interviews:

"*Our company moved away from PPM, now capital investment planning*"

- Global Solution Director, Portfolio & Programme Management, Europe, 11-05-2020 -

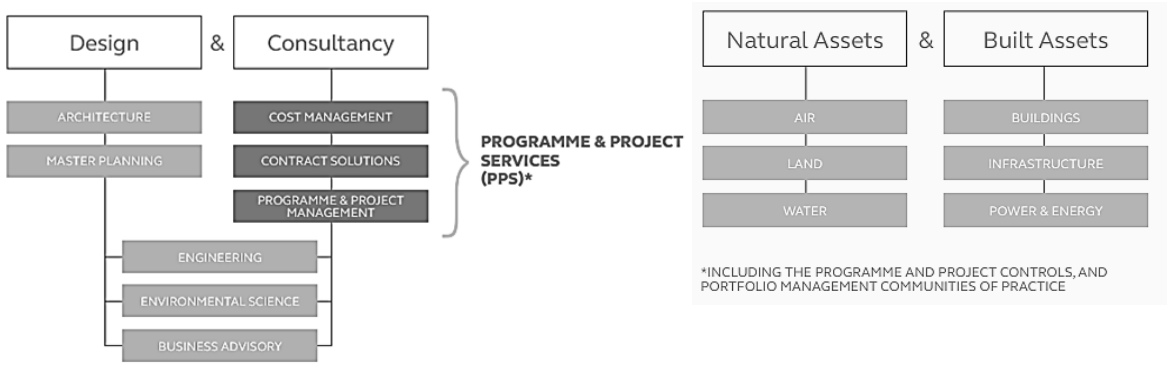

Figure 3: Schematic representation of research setting in Arcadis (Source: retrieved from arcadis.com)

2.2 Research Strategy & Design

This research intends to explore insights into the issue of *context* and *practices* of PPM to gain and understanding of underlying factors. The research aims at conducting initial research and is therefore exploratory in nature. Qualitative research is chosen and is based on the concept of triangulation (use of mixed methods) in the form of using literature review, case study and interviews. Triangulation is a strong method to overcome weakness and intrinsic bias in studies in social sciences. Due to the topic (PPM) and the exploratory nature of the research, triangulation empowers the findings and helps to build the chain of evidence in the argumentation structure.

Existing information and theories are a foundation for the framework, new findings are used to extend the existing frameworks. The research is flexible, which implies that methods are adjusted during the iterative knowledge creation process. For generalization and standardizations choices and assumptions are carefully reflected. Therefore, triangulation is applied regarding data sources and a chain of evidence is written up.

The research design is based on mixed methods (see Table 1). First desk research is used to collect and analyse already existing information to create a solid base. This data is gathered from multiple sources to increase generalizability and spread fields of interests. Academic literature, white papers and corporate literature is consulted during desk research. Secondly, field research is carried out through case studies. Third, unstructured interviews are carried out to orientate and to bring some preliminary issues to the surface so that further in-depth research needs can be determined.

The research focusses on a new field of study, namely involving more crucial factor in establishing a new framework for the project portfolio management process and decision-making. This contributes to the lack of context in the existing framework. Data on phenomenon is collected within the natural surroundings of the projects performed by Arcadis. This gives insight in context and in-depth understanding in PM and PPM practices. Organisational process blueprints are consulted to gain insight in procedures in the AEC in the field of project and project management. Case study is chosen as research design so that the aspects of the research develop throughout the data collection process. The collected data will be analysed through qualitative data analysis software (Atlas. TI), using coding as main tool. Regarding coding activities, the grounded theory will be applied, to develop an inductively derived theory from the data (Uma Sekeran, 2016).

Table 1: Overview of research questions, method, and location (Source: Author's own analysis)

Question	Research method	Chapter
RQ: "How can a PPM framework for monitoring, reporting and control be established to improve project portfolio decision-making practices in the AEC industry, using Data & Analytics?"	Literature review, case study, and interviews	7
SQ1: "What PPM factors and processes are crucial for the AEC industry?"	Literature review	3
SQ2: "What financial and non-financial project factors determine the success of a project in the AEC industry?"	Literature review, case study, and interviews	4
SQ3: "How can Data & Analytics enhance evidence-based decision-making for PPM practices in the AEC project environment?"	Literature review and interviews	5
SQ4: "What factors influence the application of Data & Analytics in PPM in the AEC industry?"	Literature review, case study, and interviews	6

2.3 Literature review

First the literature from three courses that partially overlap in the field of Project Portfolio Management was used. These courses in Managing Research and Development, Project Management: Leadership & Control and Strategic Management Control are based on based on the literature from Grant, (2005); Robert N. Anthony, Frank G.H. Hartmann, Kalle Kraus, (2014) and Tonnqvist, (2018). The literature was used to create an univocal view on PPM. Secondly influential persons according to the amount of citations and publications in Google scholar regarding research in the project management field and project portfolio management field were identified.

Literature from influential researchers were searched for and used to get an overall understanding of important topics in the fields. With this search a list of researchers was found, sorted on relevance the top researchers were consulted in their publications. Author's that are recognized as important in the PPM literature were found to be Grant, Cooper, Kopmann, Lerch, Kock and Nguyen. These names are often mentioned in PPM literature.

Third, via the website of the Project Management Institute PMI more practical and implications for managerial practices were found and included in the literature review. These findings aim for focussing on organisational and societal practices in PPM. Fourth, because it was chosen to take the perspective from the project management field, the Web of Science Group webpage has been used to search for the official Project Management and Project Portfolio Management Journals. Three websites have been used, the official website of the International Journal of Project Management, the journal website of Portfolio Management Research and the journal website of Organisational Project Management. Access to the journal issue database was used via the Science Direct website to search for journal articles around project portfolio management. Within this database of journal issues, the search terms "Adaptability Project Portfolio Management" were used.

To limit the number of hits found in the journal databases, literature after 2014 was only used for the literature review. The year 2014/2015 was used as constrain in finding relevant literature since this is the point from which "computation" was added to information and communication technologies (ICT, ICCT). Form this point the developments in technology have accelerated, which aimed for different PPM approaches as well. From this point in time the project management field was extending towards the organisational, and social sciences field, which implied the increase complexity of project management practices and project portfolio management. Fifth, a more technological standpoint was added to create a more relevant scope for master thesis writing. Search terms use were "data analytics for PPM" and "IT services in PPM". Sixth, to find existing frameworks for PPM, general frameworks are search for via influential researchers and more industry specific frameworks are found trough search with key words like "Construction project portfolio management" and "Project portfolio management AEC". The comprehensive results and structuring of the findings in the literature can be found in Appendix VII.

2.4 Case Study

With this case study set up, five criteria for a proper case study are followed up, rigorousness, unambiguousness, generalizability, a managed level of effort, an advance understanding of comparative advantage of case study (Yin, 2014).

2.4.1 Case study rationale

The case study is a form of social science research and is related to PPM in that sense that a managerial research is being performed and needs input from *people* and *processes* (Yin, 2014). The case study fits the research question which is a "how" questions that aims at explaining and exploring. Moreover, the problem identified in the problem statement shows that insight in context and practice is needed, therefore research in fixed setting with no control over behavioural and environmental factors and events is needed to make the research industry specific and gain deep understanding of the phenomenon studied (Yin, 2014). The case study is used in cases of decision-making, and thus aims at PPM in the sense of portfolio decision-making. Moreover, it includes persons, organisational governance, business processes, projects, and programmes etc.

2.4.2 Planning

The case-study set-up will be done following the linear but iterative process. The trajectory is divided in 6 stages; plan, design, prepare, collect, analyse, share (see Figure 4). The case study plan shows the trajectory from the planning phase, to setting up the case-study and collecting data, interpreting the data and processing data and showing results (Yin, 2014). The case being studied is the Arcadis company, an organisation in the AEC industry performing consultancy and design tasks for the natural and built assets.

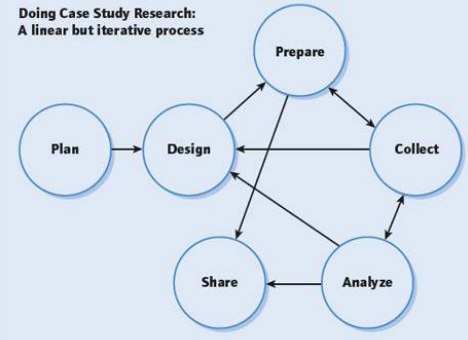

Figure 4: Case study trajectory (Source: (Yin, 2014, p. 34))

In the case of Arcadis, different parts are investigated. A multiple case study with embedded unit of analysis must be performed). Based on the developed theory cases are selected to gain insight and gather information that can be used additionally or to modify the developed theory. The case study question will be answered for each case and a brief individual case study report is attached to show the conclusions drawn (see Figure 5). To create insights, project documentation is gathered, and business process blueprints are analysed. Besides, Arcadis annual reports are analysed to identify risks and success factors and gain insight in the strategic mindset in an AEC firm. The project documentation to be analysed must come from projects in the closing phase, as evaluation reports and lessons learnt reports are necessary for analysis, which are produced after the execution phases in projects.

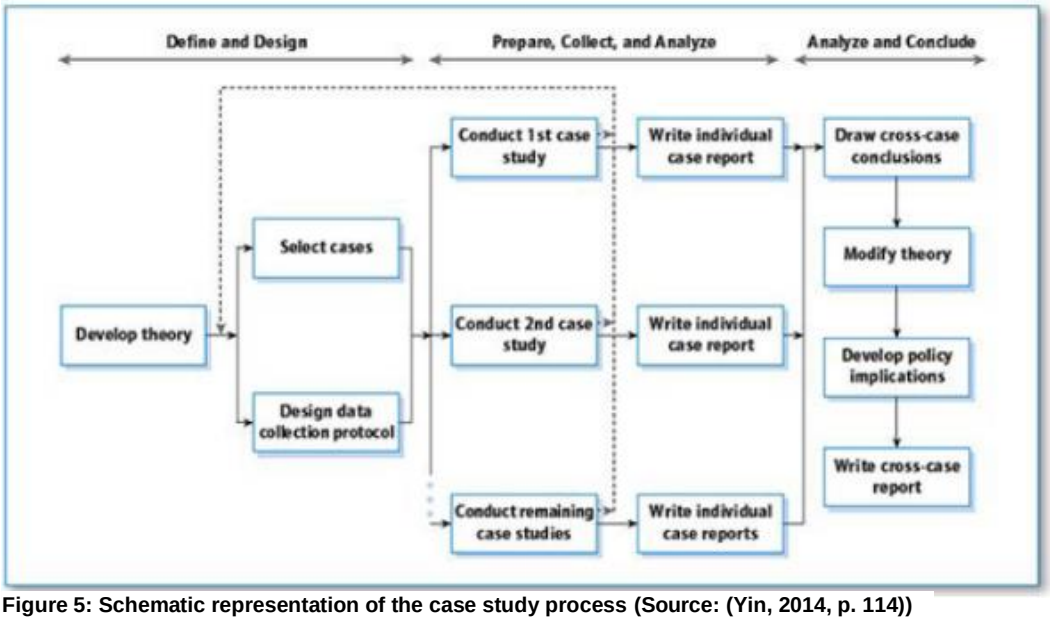

Figure 5: Schematic representation of the case study process (Source: (Yin, 2014, p. 114))

2.4.3 Design

Research design links the data to be collected to the initial goal of study. What is to be studied and what is to be learnt. The research design consists of four components; the documentation, the case study goals, the units of analysis and the method of analysis (see Table 2). For the case studies, an embedded multiple case design is applied with multiple units of analysis. This is done so that comparative studies are performed to indicate multiple crucial factors for answering the research questions. Case study is chosen to have insight in context and practice within the field. The comprehensive design of a case study would be too complex and would take too much time. The embedded design is expected to give more relevant insights from the case study. Case study design, using a strict case study protocol enhances the replication logic of the research (Uma Sekeran, 2016). The cases as shown are chosen with different objectives. The project evaluation and lessons learnt reports are giving insight in the project success factors that are needed to build selection criteria for the project portfolio management framework. The annual reports give insight in the strategic orientation of the AEC firm. The project data interview and documents help with giving insight in the data availability to give advice on the information technology structure to be used to support the PPM practices.

Client selection criteria and the results of a set of strategic pursuits are used to give guidance on the PPM processes. Lastly, the business process blueprints are consulted to filter already available information on specific topics within the AEC firm.

Table 2: Overview of case study design (Source: Author's own analysis)

Case	Documentation	Goal	Unit of Analysis	Method of Analysis	Report
Case 1	Project evaluation and lessons learnt reports	Identify project success factors and issues	All text	Coding	Appendix II.
Case 2	Annual reports	Identify strategy, risk, and success factors over period of 10yr	Values, visions, positioning, strategy, growth drivers, trends, SWOT, success factors	Content comparison	Appendix III.
Case 3	CRM project data	Identify available project data	Oracle ERP Cloud, Project performance data	Summarizing, grouping, categorization	Appendix IV.
Case 4	Client selection criteria	Identify initial client assessment criteria and procedure	2020 Client Go/No-Go assessment	Comparison	Appendix V.
Case 5	Strategic pursuits wins and losses	Identify critical factors in the bidding process for projects	Wins/ losses	Coding	Appendix VI.

2.4.4 Preparation

To further enhance the quality of the case study rules of thumb regarding the case-study questions are followed up: assessment of availability and access to documentation and identify people to be interviewed, selective attitude in finding valuable sources, objective attitude when reading documents and interview, the use of tools to structure information, adapting the research to new situations and explorative attitude, reading and gaining knowledge of the issues being studied, even in an exploratory mode to enhance subject matter focus, avoiding biases, and executing ethical research.

2.4.5 Data collection

Data collection is done throughout: literature review, case-studies that use text rather than numbers and open-ended interview questions. First the literature review positions the research in an existing body of knowledge and evaluate trends within the topic. This is based on secondary information. Secondly, case studies, based on primary and secondary information creates in-depth understanding of specific groups, practice and context. These case studies use the principle of content analysis. Coding is used as method. Third, the interviews and expert opinion help to gain more in-depth understanding of specific topics based on primary information. These interviews are thematic analysis to understand general themes in the data and how they are communicated.

2.4.6 Data analysis

The data in a case study can be extensive and therefor needs to be organised. The data consists of not only narrative or numeric information and includes different types of documents and types. Therefore computer-assisted qualitative data analysis software is used (for example ATLAS.ti), but also routine processing tools (e.g. Word, Excel). The data analysis includes examining, categorizing, testing, tabulating, coding, and recombining evidence to create an empirical base of findings. Relevant codes are defined, and patterns are observed. The specific technique used for analysing case studies is based on cross-case synthesis, pattern matching and explanation building. The data analysis is aiming at field notes, memos, transcription, databases, data-analysis tools, coding procedures, software, iterations, and triangulation.

The iterative general protocol for data reduction is as follows (Uma Sekeran, 2016), data collection, data reduction (selecting, coding, categorizing) using grounded theory tight/ middle ground, data display (visualizing, finding patterns), drawing conclusions (generalization, propositions, verification).
The logic linking between data and the propositions, will be carried out through explanation building and cross-case referencing. Therefore, the steps to be taken for developing the conceptual framework will be as follows: map data, read and categorize, code and concepts, categorize codes, integrate concepts, synthesis of conceptual framework, validating, rethinking.

2.4.7 Conclusion and data sharing

To translate abstract concepts into empirical variables that are assessed within this research, operationalization is needed (Uma Sekeran, 2016). This operationalization is of practical importance as this is the link to translating factors to measurable data as input for Data & Analytics practices for Arcadis. Measurable data implies in this case the attachment of numbers or symbols to the properties of objects based predetermined procedures.

2.5 Interviews

Different persons within the organisation are interviewed see Table 3. These interviews have the character of an unstructured interview and are mainly used to orientate within the organisation. This is chosen to get to know the company and to gain insight into the different visions that exist in the field of project portfolio management and Data & Analytics. The interview meetings were also used to network and obtain documentation for the case study. In addition, some interviewees provided insight into the business structures within the organisation and the different IT systems that are used to discover how project data is handled within the organisation. Notes of the interviews are gathered and displayed in Appendix VIII.

The interview meetings followed the agenda below:

- Introduction people (5min).
- Introduction research topic (5min).
- Discussion on project analytics (5min).
- Discussion on data management within the programmes/projects (5min).
- Discussion SOPs/ blueprints/ templates/ gateways/ initiation phase requirements (5 min).
- Discussion benefit realisation/ KPIs/ Success factors (industry specific) (5min).
- Discuss case study question and request documentation/ information (5min).

Table 3: Overview of interviewees (Source: Author's own Analysis)

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives
1.	Global Solutions Director	Project & Programme Management	Middle Eastern	>12 years	Introduction programme management, PM problems, lessons learnt reports and data handling
2.	Programme Manager	Managing Board ANL	Netherlands	>22 years	Introduction programme management, review Spalek (2019) framework, management implications
3.	Project Leader	Project & Cost and Commercial Management	Netherlands	>3 years	Project data handling
4.	Senior Project Manager	Managing Board ANL	Netherlands	>28 years	Project success factors
5.	Senior Consultant	Project & Programme Management	Netherlands	>23 years	Project success factors
6.	Global Solution Director	Portfolio & Programme Management Solution	Europe	>20 years	Introduction programme management, framework review, data handling, industry trends
7.	Global Director BI-IT	Business Intelligence	Global	>13 years	Business intelligence, project data handling, IT system configuration
8.	Consultant – Business Analytics	Business transformation	United Kingdom	>3 years	Project data analytics
9.	Business Director	Project & Programme Management	Middle Eastern	>25 years	Introduction programme management, lessons learnt reports
10.	Programme Director	Retail & Banking	United Kingdom	>30 years	Introduction programme management, barriers and needs for project and portfolio management practices

2.6 Validity and reliability

Validity includes internal and external validity. The internal validity aims at rigorousness, precision and parsimoniousness and describes the extent to which the research design permits to say that findings are true (Uma Sekeran, 2016). Therefore, the applicability of case studies is strictly predetermined with the case study protocol and the interview protocol to create a substantiated and well-thought-out research base.

The external validity aims at relevancy and generalizability and describes the degree to what extend results are generalizable to the outside world or a broader organisational setting (Uma Sekeran, 2016). Therefore, cross-sectional cases focusing on multiple industries increases the degree of generalization. Moreover, comparison between sectors show differences that apply to a broader spectrum. Face-validity of experts indicates after reviewing what degree of validity has been reached based on their professional experience.

The content validity is discussed with the graduation supervisor. And construct validity is discussed with the company supervisor. Throughout sessions with experts in the form of a workshop, expert opinions are gathered and analysed to see limitations of the framework. This is then used as recommendations for future research as well. Experts with different responsibility levels are asked for input, so that a clear understanding of perspectives on application of the conceptual framework throughout the entire organisation is being established. Moreover, through literature comparison, differences and similarities between the concept framework and the literature frameworks support validity.

Lastly, throughout using sources of institutions for project management (PMI) and Data & Analytics (DAMA), validity is increased as these institutions stay close to the industry and gather best practices and publish academic information.

The reliability focusses on the consistency of situations and time and is thus dependent on the choice of research methods (Uma Sekeran, 2016). To increase reliability triangulation between sources and methods is carried out during the research. This increases the degree of reliability across situations and time. Internal consistency during the case studies is needed to have an objective perspective during the information gathering process.

3 PROJECT PORTFOLIO MANAGEMENT

This chapter relates to sub question 1 and focuses on identifying crucial factors for the PPM framework. First the definitions of project-, programme- and portfolio management are described, and different factors are identified for shaping a PPM framework. Second, theory on shaping a framework for PPM is elaborated. Third, a PPM governance structure is proposed, and stakeholders and roles and responsibilities are discussed. Fourth, processes will be explained including the portfolio life cycle, decision-making and selection and evaluation. Fifth, requirements for information processing through technology is explored and the fifth section summarizes and concludes with an initial overview of the PPM framework.

3.1 Defining project-, programme-, and portfolio-management

In the research field of project management (PM), three different levels are described (see Figure 1). At the first level project management is focusing on the individual projects and concerns the triple constraint of time, cost, and scope (see Appendix I.). According to PMI (2018, p. 4), a project is "*a temporary endeavour undertaken to create a unique product, service or result*". Projects are temporary because they are tied to time and have a start and end. Therefore, they have limited resources and a predefined scope.

At the second level, programmes focus on the coordination of related projects. This combination of projects enhances activities over time to create benefits for the organisation (see Appendix I.). According to PMI (2017, p. 11), "*a programme is a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually*". Programmes contain extra work that in the end deliver benefits. Programme management (PgM) focusses on the triple constraint of investment, risks, and benefits.

PPM is at the third level, while PM and PgM are about execution and delivery of projects – doing projects right, PPM is related to strategic management and focuses on – doing the right projects (Oltmann, 2008). The PMI (2017, p. 3) defines a project portfolio as "*a collection of projects, programmes and other work that is grouped together to facilitate the effective management of that work to meet strategic business objectives*". The projects or programmes of the portfolio might not be interrelated to each other and are thus individual components. (David W. Ross, Paul E. Shaltry, 2006). PPM is the organisation's capability to evaluate, select and prioritize projects. PPM aims at long-term goals and stimulates the creation of new projects, products and services (Magnusson, 2019). PPM focuses on the triple constraint of value, performance, and control.

To give a more tangible or practical distinction between projects, programmes, and portfolios, Table 4 highlights the definition, the triple constraints, the scope, the implication of change, the planning, management responsibilities, monitoring activities, and success areas.

Table 4: Differences between projects, programmes, and portfolio (Source: compiled from PMI (2018))

	Projects	Programmes	Portfolios
Definition	Temporary endeavour to create unique product, service, or result	Groups of projects, programmes, and activities that have interdependencies and that are managed in a structured way to gain benefits	All projects, programmes, portfolios, within one organisation that are picked and optimized as set and managed to achieve strategic objectives
Triple constraint	Time, cost, scope	Investment, benefits, risks	Value, Control, Performance
Scope	Defined goal and objective to work towards predefined results via a predefined roadmap through objectives, or milestones	Encompassed scope, producing benefits to organisation. Output and outcomes delivered in coordinated way	Organisational scope, changing strategic objectives or firm
Change	Change is expected, processes implemented to control and manage	Programmes should adapt adapts to change and should dynamically be aligned and optimized to ensure benefit realization	Monitoring of change in the broader internal and external environment
Planning	Activities that focus on high level data and information so that a detailed planning can be established following different phases of the project management life cycle	Multiple project high level planning, focussing on interdependencies and benefit realization, including lower level planning of the programme's components	Process and communication plan establishment for entire portfolio
Management	Project managers steer or lead the project team to meet project objectives	Programme manager ensuring benefit realization through coordinating activities	Portfolio manager coordinates staff and organises reporting responsibilities for the entire portfolio
Monitoring	Project manager monitors and controls work related to product, services, and results	Monitoring progress of programme components ensuring overall goals, risks, dependencies, schedules, budgets, and benefits and looking at the bigger picture	Monitoring the dynamical strategic orientation and trajectory including resource allocation, performance results, portfolio risk leading towards business success
Success	Optimal product and project quality, time, and cost for enhancing business success and client satisfaction	Programme´s ability to deliver benefits and programme´s performance and effectiveness in 0benefits realization	Aggregate investment performance and benefit realization

3.1.1 Strategic management underlying PPM

Project management practices are data-driven, as extensive information is created throughout projects. Portfolio decisions are based on available information and are thus dependent on the interaction between projects and the entire project portfolio and strategic objectives. Managers are focussing on getting optimum results from projects under way. But projects are often not linked to the organisational strategy and project managers and top-level managers are not properly taking into account the quantity and scope of all projects (Spalek, 2019). "*Projects are the means of transforming strategy into execution*" (Spalek, 2019, p. 64). Growth of the organisation and the creation of competitive advantage is the result of managing successful projects that will in the end generate new products, services, or procedures and thus contribute to the future readiness of the organisation.

Strategic management is the capability to decide on targets and the belonging actions to achieve objectives within a predefined timeframe with a clear roadmap (Pearce & Robinson, 2008). Different steps in strategic management are known as formulation, implementation, and control. There is a difference regarding strategy formulation and implementation and firms experience more difficulties with strategy implementation than formulation (Meskendahl, 2010). As portfolio management has to do with strategy execution and thus implementation, the link between strategy formulation and strategy implementation must first be understood before diving into portfolio management theories.

Strategy formation is an analytical process for establishing goals for the organisation on the long term. The Mintzberg & Waters (1985) model indicates that strategy formation consists of five factors, intended strategy, deliberate strategy, unrealized strategy, emergent strategy and realized strategy (see Figure 6). Intended strategy are the plans to be implemented in a business or in a project that are beneficial and rewarding based on analysis of competitive and dynamic organisational capabilities. Due to circumstances that are limiting goal achievement, change is needed, and some intended strategies may go unrealized, these strategies are known as unrealized strategies (Mintzberg & Waters, 1985; Simons, 2019). The remaining strategies that continue the strategy formation trajectory, which are exactly as intended are known as deliberate strategies (Mintzberg & Waters, 1985; Simons, 2019). But due to strategic uncertainties and emerging (technological) circumstances that emerge spontaneously in the organisation, threats and opportunities are unplanned strategies that arise (Mintzberg & Waters, 1985; Simons, 2019). These strategies are known as emergent strategies. The deliberate strategies and the emergent strategies together, form the realized strategies of the organisation (Mintzberg & Waters, 1985; Simons, 2019).

Strategy implementation is the transformation of the formulated strategy into action. Three levels of strategic management are recognized, and the decision-making strategy differs per level. On the organisational strategy level, senior managers, manage and use their firm's competencies and capabilities through portfolio management for managing the business. Long-term plans, for a three- to five-year period are being developed on this level. On the middle level, decision-making strategies are focusing on the business units, here corporate managers and business unit managers cooperate and decide on division level. Knowledge and expertise regarding to the product-market-arena is specific and needed on this level. On the lower level, decision-making is carried out on functional level (Pearce & Robinson, 2008; Meskendahl, 2010). Strategy implementation actions on senior management level are for example downsizing, restructuring, and reengineering (Pearce & Robinson, 2008). These actions are thus supported by project portfolio management and portfolio decisions and are thus the scope of this research.

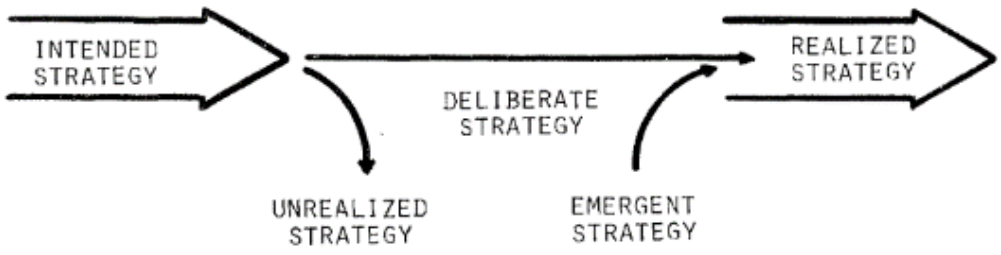

Figure 6: Mintzberg 1985 Model of strategy (Source: (Pearce & Robinson, 2008))

As described in 1.1, the capability of creating competitive advantage is determined by adapting to the internal and external complex and rapidly changing environment through adequately and regularly reconsidering the project portfolio (Martinsuo & Lehtonen, 2007; Cooper & Edgett, 2008; Spieth & Lerch, 2014). To achieve this, the model of organisational learning and organisational culture is applied (see Figure 7), linking operations on the project level to strategy and organisational culture. Feedback on the higher level, towards strategy is identified as single loop learning and processing and using this feedback to obtain better results and consequences is known as operationalization. Feedback on organisational culture which is linked to the organisations vision and mission is identified as double loop learning. Performance assessment is focussing on results and consequences (what we get), single loop learning is focussing on strategies and techniques (what we do) and double loop learning is focussing on goals, values and is aiming at new conceptual frameworks (why we do what we do) (Daniel Dauber, 2012). This model does account for the to be developed conceptual framework for portfolio management as well in the sense that single loop learning and double loop learning needs to be captured through the framework and assessed against corporate values and the organisations mission and vision.

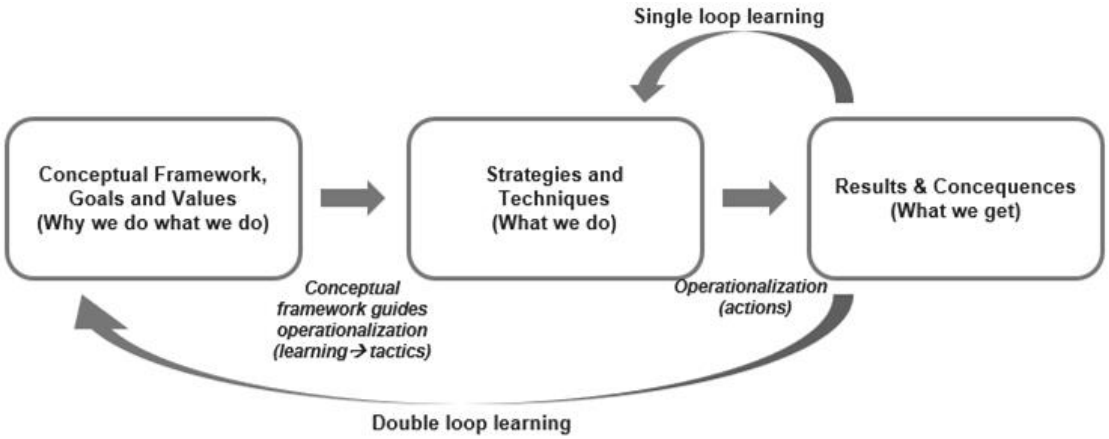

Figure 7: Model of organisational learning (adapted from Daniel Dauber (2012))

Different management strategies exist in PPM. The portfolio can be managed in an active way or a passive way. Active portfolio management is an approach in which senior level management practices assign strategic activities to the bottom level management layers and in which lower level management reports to higher level management so that feedback loops are established and dynamically used (Abubakar, Dalibi, & Wang, 2018). At the other side, passive portfolio management, is not connected to strategy and objectives besides financial matter (Abubakar, Dalibi, & Wang, 2018). Passive portfolio management focusses more on financial investments or on efficient market information handling in an organisation. In the in the case AEC firm the portfolio is managed in a passive way (see Appendix VIII.). Besides, three sub categories of portfolio management strategies are identified, under which patients portfolio management, aggressive portfolio management, and conservative portfolio management (Abubakar, Dalibi, & Wang, 2018). Patient portfolio management strategies makes decisions based on well- known markets. Aggressive portfolio management strategies are focussing on markets that ensure profitable returns only. conservative portfolio management strategies observe market returns, earnings growths and consistent dividend history (Abubakar, Dalibi, & Wang, 2018).

3.1.2 PPM Goal and Objectives

To elaborate on the project portfolio level, a project portfolio is a term used for all projects within the organisation or within a business unit of the organisation. In contrast to a programme, the projects within a portfolio are not interlinked to each other, although they often do compete for the same resources. The organisational project portfolio encapsulates projects, programmes, subsidiary portfolios, and operations that are organised as a group (Project Management Institute, 2017). Selecting the right projects for the project portfolio is increasingly important as more companies are project-based and have more projects going on at the same time (Tonnqvist, 2018; Project Management Institute, 2017). Fundamental principles for project portfolio management are optimizing strategic execution, being open and fair (transparency), being responsible, being accountable, focussing on sustainability and fairness. But also, the balance of the portfolio value against risks and the assurance of investments in portfolio components that are contributing to the strategic orientation of the organisation. Moreover, obtaining and maintaining engagement of senior management and other stakeholders and exercising leadership for the resource optimization is important. (Project Management Institute, 2017). Using these principles delivers benefits and are reflected in decision-making improvements, reduction of organisational risk, and increased profits (Hadjinicolaou & Dumrak, 2017).

3.1.3 Factors shaping PPM

Due to the different knowledge area's and span of control in PPM many factors shape a PPM framework. Abubakar (2018) identified 9 factors that are shaping PPM and offered options for strategic choices. These factors together determine and shape the way PPM is organised in an organisation. Some factors are strategic attributes, and some factors are operational attributes. As these factors are generic, deeper understanding of these factors in the natural surroundings and business practices needs to be investigated. When these factors are tied together, the foundation of a well-thought-through framework is established. Context variables that are important for establishing a PPM framework are to be found in external environmental changes, internal organisational changes including IT, telecommunication, engineering, services, government, education, other), geographical changes orientation and positioning, the change of governance structure etc. (Sanchez & Robert, 2010).

Table 5: Attributes for the PPM framework (Source: adapted from (Abubakar, Dalibi, & Wang, 2018, p. 525))

Factors	Description
1. Strategic alignment	Business objectives align to portfolios and between the different portfolios
2. Resource allocation	Availability and timely allocation of resources to projects in a portfolio
3. Single project performances	Performances of various single projects within the portfolio
4. The PPM frameworks and models used for PM	(P3M3, PMI model, Prince)
5. Project portfolio tools and techniques	Methods for selection, evaluation, decision criteria, analysis, and balancing
6. Organisational culture: adopted PPM theory and practice	Modern portfolio theory, multicriteria utility theory, organisational theory, systems theory, complexity theory and stakeholder theory
7. PPM strategy	Active, passive, patient, aggressive, conservative
8. Expert judgement	Rational decision-making, highly experienced, reputable, certified professionals
9. Global business environment	Comprising PESTEL factors

3.2 Shaping a framework for PPM

A PPM framework is a set of practices, functions, and processes within a framework, based on principles that are accepted as norms, rules or values that guide activities to optimize the strategic goals (Project Management Institute, 2017). Many different frameworks for project portfolio exist and emphasize different aspects, such as frameworks for value management in PPM, risk management, capability, and capacity management. Establishing a framework for PPM encounters key challenges that include combining quantitative and qualitative data from multiple sources, simplicity, decision-making, roles and responsibilities, processes, traceability, and the mutual links between portfolio levels. (Ryan & Abbasi, 2018).

A PPM framework can be seen as a socio-technical system. The theory of sociotechnical systems stems from systems of innovation, innovation systems were the focuses is mainly on new product/ service development and aimed at technological factors (see Figure 8). The unit of analysis in these systems is broad and varies from sectoral systems to social factors and factors of the society (Geels, 2004). This broad perception is captured in the so called "*sociotechnical system*". Sociotechnical does not only imply technical in the sense of technology, but also incorporates the interaction between socially complex structures, knowledge and processes (Geels, 2004). The sociotechnical systems theories do apply for project portfolio management practices as well, especially in the technology intensive industry. Nevertheless, since PPM practices are process related and PPM frameworks are built on integrated knowledge domains, the characteristics of sociotechnical systems are important.

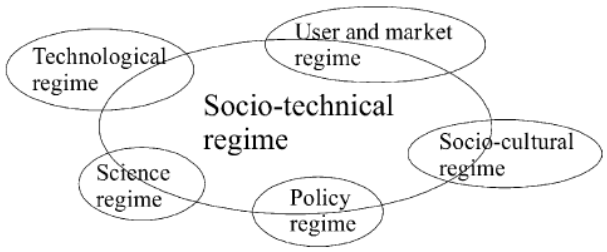

Figure 8: Factors of a socio-technical regime (Source: (Geels, 2004, p. 905))

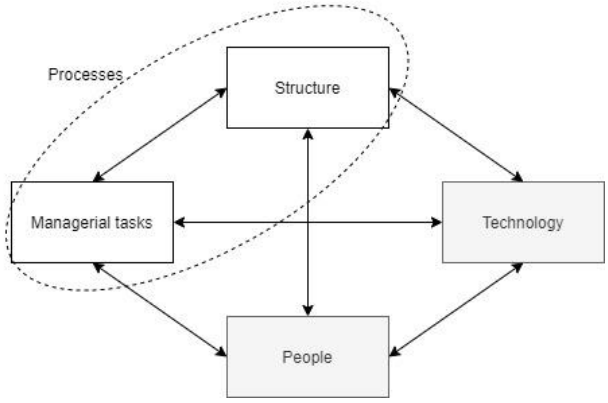

Figure 9: Leavitt's diamond (Source: adapted from (Leavitt, 1965, p. 1145))

Transforming the thoughts of the "*socio-technical*" school into a framework for strategic organisational change often writes back to organisational diamond model developed by H.J. Leavitt (see Figure 9). The organisation is in this model represented as a "*diamond*", with the components: people, tasks, technology, and structure. Introduction of an PPM framework using Data & Analytics involves changing the organisation's components which automatically triggers changes in the other components of the organisation (Leavitt, 1965). The structure for the to be developed framework for PPM is a simplified structure that is adapted from the sociotechnical systems theory and the Leavitt organisational diamond and will consist of three pillars, **People**, **Processes** and **Technology**.

3.3 People

Developing and implementing strategy need the support of groups, people, stakeholders, government, political parties, organisations, and other actors. Organisations need agencies, target groups, suppliers, consumers, store chains and internal support (Bruijn & Heuvelhof, 2008). Actors reproduce the elements and linkages in sociotechnical systems in their activities (Ryan & Abbasi, 2018). People are involved in PPM and the decision-making processes. People do have different interests and do have different power and influence. Collaboration, dependency, and interaction of actors are known as networks of actors (Bruijn & Heuvelhof, 2008). Both strategic management and portfolio management are management practices that are thus subjugated to management in networks (Bruijn & Heuvelhof, 2008). Management in networks or multi-actor systems to implement strategy is unstructured and capricious through the hierarchical superiority within actor networks (Bruijn & Heuvelhof, 2008). Models, frameworks and streamlined processes are supporting and guiding management practices but are sequential and the real course of actions is never sequential (Bruijn & Heuvelhof, 2008). Within project-based organisations, there is a difference between the to be executed projects and the way they are managed.

3.3.1 Governance

The amount of data associated with projects is soaring, therefore organisational project data must be organised and structured so that information flows are optimized and accessible for the right people at the right time. The project management office (PMO) is positioned to guide information streams and plays an important role in setting up a governance structure for PPM. Governance refers to "*the set of policies, functions, processes, procedures, and responsibilities that define the establishment, management, and control of projects and portfolios*" (Spalek, 2019, p. 134). Governance is an important part of a PPM framework as it enhances oversight, decision-making, control, and integration (Project Management Institute, 2017). Governance through projects, programmes and portfolio's is organised in different ways.

Based on the links between objectives and the way resources are shared, four different ways of implementing governance are identified. First the multi-project organisation (unrelated objectives and unshared resources), second the programme driven organisation (related objectives and shared resources), third the hybrid organisation (related objectives and shared resources), and the portfolio driven organisation (unrelated objectives and shared resources) (Müller, Martinusuo, & Blomquist, 2008). Within PPM governance higher level governance practices (top-down) focus on oversight, control, integration, and decision making. Management activities on the lower level (bottom-up) include performance reporting, change requests and issue and risk escalating (Project Management Institute, 2017).

PMOs do play an important role already in PPM practices, but with the increase of information availability this the role of the PMO is even more important. Therefore, PMOs need to grow in analytical maturity and the focus areas and the technologies (IT) they use need to transform with them. Besides human resources and the entire project environment and specific knowledge domain need to need to be revised to some extent.

The PMO should be organised as a data management and analysis centre of excellence and is becoming crucial in handling data from projects, portfolios and providing feedback to steer the course of action of the entire organisation. An important aspect for digitizing PPM is the set-up of an enterprise project management organisation (EPMO) (see Figure 10). This is a PMO for the entire organisation, or so-called centre of excellence. Tasks, services, and responsibilities of the EPMO are shown in Table 6. (Spalek, 2019)

Table 6: Responsibilities or the EPMO (Source: compiled from (Project Management Institute, 2017; Spalek, 2019)

Focus areas of the EPMO
Managing individual portfolio components (identify, analyse, coordinate, negotiate, monitor and control)
Assessment and evaluation of project and programme proposals (prioritize, authorize, and terminate)
Resource allocation aligned with organisational strategy
Framework development for portfolio maintenance and setting up methodologies
Development and maintenance of knowledge management structure (best practices and lessons learnt reports applying a double loop organisational learning pattern)
Portfolio performance monitoring (establishing KPIs and implementing diagnostic control centre and interactive management control centre)
Risk assurance assistance on component level
Developing and maintaining communication channels and communication with the portfolio components
Organizing for training, mentoring, and learning (HRM in PPM skills, technology and services)

Within the fragmented AEC industry, it is important to also establish a PMO (see Figure 10) on a lower management level as well (Spalek, 2019; Project Management Institute, 2017). On the domain specific level, the divisional or regional PMO must be established and is responsible for PMO activities within its domain. Table 7 shows an overview of the PMO's services to be provided to projects and programmes.

Table 7: Responsibilities of the PMO in PPM (Source: compiled from (Project Management Institute, 2017; Spalek, 2019)

Focus areas of the PMO
Establishment of the portfolio management strategy
Monitoring and managing the project portfolio and its value of the individual components and overseeing benefits and interdependencies
Based on higher level requirement setting up a vision and mission to further structure management practices
Setting up standards based on best practices and formulate guidelines for project and programme management practices
Performance management using the KPIs and metric established by the EPMO
Risk management on both budgeting practices and planning practices
Pipeline management including stochastic forecasting on the portfolio level to foresee the supply and demand
Resource allocation on component level

3.3.2 Stakeholders and communication

Project portfolio management influences several individuals and groups throughout the organisation. There are three main stakeholder groups that are identified as affected by the portfolio. First the executive leadership group and managers of the organisation. They are affected through the changing and shifting focus and resources from portfolio components and their interests are affected as well. Besides internal and external organisations and individuals working for portfolio components are affected. They have strong personal interest and connections with funding and executing the components, but the portfolio influences decisions on the component level strongly. In the end, also internal and external end-users and customers are affected by portfolio management. Their documented requirements are approached differently, and expectations and satisfaction are affected through change (Project Management Institute, 2017).

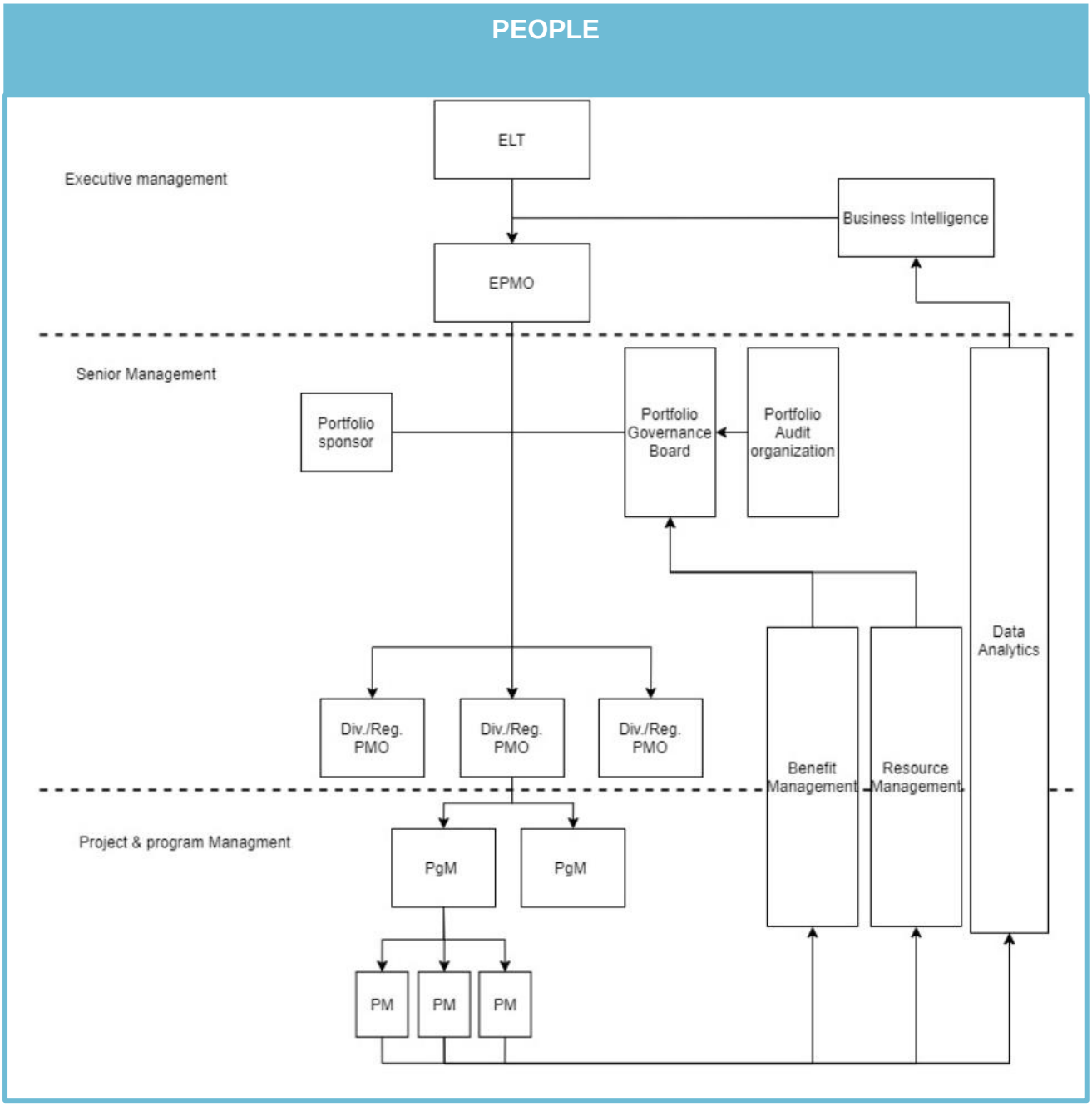

Figure 10: Proposed governance structure for digitized PPM (Source: Author's own analysis)

The focus on these stakeholders and the approaches towards their engagement and interests is an important part of portfolio management as well. Therefore, continuously monitoring changes in the broader internal and external organisational environment, changes in resource allocation, performance results, and risk management is the task of project portfolio managers (Project Management Institute, 2017). Moreover, portfolio managers must ensure right balance for the portfolio, sequence portfolio components to account for the dependencies, balance constrained resources. Besides the portfolio manager, other roles in portfolio management are sponsors, governance body, project management organisation (PMO), portfolio analyst, programme and project managers and team members, change control board and subject matter experts, business analysts and functional managers. The sponsor is responsible for resource allocation and portfolio success. The portfolio governance is the framework and the function and processes that guide all activities and make decisions on investing in projects and programmes.

To identify roles and responsibilities on stakeholders, key functions are connecting the context to the ones that are accountable (see Table 8). Portfolio key stakeholder functions are the owner that expresses the need in strategy implementation, the architect describes the owners need, the engineer designs the solution (specification, drawings and models), the builder implements the solution, the user uses the solution and the community receives the results and effects of the solution (Project Management Institute, 2017).

Table 8: Stakeholder roles, interests, and expectations (Source: Author's own analysis)

Stakeholder groups	Stakeholder roles	Stakeholder interests	Stakeholder expectations
Portfolio Sponsors	Provide funding Provide resources Provide high-level scoping	Benefits and outcomes that meet the organisation's goals	To be informed regularly of portfolios return on investment, key portfolio milestones, risks, costs, and schedule
Enterprise project portfolio organisation (EPMO)	Identifying, analysing, coordinating, negotiating, monitoring, and controlling portfolio components; supporting component proposals and evaluations; facilitating prioritization; authorization; termination of components; and facilitating the allocation of resources in alignment with organisational strategy and objectives;	Developing and maintaining portfolio, programme, and project frameworks and methodologies; Managing knowledge regarding the project management discipline, including good practices and lessons learnt, developing, and conducting training and mentoring of human resources in portfolio management skills, tools, and techniques.	
Portfolio Governance (board)	Oversees the portfolio Sets priorities Manages the spending Reports progress Manages timely delivery of benefits	Portfolio performance Governance decisions Change decisions Concerns of sponsors and governing body	To be the most knowledgeable party of portfolio progress against goals To be aware of all developments of consequence
PMO	Translate corporate strategy into divisional or regional strategy and gather and communicate information.	Project progress Lessons learnt Developing PMO materials for future use	To receive notification of all portfolio changes and portfolio needs
Portfolio audit organisation	Delegate responsibilities to the component governance board for component specific plans for audits.	Perform audit assessments or organise them by external parties	Communicate planned and ad hoc audits.
Contract management team (vendors, legal)	Ensures that funding is intact Manages the contract Ensures efficient availability of contractor staff	Financial standings Project progress Contract impacts and changes	To be made aware of progress against contractual deliverables To be made aware of any

			changes to the contract including increased resource requirements
Portfolio component team	Report progress and completion of components	Portfolio changes Portfolio risks and issues	To receive notification of all portfolio changes, risks, and issues
Portfolio manager	Establishes and implements portfolio management Ensures proper communication and coordination among components Designs and improves appropriate processes Adjusts portfolio components Communicates with the portfolio governing body.	Alignment of the portfolio with strategic goals Creating value for the organisation through balanced portfolio components Effective communication between portfolio stakeholders and component managers Efficient use of portfolio resources	To be fully informed of organisational strategic goals and objectives To be provided with sufficient resources for portfolio components To be empowered to communicate with all portfolio stakeholders
Programme manager	Authorized by the performing organisation to lead the programme (team). Monitor the output and outcomes of programme components and activities and ensure adapting to the needs.	Coordinating the management of complex issues that arise during programme delivery and deliver benefits	Responsible for leadership, conduct performance of a programme and building the programme team to achieve programme objectives
Project manager	Report relationships among managers. Delegation of duties. Responsibilities for rules and procedures.	Project performance management, controlling and reporting. Knowledge sharing and application to processes tools and techniques	Motivate individuals and the team to ensure high project performance
Project team	Follow the organisationally established processes and execute project according to the requirements	Deliver the projects	Meet project objectives within the triple constraint of time, cost and scope
External stakeholders	Stay informed of the funding and direction of the portfolio and its component(s) Execute work decisions based on the progress of respective components	Effect of portfolio and component execution on their requirements and interests	Full and open communications on portfolio and component execution and progress Appropriate consideration of their interests and concerns in the implementation of the portfolio and components

3.4 Processes

In the previous chapter governance was discussed, process visibility, enabled by data, is a key to governance. Therefore, Data & Analytics provides a foundation for control and improvement. As described in 3.2, sociotechnical system include policy regime, which are rules which structure procedures and processes, and are formal regulations of technology and actors. Processes are thus based on policies or regimes that are established and transformed into managerial tasks and actions within a specific structure (Geels, 2004; Leavitt, 1965). Organisations must understand the portfolio decision-making process to investigate what data, measures and metrics are needed to establish processes that drive better decision-making.

To start, PPM is taken from a perspective of rational decision-making (Cooper & Edgett, 2008; Gutiérrez & Magnusson, 2014; Magnusson, 2019; Picciotto, 2019a; Tonnqvist, 2018). Therefore, the principles of PPM are based on systematic assessment; relevance, efficacy, and efficiency (Magnusson, 2019; Picciotto, 2019a). This systematic assessment is needed to manage the corporate project portfolio in line with the business strategy & objectives and the resource allocation within the company (Grant, 2005; Kopmann et al., 2017; Martinsuo & Lehtonen, 2007; Nguyen et al., 2018; PMI, 2017; Tkachenko & Evseeva, 2019). Systematic assessment can be achieved through formalized and well-defined processes. PPM is a composite cluster of processes. According to Cooper et al. (2001a), portfolio decision-making is not a singular process, but it is an interrelated decision-making process. The decisions are made involving different departments in the organisation and is thus subject to manifold decision makers that pursue different goals which makes project portfolio management a complex system (Jerbrant, 2019). In the earlier stages of the decision-making process, the problem formulation stage, establishing scope stage and the information gathering stage a more project-based approach is thus needed. But in later stages, more process-based approach is required to adapt to change and follow up actions regarding strategic choices. As part of the PPM processes, the process of strategy formulation and implementation is already described in 3.1.1. Other processes which are more at the core of PPM are the portfolio life cycle, decision, decision-making processes, and the core PPM selection and portfolio composition process. These processes are described in this section.

3.4.1 Portfolio Life Cycle

In the portfolio life cycle (see Figure 11), different stages are identified, the initiation stage, the planning stage, the execution stage, and the optimization stage. *Decision-making* takes place in the stages and between the stages. In contrast to the programme and project life cycle, the portfolio life cycle is not necessarily sequential.

In the initiation phase portfolio strategy and management plans are created, the portfolio management process (vision, governance, and stakeholders) is established, governance and communication planning is defined, portfolio selection and prioritization criteria are defined, the portfolio charter is defined, value metrics are defined and a portfolio roadmap is outlined. In the planning phase, yearly goals/objectives are set, governance structure is revisited, capacity and capabilities are planned, the portfolio strategic alignment is updated, portfolio metrics are refined, the portfolio is optimized and transitioned, the portfolio roadmap is refined, the portfolio is adapted to strategy based changes, business influences and technology factors, and the portfolio time frame and planning is revised.

In the execution phase of the portfolio life cycle, optimization and transition takes place, health and status metrics are reported, demand and resource capacity planning is adjusted, governance decisions via change management are made and the portfolio is continuously realigned with strategy bases changes and business and technology factors. In the final phase, the optimization phase, re-optimization of the portfolio is carried out, lessons learnt are produced, the portfolio is closed, demand and resources capacity planning is adjusted, governance documents are being revisited, value metrics are revisited and the portfolio is realigned with strategy based business factors.

These phases and activities are taking place at the portfolio level, but apart from that, the same life cycle occurs on the component level. In the initiation phase of the component level an initial list of components must be created, and the component list must be reviewed, based on alignment to strategy and prioritization criteria. Also, validation of feedback must be incorporated into the revised planning. (Project Management Institute, 2017)

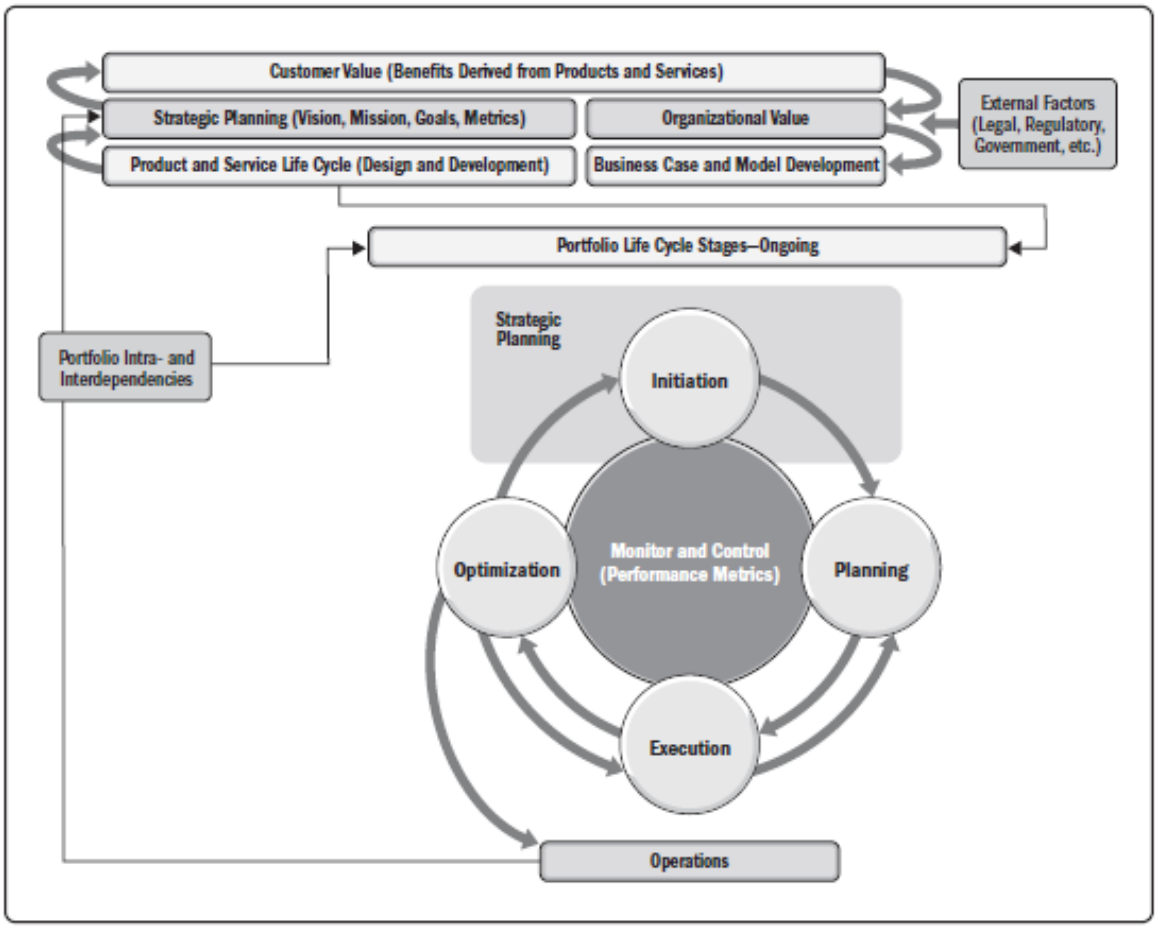

Figure 11: The portfolio life cycle (Source: (Project Management Institute, 2017, p. 22))

3.4.2 Selection and evaluation

To go more in detail, the core process in PPM that is often described as foundation is the integrated PPM process. This process is a stage-to-gate process in which every stage is ended through a decision or selection. To choose the right projects, parameters and methods and techniques for prioritization are needed. Therefore, several perspectives and manners can be applied.

The framework from Ghasemzadeh & Archer (1999) is widely accepted and is a solid foundation for both quantitative and qualitative approaches. On top of the entire selection process for the project portfolio, guidelines and resources allocation should be established based on strategy development (Ghasemzadeh N. A., 1999). Strategy development is an unstructured process and requires extensive managerial time, but it is the critical foundation for portfolio selection when business objectives should be reflected throughout the organisational project portfolio. Setting the strategic focus is a onetime action, while the portfolio selection process is occurring at intervals (Ghasemzadeh N. A., 1999).

The selection framework for the project portfolio describes a series of discrete stages (see Figure 12). The major stages are pre-screening, individual project analysis, screening, optimal portfolio selection and portfolio adjustment (Ghasemzadeh N. A., 1999).

In follow up on the major stages, the pre-process stage is the project proposal and post-process stages are project development, phase/ gate evaluation and the successful completion. All project characteristics developed throughout different stages together should be stored in the project database. This project database is the reference point for later project analysis. The stages, part of the post-process stage mainly are data generating (Ghasemzadeh N. A., 1999). The different phases in this process are generic and need to be adapted to the industry specific needs through extension of the process phases, selection of the assessment methodology, specification of criteria, description of roles and responsibilities, and specific technology.

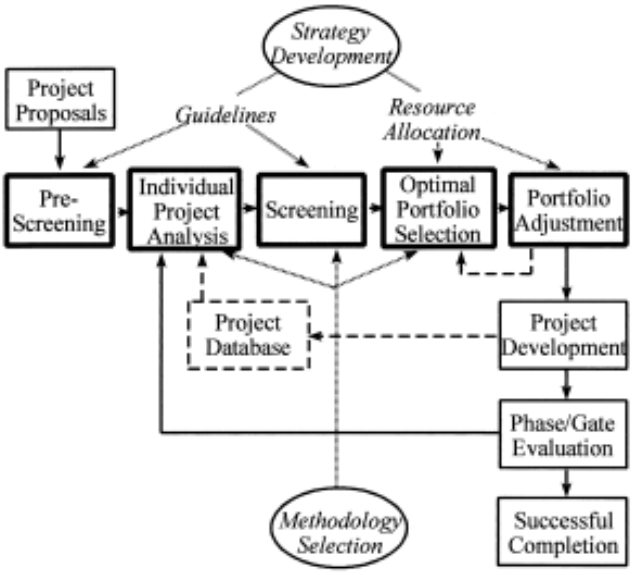

Figure 12: Integrated framework for PPM (Source: (Ghasemzadeh N. A., 1999, p. 211))

Forecasting

In the AEC industry context, projects are promoted by clients and won by contractors through bidding for the project in tender rounds or other procurement methods (Shojaei & Flood, 2017). Shojaei & Food (2017) argues that it is fundamentally wrong to use a company's historic project data only to make future predictions for project selection. Using external data from the market combined with this internal data would enhance the forecasting power and capability. This can also be deduced from the strategic pursuits analysis in the AEC company in case study 5 (Appendix VI.), and the interviews (see Appendix VIII.) did confirm this need as well. Moreover, stochastic forecasting should precede the pre-screening phase (see Figure 13) in the core PPM process and can be done through analysing time series, based on project costs and frequencies, durations and macro-economic variables that are location dependent (Shojaei & Flood, 2017).

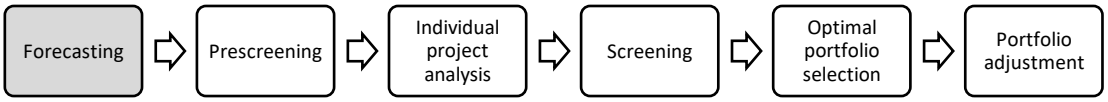

Figure 13: Expanded PPM process flow diagram (Source: Author's own analysis)

Pre-screening phase

To further elaborate on the different phases, the first phase of the major selection stages is the pre-screening stage. This phase is based on guidelines and is a first check if the proposed projects match the overall strategic focus of the organisation or the department. Within this phase a feasibility analysis must be carried out and KPIs to evaluate and compare all projects must be anticipated. Within this phase, guidelines that are being developed in the strategic development stage are applied on projects to be considered for the portfolio. Therefore, projects must be classified according to criteria that override other considerations. These criteria often arise form influential stakeholders, operating necessity, and competitive necessity. Moreover, projects must be classified to independence, interrelatedness, and synergy. Requirements for this pre-screening are feasibility analysis, estimates of parameters to evaluate each project, and the selection of a project champion to be a comparative source for further implementation (Ghasemzadeh & Archer, 1999).

The pre-screening phase in the core PPM process is not specifically defined for the AEC industry by Ghasemzadeh & Archer (1999). An initial categorization needs to be done as first alignment to the strategic orientation of the company. In the AEC industry and organisational fit in the client selection process is comparable with the pre-screening phase, as clients are categorized according to overarching risk factors that influence the client. Here, location is likely to be relevant since there is typically greater transparency and availability of information on clients based in low risk countries than in higher risk countries. As shown in case study 4 (see **Error! Reference source not found.**) the International Corruption Perception Index (CPI) of Transparency is used to identify and categorize clients according to relative risk of a country and the legal business structure (e.g. PLCs., LLCs., etc.). Moreover, an initial assessment is thus carried out on the client fit with values (in the case study, transparency, integrity, and sustainability). Another initial assessment in the pre-screening phase is the strategic fit with the client according to sector planning and regional planning (see Appendix III.). Depending on the risk level, the portfolio decisions are being made by different management

levels. With high risk, executive levels are involved, with medium risk senior level management and with low risk the project management levels.

Individual project analysis and screening

The second stage is the individual project analysis. Throughout a separate calculation for the project, based on historic project documentation/ data, feasibility studies and completed projects, a common set of parameters or KPIs must be created for each project. In this stage, also qualitative data must be included. Besides the KPIs, quantitative implications should sketch characteristics of the projects e.g. resource requirements, time framing, uncertainties etc. In the individual project analysis phase methods that are being applied are decision trees, risk estimates, NPV, ROI, resource requirements, estimated uncertainty etc. Therefore, a common set of parameters is required for equitable comparison. These set of parameters is be based on feasibility studies and from a database of completed projects. Also scoring models, benefit contribution, market research and checklists may be used (Ghasemzadeh & Archer, 1999). Internal assessment and comparison based on historic project data is carried out. This analysis is focussing on the micro-economic, mainly financial, project characteristics. Calculations must be made on common project parameters (Ghasemzadeh & Archer, 1999).

Screening

The third stage is the screening phase, profiling and categorizing projects, based on attributes from the individual project analysis stage, must be done. The objective for the screening stage is an initial selection where the total number of projects to be considered is being reduced. Setting to arbitrary threshold in this phase must be prevented. Yung & Siew (2016) argue that in the screening phase, different financial and non-financial methodologies are combined to assess the projects. In this phase economic criteria can be based on profit, expenditure risk or debt and aid from government organisations. Environmental criteria can be energy consumption, waste production, water consumption, water savings, emissions, incidents, land productivity, and recycling estimates. Besides, also social criteria, like leadership and knowledge management, supply chain, health and safety and training can be incorporated in this phase. Client quality relationship criteria and invoicing and payment criteria do fit the social assessment in this phase. In case study 4 (**Error! Reference source not found.**), it is deduced that in the AEC industry also the micro-economic analysis is incorporated, but the phase is extended with quality assessment of the relationship with the client and the expected client behaviour on invoicing and payment.

Quote from interviews:

"Sustainability is still vague, what should be monitored regarding sustainability? Our company is defining the term sustainability. It is not clear what the company sees as part of sustainability. Flex fields show on project level some minimal health and safety plans, this is mostly linked to the type of projects. This does account as well for sustainability. We try to connect our core strategic values to our project, for example we try to identify how much CO2 is being produced with a project. When it gets clearer about what we want to measure, we want to monitor this on the lower (project) level in the organisation. What type of service we serve to the customer? Core value propositions are monitored. What should the project manager provide as input for this system? We don't know yet."

- Global Director IT, Business Intelligence, Global, 28-07-2020 -

Optimization

The fourth stage, the optimal portfolio selection stage, interdependencies between projects, interactions and issues regarding resources and timing must be determined (Ghasemzadeh N. A., 1999). A two-step approach for the portfolio selection, *first* a comparative approach (Q-sort, pairwise comparison, AHP) should be used for

small sets of projects, focussing on both qualitative and quantitative characteristics. Large sets of projects should be compared through scoring models.
Both methods aim at creating an overview of the relative worthiness of the projects. The *second* step in the fourth stage, focusses on project interaction and resources constraints. If all project characteristics are expressed quantitatively, optimization is carried out through a mathematical programme. If there is no importance regarding interdependence and time limitation, ranking is done, based on the value of the projects. To optimize projects with interdependencies and time constraints, linear programming models, including resource, timing and interdependence can be used (Ghasemzadeh N. A., 1999).

Within project portfolio optimization prescriptive analysis is important. The EPMO should strive to get to the point of optimization as this can create strong competitive advantage. And can deliver value to strategic execution. Different constraints in the optimization process are budgetary, resource availability, ethical constraints, political and legal constraints etc. There are four basic types of portfolio optimization, first cost-value optimization is the most popular type of portfolio optimization and uses efficient frontier analysis. The constraint of cost-value optimization is the portfolio budget. Secondly, resource optimization is used widely to optimize the portfolio and focuses on capacity management analysis. The constraint of resource optimization is human resources. Thirdly, schedule optimization is used with project sequencing, which relates to project interdependencies. The constraints of are project time and planning and project dependencies. Lastly, work type optimization or balancing is sometimes used and is constrained by categorical designations of services delivery and project types (Ghasemzadeh N. A., 1999).

Quote from interviews:

"In the proposal phase we are very concerned with what we do with this customer. Categorization of projects within the company is being done, but we do not run analytics on this, but we want to gain more insights on this through machine learning. Advanced analytics and my responsibility must come together in this case to gain more insights. In the UK predictive analytics are being used for the "make every project count mindset"."

- Global Director IT, Business Intelligence, Global, 28-07-2020 -

Adjustment

The fifth phase, portfolio adjustment is the last and final stage of the major selection process, creating an overall overview (based on matrix-type displays) showing critical project characteristic, opportunity is given to final decisions and changes. The impact of the changes to be made, should be analysed (through sensitivity analysis) on risk, project size, and running term (long/ short). Equivalent to the project life cycle (initiation phase, implementation phase, controlling phase, closing phase) and the programme life cycle (definition phase, the delivery phase, and the closure, portfolios do have a life cycle (see Appendix I.)

In contrast to the life cycle of projects and programmes, the life cycle of a portfolio has greater longevity and management. Moreover, the portfolio life cycle is a continuous process and needs to be adaptable and flexible in the rapidly changing environment. Both the internal (organisational) environment and the external environment have changing needs that influence the project portfolio. This implies that the project portfolio management controls should be flexible and adaptable to complexities and multiple portfolio options. Controlling and monitoring the portfolio is an ongoing process and strategic planning, organisational performance metrics

and product and service design are critical elements of the portfolio life cycle. (Project Management Institute, 2017)

To summarize the core process of PPM, Figure 14 shows an overall picture of all the different phases, with the underlying elements.

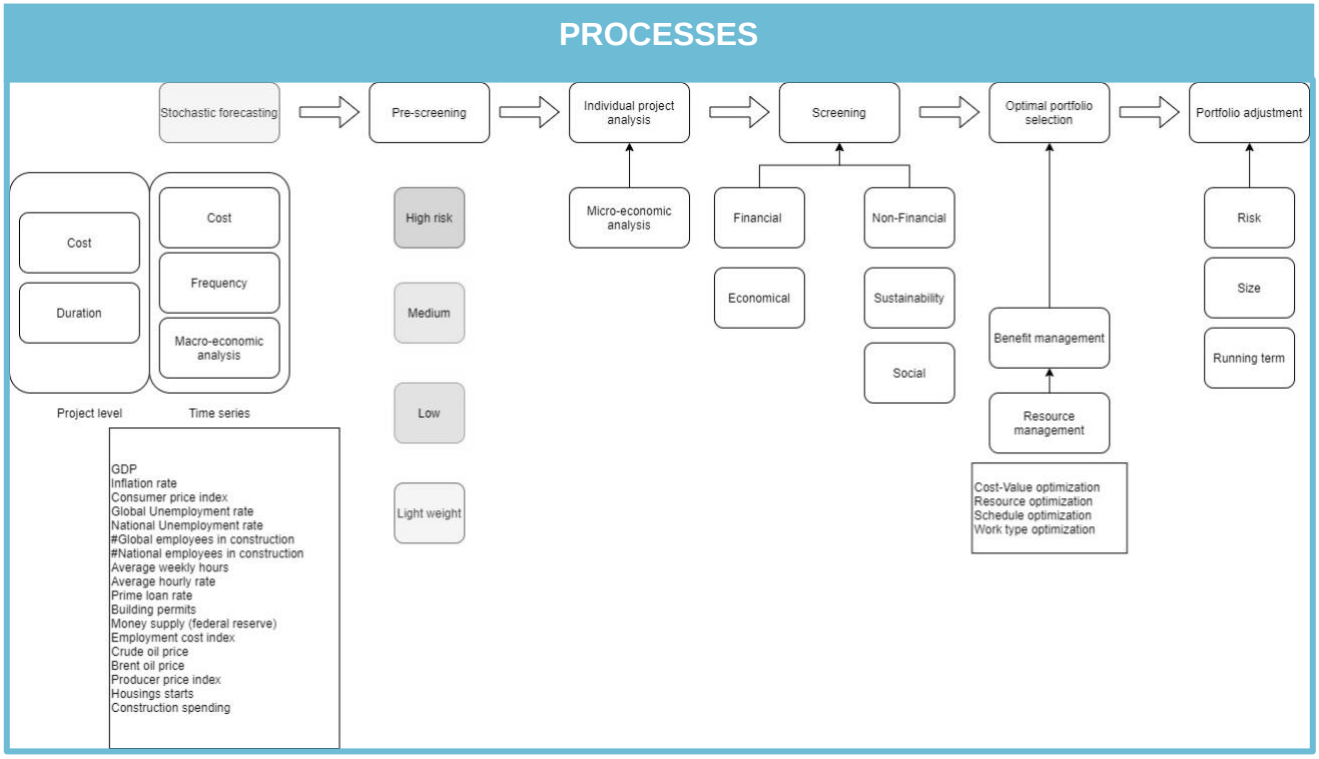

Figure 14: Overview of total PPM core process (Source: Author's own analysis)

3.4.3 Decision-making

As described, an important topic in PPM is decision-making, as this is needed in and between multiple phases of the portfolio lifecycle and the selection and evaluation process(see 3.4.1). To describe how decision-making in the organisational context is made, the general model of portfolio decision-making process from Linda Kester, Abbie Griffin, Erik Jan Hultink, & Kristina Lauche (2011), is used (see Figure 15). This model describes that the organisational effectiveness of portfolio decision-making consists of three factors. First, the portfolio perspective describes the need for a complete understanding and overview of the entire project portfolio. Second, the focus describes the relationship between short-term and long-term actions and decisions. Third, the decision-making agility describes the speed, warranty, adaptability and innovativeness of the PPM processes (Kester, Griffin, Hultink, & Lauche, 2011).

The effectiveness of portfolio decision-making is derived from three decision-making processes that interact with each other. These decision-making processes are the evidence-based process, the power-based process and the opinion-based process (Kester, Griffin, Hultink, & Lauche, 2011). Kester et al., (2011) provides empirical support for the process of evidence-based decision-making and its inputs (contribution to evidence-based management). The evidence-based process is the presentation and discussion of technical, financial and market or client information that is generated and is based on factual empirical and objective information (Kester, Griffin, Hultink, & Lauche, 2011).

The influence of each of the three decision-making processes is dependent on the availability of data input that is required. The more data is available the more the focus is on the evidence-based decision-making process (Kester, Griffin, Hultink, & Lauche, 2011). Organisational antecedents are at the foundation of the three decision-making processes and determine which decision-making process is emphasized. Evidence-based decision-making uses a combination of inputs to obtain a full understanding of the data for making portfolio decisions. To date, only few studies have investigated the inputs to rationality.

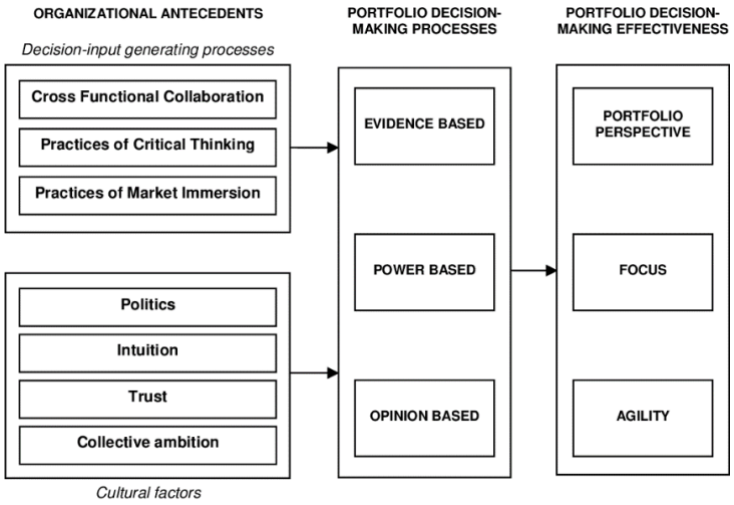

Figure 15: Organisational decision-making model on the portfolio level (Source: (Kester, Griffin, Hultink, & Lauche, 2011, p. 645))

Portfolio decisions deal with uncertainty, varying information, and data. The decisions are based on both the individual project characteristics and the entire organisational project portfolio (see Figure 16). Decisions should be placed in context of the strategic goals (Kester, Griffin, Hultink, & Lauche, 2011). The following decision-making models are known or considered in the context of portfolio decisions: decision theory, expected utility theory, probability theory, prospect theory, decision framing, agency theory and group decision-making (Meyer, 2012). Decision-making is often done under time pressure and uncertainty (Spalek, 2019).

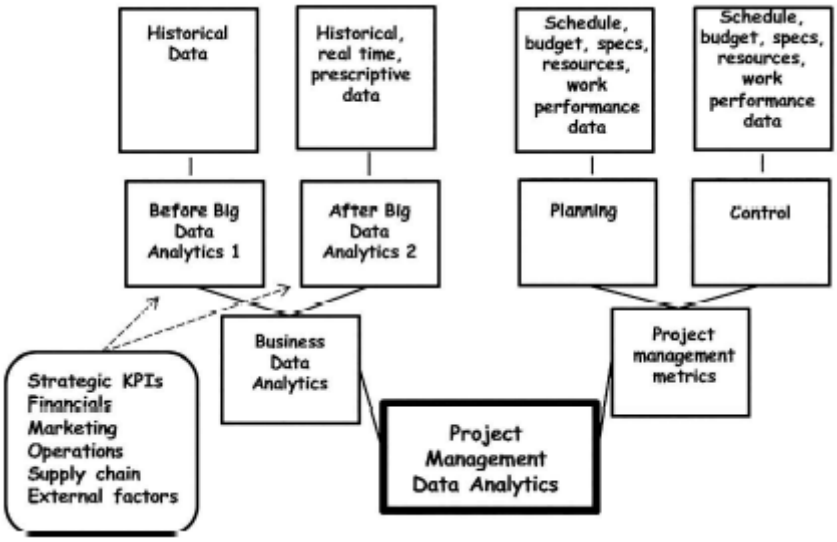

Figure 16: Business data analytics and individual project characteristics (Source: (Spalek, 2019, p. 12))

Decisions must be grounded in knowledge to be beneficial to strategic goals and must not consist of personal biases. Therefore, decisions must be made according to a well-established process (Spalek, 2019). First, the process for making decisions should be clear (decide how to decide), the responsibilities and accountability of stakeholders are identified, and the input and method must be established. Second, decisions are being delegated (decide what and when to decide), as requirements, subjects, time planning and persons are identified. Third, the materials, tools, information etc. for decision-making must be of high quality (proper decision support). Therefore, data sources and analysis techniques must be reliable, and people should have the right skills and insights. (Spalek, 2019)

In the rapidly changing business environment, data, data analysis and data visualization are from utmost importance. For PPM this implies that organisations need data, and robust data analysis to enhance decision-making to improve strategic execution. But gathering data is complex and challenging. When data is gathered and is not being used, it is a waste of organisational resources. Therefore, knowing what data is needed for informed decision-making ensures focused data collection.

Project portfolio management and decision-making should be based on several aspects from different business levels (Spalek, 2019). Data is created on the project level for executive purpose, and throughout the organisational hierarchy the value of data is growing (see Figure 17). Value creation is accumulated through the programme level and portfolio level, and once internal data is combined with external (economic, environmental, and social) datasets the value of data is incredibly high and can be used as for example for investment appraisal and thus the composition of the project portfolio.

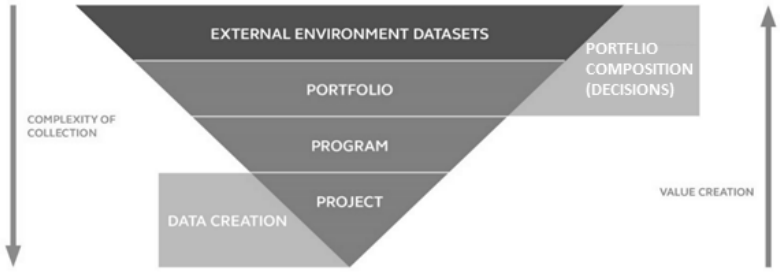

Figure 17: Value creation and complexity of data (Source: adapted from (Arcadis, 2020))

Portfolio decision-making is a practice supported by project portfolio principles (see Figure 18, monitoring, reporting and control, portfolio risk, resources, project proposals and the project portfolio itself (Belarbi, 2016). The PPM principles are structuring the project portfolio, ownership, rearrangement strategies, investment strategies, success factors and key performance indicator selection are at the foundation of PPM principles. These project portfolio principles are influenced by organisational circumstances, strategic objectives, management commitment and governance (Belarbi, 2016).

To explain the influential factors on the project portfolio principles, organisational circumstances are different per organisation. This has to do with the maturity level of the organisation, the organisational culture, the complexity of the environment and change and risk perception (Belarbi, 2016). The strategic objectives do differ per company as well as each company formulates different goals. With these different goals, different strategic objectives arise, and the execution of these strategies have influence on the portfolio composition (Belarbi, 2016). Management commitment regarding top management involvement in the decision-making process vary per organisation, the support of top management is critical and key to successful PPM towards reaching strategic alignment (Belarbi, 2016). Organisational governance is mostly linked to creating strategic alignment and aims at creating transparency, role definition, risk management, resource allocation and performance management (Belarbi, 2016). Project portfolio decision-making is a complex activity as it is influenced by multiple organisational variables (Belarbi, 2016; Abubakar, Dalibi, & Wang, 2018). Monitoring, reporting, and control play an important role in the portfolio decision-making construct.

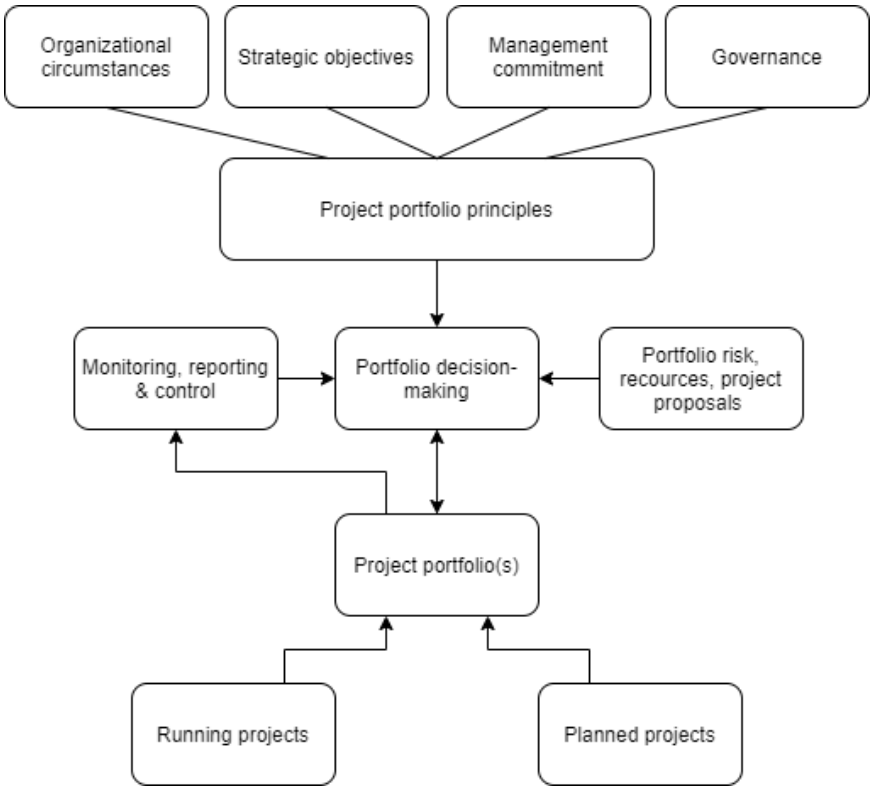

Figure 18: Framework portfolio decision-making factors (Source: (Belarbi, 2016, p. 4))

3.5 Technology

3.5.1 Monitoring, reporting and control

This section focuses on attributes of and influences on information technology (IT) in projects and project portfolio management. As described in 3.4.3, monitoring, reporting and control is an important part in PPM and evidence-based decision-making. The monitoring, controlling and control process (see Figure 18) is for reviewing portfolio performance and periodically alignment with strategic objectives (David W. Ross, Paul E. Shaltry, 2006; Belarbi, 2016). Furthermore, monitoring and controlling is closely related to business intelligence and Data & Analytics.

Quote from interviews:

"Tools and systems need to be developed for time saving, high quality and transparency, systemic use of data and knowledge, saves time for human consideration"

- Project Leader, Project & Cost and Commercial Management, The Netherlands, 16-04-2020

For monitoring, reporting and control an extensive amount of data is required and collecting the right data is an important task. The use of systematically gathered data can create business benefits but is determined by the stakeholders that should give input to the data gathering process. This gathering of data can be done by asking for performance feedback through series of questionnaires on a periodically reoccurring base. This stakeholder includes management, staff, leaders, and customers. Interactive dashboards can be created based on this information and will be always up to date, so that the PMO or the EPMO in the organisation has actual insights in the project portfolio performance (Spalek, 2019).

3.5.2 Business analytics and project performance metrics

But according to case study 3 (see Appendix IV.), IT now enables the AEC industry to collect, store, analyse, and share extensive amounts of data in efficient ways. This means that businesses should not only rely on historical information. But also, real time, and prescriptive information must be incorporated. And if combined with strategic key performance indicators (KPIs), financial data, marketing feedback, and operational and supply chain performance data, the strongest competitive advantage can be achieved through information salience (Spalek, 2019). Transcendent is the integration of this internal data with external data. Which can for example strength the stochastic forecasting phase in the PPM core process. Depending on planning and controlling the data concerns schedules, budgets, specs, resources, and project performance (Spalek, 2019). In other words, data from the triple constraint of project management (time, cost, and scope) needs to be integrated. And this data needs to be refreshed periodically to guarantee the accuracy and precision to enhance the dynamic adaptability of the organisation to changes in performance through internal and external factors.

Bringing together conventional business analytics with project performance metrics will constitute project analytics, which can be monitored for portfolio decision-making and other application. Figure 19 shows the mind map, adapted from Seweryn Spalek (2019, p. 12). It shows how data from projects, coming from the triple constraint (time, cost and scope, as described in 3.1), goes beyond the standard project metrics when combined with business data from *internal* and *external* analysis. Moreover, the metrics divided over the three factors shaping project performance are to some extend specified, which will be further elaborated in Chapter 4 and 5.

First, planning (time) is including schedules, resources, and project performance. Second, budget (cost) is including budget, ROI, IRR, PV and EVM. And third, scope is done through categorization including contract types, project types, service types, and stakeholder analysis.

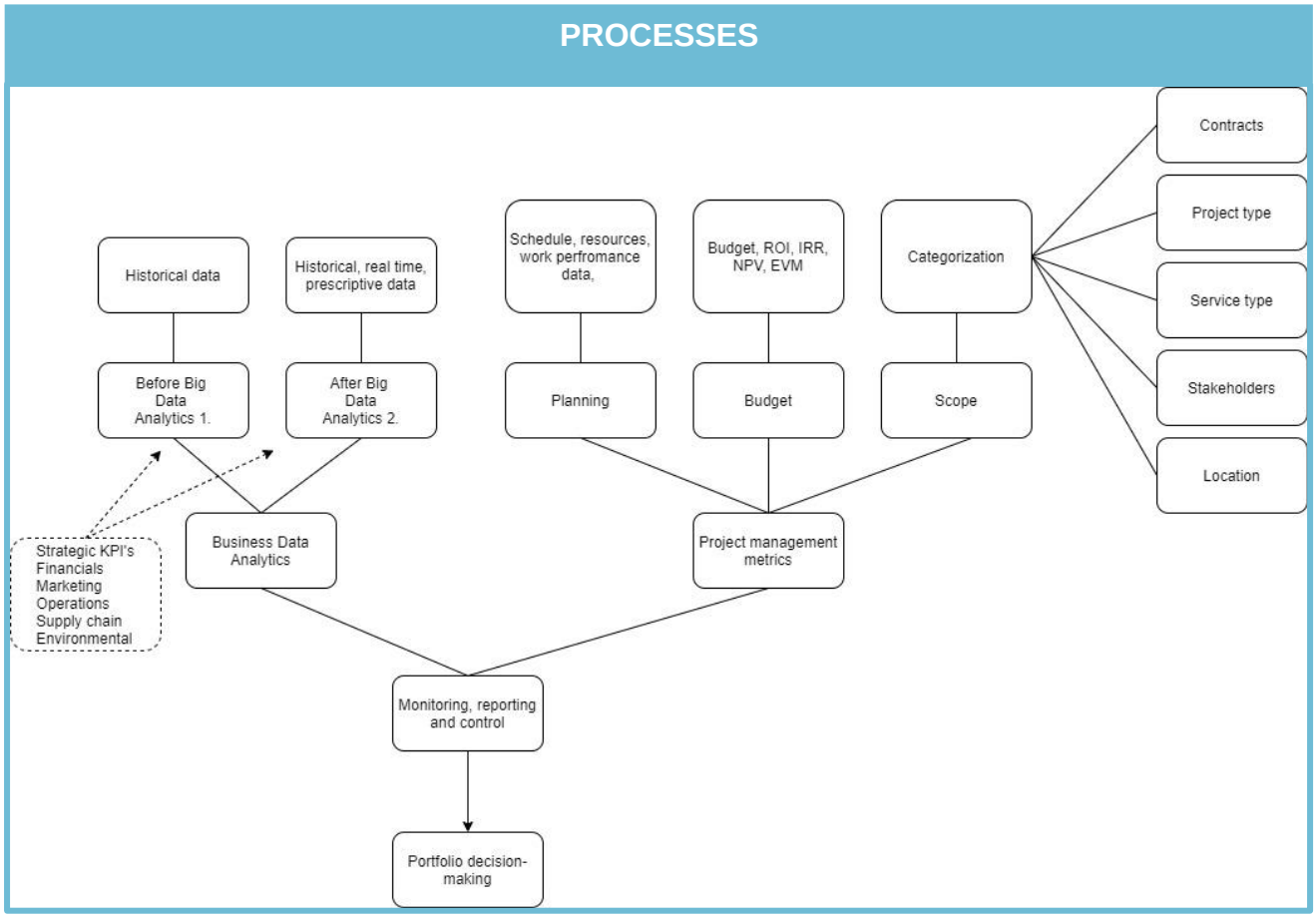

Figure 19: Mind map Business and Project data analytics (Source: adapted from (Spalek, 2019, p. 12))

Most data is fragmented and stored on different locations in databases. Collecting, massaging and storing the data in a systemized way in a data warehouse is needed (Spalek, 2019). The software processes that facilitate this original loading and periodic refreshment of data is known as extraction-transformation-loading (ETL) processes (Vassiliadis, 2009). Data extraction is the physical collection of data from different sources. After the collection, transformation data is changed from raw data into a format that enables it to be processed and analysed. The transformation processes know two types, under which analytics 1.0 and 2.0. In analytics 1.0 an extensive amount of time is invested in the data preparation process. With analytics 2.0, new technologies and methods (partially) automates this process through programming. Loading is the physical storing of data in another database or warehouses. (Vassiliadis, 2009; Spalek, 2019)

Quote from interviews:

"All data in it is sent daily to the Oracle Analytics Cloud to the data warehouse and is being refreshed. All customers, pipeline, timesheets, project costing are incrementally loaded to the data warehouse. Mostly descriptive analytics are used, we visualize data on this dashboard the different work areas are shown. Little analysis is being run on the hours spend by employees on the project, no root-causes for example project delays are being identified on this level, as we don't see the details but only financial data.

- Global Director IT, Business Intelligence, Global, 28-07-2020

AEC industry data is thus voluminous due to the design data, schedules, enterprise resources planning (ERP) systems and financial data etc. The size of the files is increasing, due to the advent of devices and sensors that generate data on a massive scale. The variety or diversity in the data is tremendous as many various formats are being used (Bilal, et al., 2016). The concept of an enterprise wide system that integrates data from many sources throughout the organisation and from outside the organisation, an online control room for monitoring, reporting, and control has an enormous potential value. And a wide variety of platforms that use robotic process automation (RPA) to organise data configure data to save manual administrative and communicative tasks would have a lot to promise. Advantages in business process automation (as compared to using human analysts) are the ease of integration with enterprise systems, dashboards, and management control tools. Quick, comprehensive, and continuous data collection can provide actual and accurate insides for PPM (and thus for business success and improved decision making). Continuous monitoring and the availability of status reports through logs and management dashboards give updates through multiple managerial layers (see Figure 20).

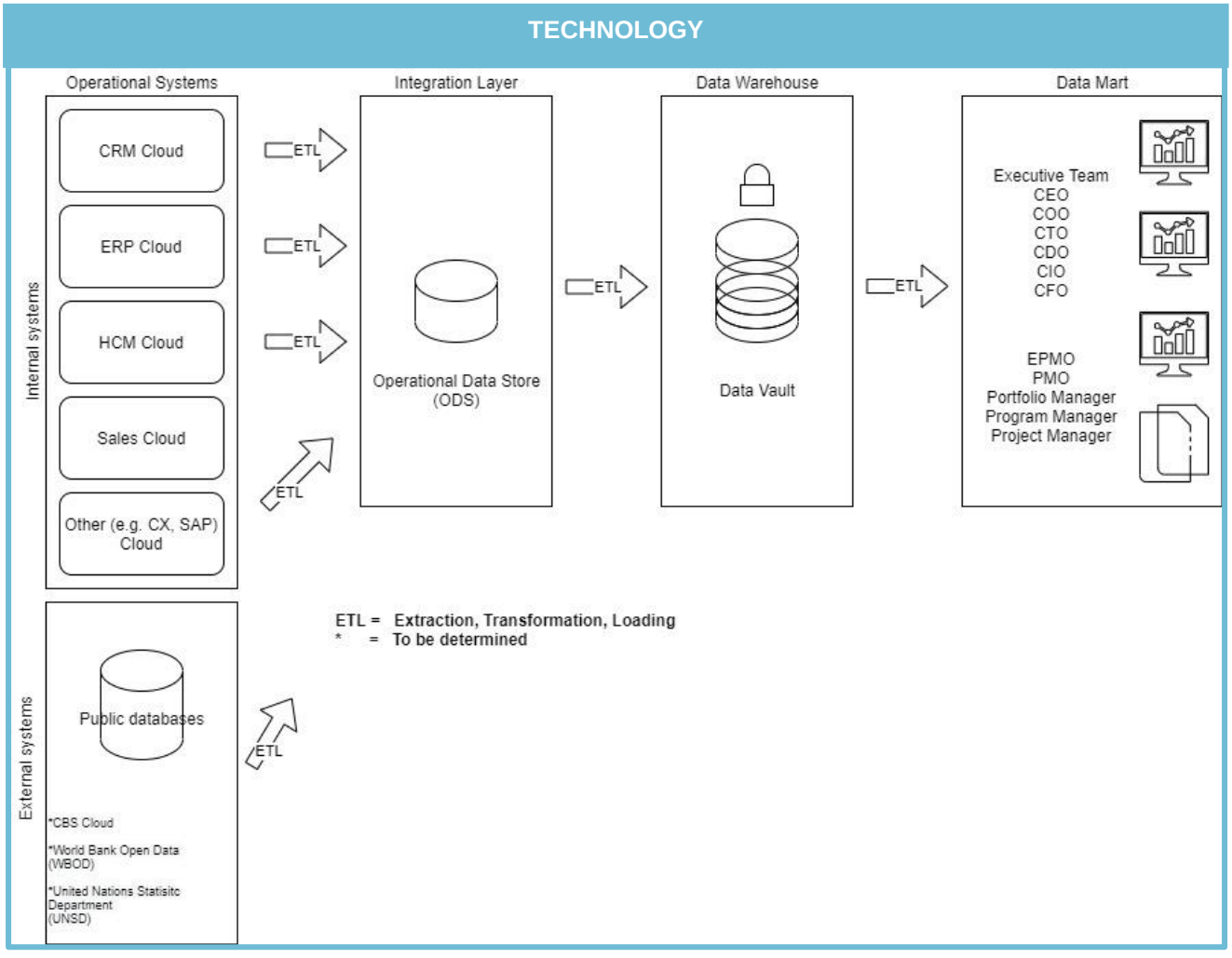

Figure 20: High level visualization of integrating different operational information systems (Source: Author's own analysis)

First, since the different sources structure information in completely different schemata the need to transform the incoming source data to a common, "*global*" data warehouse schema that will eventually be used by end user applications for querying is imperative (Vassiliadis, 2009). Second, the data coming from the operational sources suffer from quality problems, ranging from simple misspellings in textual attributes to value inconsistencies, database constraint violations and conflicting or missing information; consequently, this kind of "*noise*" from the data must be removed so that end-users are provided data that are as clean, complete and truthful as possible (Vassiliadis, 2009). Third, since the information is constantly updated in the production systems that populate the warehouse, it is necessary to refresh the data warehouse contents regularly, to provide the users with up-to-date information (Vassiliadis, 2009). All these problems require that the respective software processes be constructed by the data warehouse development team (either manually, or via specialized tools) and executed in appropriate time intervals for the correct and complete population of the data warehouse.

3.5.3 Information Technology

The configuration of the above-mentioned structure is subject to many different options. It is outside the scope of this research to go in depth on the data architecture for PPM, but a brief comparison is given on different software options. For successful project management and portfolio management an efficient supporting infrastructure must be implemented, and IT is regularly used to reduce fragmentation issues (Damiani, Revetria, Svilenova, & Giribone, 2015).

Quote from interviews:

"Primavera is not pulling together specific data."

- Global Solutions Director, Project & Programme Management, Middle Eastern, 17-06-2020 -

Technical and managerial information about the usage of different available technologies are identified along popular systems using the 9 criteria (see Table 9) collaborative software, issue tracking system, scheduling, resource management, document management, workflow system, reporting and analyses, budget management, and invoicing (Damiani, Revetria, Svilenova, & Giribone, 2015). Based on this criteria, leading technologies are in descending order Oracle Primavera EPPM (P6), Ecosys EPC, Spider Projects, Easy Plant, Prolog, SIGEP, and Clickhom (Damiani, Revetria, Svilenova, & Giribone, 2015).

Quote from interviews:

"The platform we use for all dashboards and functions that we operate there include mainly finance-related KPIs. Project managers have little insight into their project status based on this data. Only financial insights are used to inform project managers about performance."

- Global Director IT, Business Intelligence, Global, 28-07-2020 -

Table 9: Capabilities for project management software (Source: adapted from (Damiani, Revetria, Svilenova, & Giribone, 2015))

Priority	Capability category
1.	Scheduling
2.	Collaborative software
3.	Budget management
4.	Reporting and analysis
5.	Resource management
6.	Document management
7.	Issue tracking system
8.	Workflow system
9.	Invoicing

The ideas and technologies mentioned are all related to data and information; therefore, the definition of Information Technology (IT) is elaborated in this section. According to Aithal & Aithal (2019), information technology is one of the two technologies that are identified as general purpose technology (GPT) of the 20th century. They are categorized as radical innovations and have disruptive effects. General purpose technologies affect entire economies and have the potential to change societies and even the world population (Aithal & Aithal, 2019). As GPT is a generic term to describe the technology that is built on several underlying technologies. Information, Communication and Technology (ICT) consists of Artificial Intelligence (AI), Big data and Business Analytics, Blockchain, Cloud computing, Digital business and Marketing, 3D-printint technology, Internet of Things (IoT), Online Ubiquitous Education & Training, Optical Computing technology, Information storage, Virtual and Augmented reality technology (Aithal & Aithal, 2019). Big data and IT are used to improve business methods and enhance values and various services offered in business management like PPM. Four main characteristics of using data and IT in PPM are intangibility, high technology, invariance, and scalability (Aithal & Aithal, 2019). Systems and information architectures should be developed around these characteristics and attributes.

From the ICTs mentioned above, AI and big data & business analytics have potential in enhancing the PPM processes. The objective of AI is namely performing by thinking and doing better than human beings. The objective of business analytics is developing effective information using hidden patterns, unknown correlations, market trends and customer preferences to help organisations for making better business decisions. Both technologies enhance the PPM process through automation of software development & coding, knowledge management, information security services, semantic web services, decision automation, performance measurement, risk forecast, predictive analysis and knowledge discovery (Aithal & Aithal, 2019). The potential of these technologies in PPM is clear, but the adaption and setting up a strategy to create benefits from these technologies is a challenge. Therefore the Chapter 4 and 5 will go more in depth on data analytics and barriers that prevent the implementation of these technologies and techniques.

3.6 Conclusion

To answer sub question 1: *"What are the characteristics that are crucial for a PPM framework?"*, it is proposed to develop the conceptual framework based on the three pillars, people, processes, and technology (IT). Based on Section 3.3, 0, and 0 the complete framework has been established as shown in Figure 21.

The people pillar describes a governance structure that facilitates PPM through the use of data and assigned roles and responsibilities to different stakeholders in PPM. It is to be specified and is to be linked to the different process phases and IT architecture. Important is the establishment of the EPMO and divisional or regional PMOs, these bodies are critical in the data flows to drive digitized PPM. The EPMO will be charged with many projects and with many dataflows, and analytics will enable the EPMO to gain insights and guidance in all projects running and thus the project portfolio. Besides, the PMO can compile performance reports to inform the EPMO or senior level management. The project manager's use of data will be to have a good understanding about the triple constraints of time, cost, and scope for operational purposes for the benefit of the individual project performance. This includes scheduling, budgeting, and work requirement follow-up. On the strategic executive level, roadmaps are being established and cover all aspects of business, including marketing IT, finance, operation and legal. Examination of the project portfolio must provide business analysts with information to identify new projects for the portfolio, which is called the pipeline.

The processes pillar describes the core PPM process that forecasts, selects, and optimizes the composition of projects in the project portfolio. Six phases, stochastic forecasting, pre-screening, individual project analysis, screening, optimal portfolio selection and portfolio adjustment describe in detail in detail what the core activities are and what information and analysis is needed to drive decision-making. Moreover, the overall performance of the portfolio can be assessed. Imbalance can be identified, and resources can be directed to projects to prevent or react to problems.

The technology pillar describes the required IT structure for the integration of internal and external data bases that should facilitate the different stakeholder at the executive level, the EPMO and the PMOs with information to drive digitized PPM. Focus is put on the composition, of the current portfolio components, new components, gaps in certain service or business lines, revenues, personnel requirements, and investment requirements. In this case data analytics plays a central role. IT requirements and R&D requirements are part of the strategic plan. Capabilities are matched future requirements, and data analytics can help identify how capabilities can be achieved through the projects and the entire portfolio. Chapter 4 further specifies what project performance data is needed and Chapter 5 will further detail how the specific data is being analysed through different types and methods to gain the needed insights. Here it is only concluded how the final data (insights) is being shared (delivered) and being used.

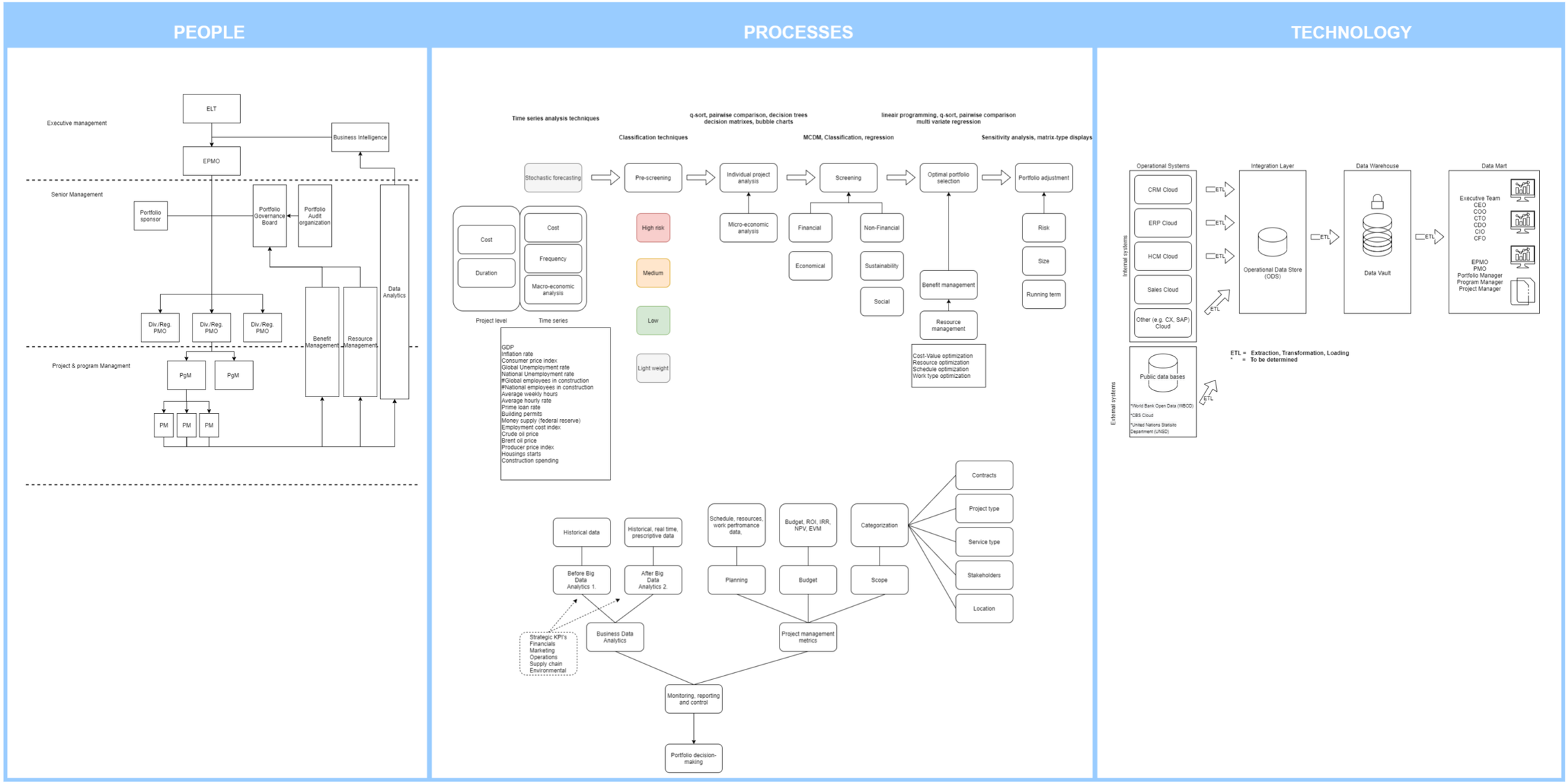

Figure 21: Overview of conceptual framework for digitized PPM

4 PORTFOLIO PERFORMANCE AND SUCCESSFUL PROJECTS

In the previous chapter, the conceptual framework for digitized PPM is presented. To substantiate this framework, it is important to defined critical success factors, that can be transformed into selection criteria and eventually KPIs that can be used in the core process. Moreover, data needs to be identified that can be used as input for the framework. This chapter is about project portfolio performance and successful projects and will elaborate on sub question 2. First, characteristics of successful project portfolios and the contribution to business success is explained, and monitoring, reporting and control of the project portfolio is elaborated from a strategic point of view, finding critical performance variables. Second, individual project performance is explained and based on the three pillars of time, cost and scope, critical success factors and key performance indicators are identified. Third, the availability of data and performance indicators in the AEC industry are considered and finally implications for the PPM framework are concluded.

4.1 Project portfolio performance

Tools and techniques for the assessment, evaluation and prioritization in project portfolio management are investigated extensively (Banihashemi et al., 2017; Hansen et al., 2019; Heising, 2012; Magnusson, 2019; Picciotto, 2019b; Spieth & Lerch, 2014). But explaining factors for PPM performance are limited. Factors for monitoring, reporting, and controlling the project portfolio to enhance decision-making are needed. Business success dependents on project portfolio success and can be recognized in economic success and to future readiness. This economic success is often measured through commercial success and market success. Economic success is built on two factors, market success through volume and market share and commercial success through financial measures such as break even, ROI, and profit, which is related to individual projects success as well (Heising, 2012).

Sanchez & Robert (2010) indicated two levels for measures, one measuring the realization of key benefits and one measuring the achievement of the objectives of the portfolio. First it needs to be understood what key performance indicators (KPIs) and critical success factors (CSFs) are. "*KPIs are metrics for assessing performance regarding the needs and expectations of stakeholders, the achievement of goals, and reflecting the critical success factors*" (Sanchez & Robert, 2010, p. 65). KPIs have a lifetime and must be updated regularly to fit the strategic objectives. Moreover, KPIs must be complemented by a target with the desired level of performance. The more frequently measured, the more accurate the performance assessment. "*CSFs are the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organisation*" (Sanchez & Robert, 2010, p. 65). CSFs are thus the necessary factors to meet the strategic objectives of the portfolio.

4.1.1 Successful project portfolio's

Within project-based organisations, the performance of project portfolios is thus a driver to business success and competitive advantage. The performance of the project portfolio is dependent on the performance of projects, but from a strategic perspective, tracking projects in an isolated way is not enough to track the entire portfolio's performance. Although the majority of the success factors are indicated at the project level, measures must be linked to strategic objectives and must be timely and effective (Sanchez & Robert, 2010).

Meskendahl (2010) developed a framework (see Figure 22), indicating the link between business success, portfolio success and project success. Portfolio success is determined through first, the average single project success (which will be further elaborated in Section 4.2), second the use of synergies and dependencies, third strategic fit and, fourth portfolio balance (Meskendahl, 2010). Building on this, Heising (2012) agrees that the portfolio success depends on the four factors, but additionally identified critical success factors that are found in strategic positioning/ orientation, stakeholder management, and the ideation culture. Moreover, other factors that are important in the structuring of portfolios are consistency, integration, formalization and diligence (Meskendahl, 2010; Heising, 2012). Formalization is a central construct in organisational theory and is needed on both the project management level as the portfolio management level, standardized processes and routines are needed (Teller J. , Unger, Kock, & Gemünden, 2012; Magnusson, 2019). Formalization improves transparency in a project portfolio environment because of complexity and increased availability of information.

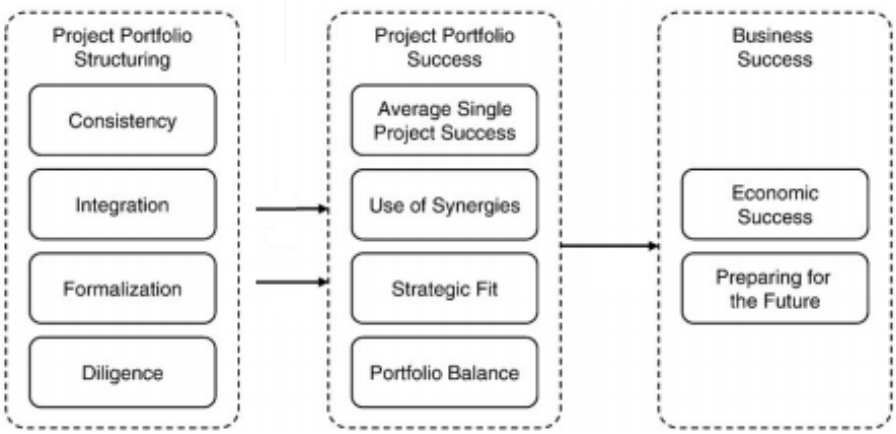

Figure 22: CSFs for portfolio success and business success
(Source: adapted from Meskendahl (2010, p. 811))

To further elaborate on the different factors that determine success, According to Meskendahl (2010), the strategic orientation or positioning is established through the organisational analytical posture, the risk taking posture, and the aggressive posture. The analytical posture is important since this research focusses on information and evidence-based decision-making and can be strengthened through Data & Analytics. It refers to the organisational abilities in systematically producing information and creating knowledge to enhance competitive advantage. Improving the analytics posture should include external analysis towards technological developments, market developments and strategic competence as well (Meskendahl, 2010). Other critical success factors are clear goals, management support, ownership, resource allocation, and prioritization (Fricke & Shenbar, 2000; Martinsuo & Lehtonen, 2007).

There is an interdependency between project portfolio complexity, that has to do with firm size, project interdependencies, portfolio size, an internal project ratio, and the quality of the project portfolio performance (Sanchez & Robert, 2010). Tracking the portfolio in its entirety can thus be done through focussing on project interdependencies, which are also often measured on the programme level. Identification of relations between projects and the creation of the strategy determines the portfolio's success (Bilgin, et al., 2017). Dependencies between projects within a portfolio significantly affect the entire portfolio's success. Dependencies exist because the use of shared resources, similar technical requirements, project locations, contracts and other similarities through the external environment (Bilgin, et al., 2017; Meskendahl, 2010).

To first categorize the different types of dependencies in the AEC project portfolios, resource dependencies are a limitation where resources are used jointly or link projects through constraints at the start and end of projects. Market dependencies are competitive effects for projects for each other. Product dependencies are more of a technical requirement when the interchange of products is needed to make progress. Another dependency is the experience or knowledge and skills, which connects the knowledge created in one project to the knowledge and insights needed, for another project. Moreover, financial dependency can exist when projects are interlinked through financial relationships. Measuring these dependencies is difficult because no specific measurable units can be linked to the different dependency types. But, attributes to measure could include client, currency, personnel, manpower, machinery and equipment, material, country, project type, technology, contract type, delivery system and partnering companies (Bilgin, et al., 2017). Categorization and linking projects to their success based on those attributes is thus indicating portfolio success to some extent. But, setting up measures, that can be translated in KPIs on the entire portfolio level is difficult and are mainly subsequently. Therefore, the scope on the portfolio level is limited to the identification of the CSFs.

Moreover, a number of CSFs in PPM are important for the AEC and are identified as the role of clients in identification, knowledge management in evaluation, commitment to high quality workmanship, strategic direction/ health and safety protocols (in organisation), project managers KSAs (knowledge, skills, and abilities) and tighter control over construction activities (Banihashemi, Hosseini, Golizadeh, & Sankaran, 2017). CSFs for integrating sustainability in construction projects are also identified and important for the AEC industry. They have implications on different phases (identification, evaluation, commitment, preparation, implementation) of the integration process. In the implementation phase, a comprehensive contractors' portfolio investigation in terms of their level of awareness of the sustainability concept and their previous records of sustainable projects implementation is important. Moreover, water and noise pollutions minimization during execution, implementing a particular project monitoring and feedback methodology to evaluate the current state of sustainability and rectify any discrepancy and/ or deviation are important (Banihashemi, Hosseini, Golizadeh, & Sankaran, 2017).

To further define key performance indicators for measuring the achievement of the project portfolio strategic objectives, the mission statement of the organisation, the vision, the objectives, and the organisational critical success factors are the foundation (Sanchez & Robert, 2010). Based on case-study results, the mission in the AEC case firm is aimed at client expectation and sustainability with strong visions to enhancing liveability, digitalizing, and reacting on the customer needs.

In the case of the AEC industry CSFs are identified and include: balance regarding portfolio of geographies (developed and emerging), clients (public and private), and types of work and business lines; organic growth through focus on existing core markets and clients, focus on operational excellence, margin discipline, cash flow and working capital; strong leadership and management, a health and safety focus, and employee focus (see Appendix III.)

CSFs can be found in both the internal and external environment. The external environments are associated with changes in social, political, legal, economic, financial, and climate factors. Considering the external factors, appropriate project identification, stable political and economic situation, attractive financial package, acceptable toll/tariff levels, reasonable risk allocation, selection of suitable subcontractors, management control, and technology transfer are important. Internal factors comprise solid consortium with a wealth of expertise, considerable experience, high profile and a good reputation, an efficient approval process that assisted the stakeholders in a very tight timeframe, and innovation in the financing methods of the consortium. Moreover, innovative technical solutions, social support, commitment, and mutual benefit is important as well. And especially for the AEC industry, the importance of procurement transparency and competitive procurement processes is needed. Chau, Kog & Loh (1999) conducted study on CSFs in AEC projects, where the factors were divided into four categories namely project characteristics, project participants, contractual arrangement and interactive process. In that study, monitoring and feedback factor was identified as most influencing CSFs under interactive process factor.

In another research commitment of the board and senior management, risk identification, analysis and response and objective setting were identified as CSFs and additionally the three underlying CSF groupings are (1) execution and integration; (2) communication and understanding; and (3) commitment and involvement of top management (Zhao, Hwang, & Low, 2013). Denni-Fiberesima & Rani (2011), indicated some more CSFs that include proper contract planning and management , good project formulation, project management capability, good project implementation, realistic project duration, effective risk allocation , understanding of local environment, resource availability, access to secure finance, fast project delivery, communication, innovative technology, and proper estimation of capital cost. Moreover, the term "*soft*" critical success factors are also suitable on the PPM level to better indicate the level of tangibility. Soft CSFs thus include social support, commitment, mutual benefit, the importance of procurement transparency, competitive procurement process, effective management of constraints of the stakeholders, leadership styles, and work environment. To summarize the most important factors influencing the entire portfolios success, Figure 23 visualizes the factors and the belonging characteristics.

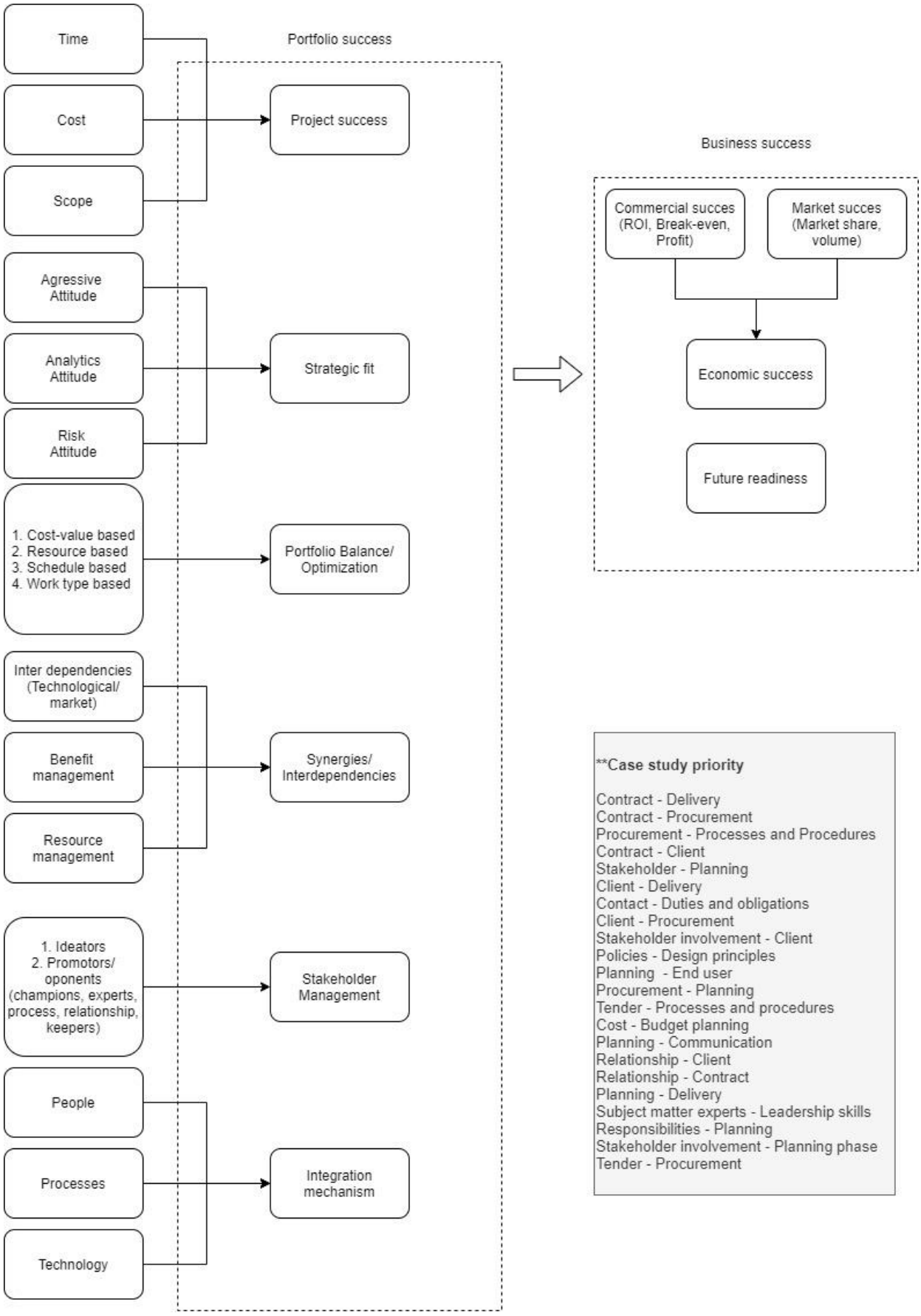

Figure 23: Success factors on the portfolio level and business impact (Source: Author's own analysis)

4.1.2 Portfolio monitoring and reporting

Due to differences between intended strategies and realized strategies caused by several internal and external factors, the organisation's project portfolio must evolve in line to keep track of the strategic goals. Strategy formation is the predecessor of strategic management control. Strategic management control systems (SMCs) gather and use information to evaluate the performance of different organisational resources (human, physical, financial) and the organisation as a whole to adhere to strategic goals. Robert Simons (2016, 2019), investigated the four levers of control (see Figure 24) that offer a framework for strategy development, execution and improvement. Simons four levers of control describe the belief system, the boundary system, the diagnostic control system, and the interactive control system. The belief system creates core values and creates the vision and mission to obtain commitment to the grand purpose (strategy as perspective). The boundary system identifies risks to be avoided and is taking out the territory (strategy as position). The diagnostic control system formulates critical performance variables that enhance the job execution (strategy as a plan). And the interactive control system focusses on strategic uncertainties and stimulates experimentation and learning (strategy patterns in action) (Simons, 2016, 2019).

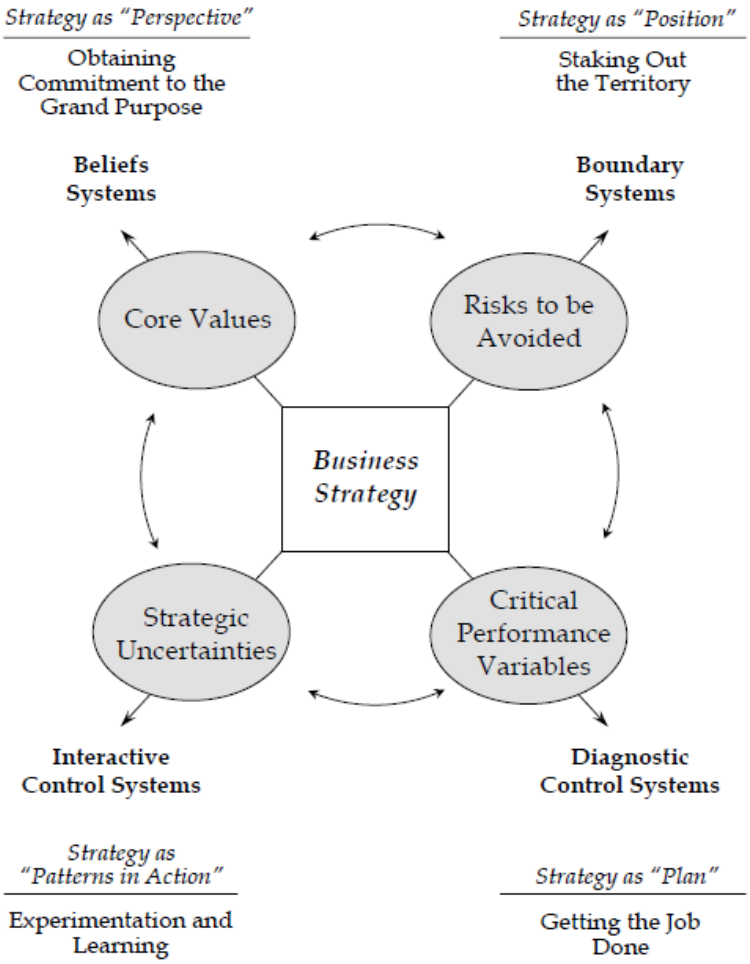

Figure 24: Simon's levers of control (Source: (Simons, 2016, p. 5))

The diagnostic control system (see Figure 26) and interactive control system (see Figure 25) are systems that need to be developed to enhance project portfolio practices and align the project portfolio with strategic goals. Depending on the level of maturity of the organisation, the stage of development of the strategic control systems are more advanced for some organisations than others. Throughout the organisational life-cycle, different stages are identified as the start-up stage, the growing stage and mature stage (Simons, 2016, 2019).

The belief system and boundary system are systems that are mostly developed in early stages of the organisational life cycle as well as diagnostic control systems. The interactive control systems are developed in the mature stage of the organisational life-cycle and is applicable once the organisational structure has developed and is focusing on products, regions and customer groupings (Simons, 2016, 2019).

Especially identifying factors that are industry specific to incorporate in the diagnostic control system to measure performance of the project portfolio are important. Once the diagnostic control system is reaching higher maturity levels, more insight is gained through the KPIs. These insights based on measurements open the organisational dialogue throughout the interactive control system. The interactive control system searches for disruptive change and is driven by top management unease and focus. Decision-making should be based on performance measurement (diagnostic control system) and should adapt to strategic uncertainties. In project portfolio management systems, reporting and monitoring information about the project performance and the discovery and integration of (emerging technological) uncertainties is needed (Simons, 2016, 2019). The interaction between the diagnostic control system and the interactive control system is at the foundation of organisational learning.

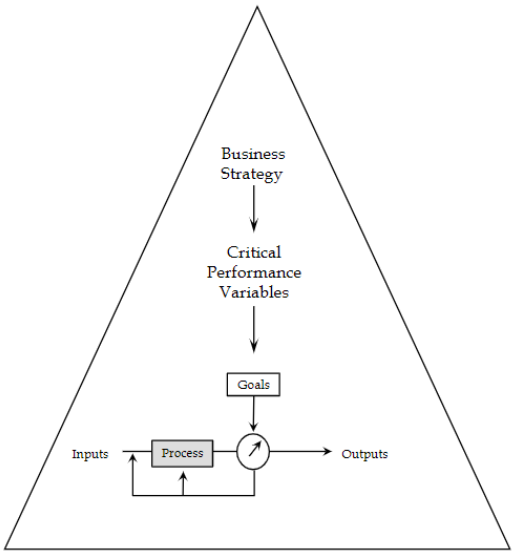

Figure 26: Simon's levers of control, visualization of the diagnostic control system (Source: (Simons, 2017, p. 5))

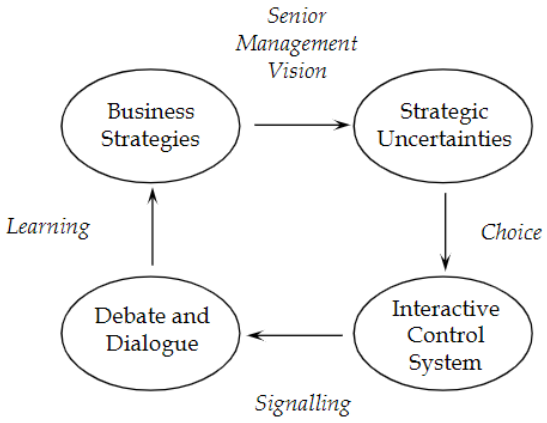

Figure 25: Simon's interactive control system (Source (Simons, 2017, p. 11))

The top-down pressure to use a system interactively is established through the involvement of high-level management. The best way is through face-to-face meeting with senior managers and lower level managers to attract the attention and indicate the importance (Simons, 2017). Changes in the business environment are in this way identified early on and adapted plans of action can be established in early phases. Organisational learning is a process which is dependent on bot top-down pressure and bottom-up input.

The value of information rising from the bottom to the top is gaining value for decision-making practices because deep insights is created in the performance and actions of the operational divisions (Simons, 2017).

Monitoring and reporting is connected to the diagnostic control system and is about representing the performance of the organisational (project portfolio). Matrices are often used to display KPIs, metrics or parameters on two three of four dimensions (Ghasemzadeh & Archer, 1999; Morris & Pinto, 2007). The disadvantage of bubble diagrams or other visual representations is that there is little theoretical or empirical support. Besides these diagrams can sometimes lead to being over optimistic on profit maximization. Therefore, they should be used in combination with other tools, and should only be used to illustrate project characteristics for balancing processes.

4.1.3 Portfolio control

Based on information from the monitoring and reporting system (diagnostic control system), internal data must be discriminating and only focussing on factors that are related to the corporate strategy. Key strategic benefits are the focus of executing projects, and each project should to some extend contribute to these key strategic benefits. Roughly stated, termination or adaption of projects that do not contribute to the strategic benefits is the goal of portfolio control (Sanchez & Robert, 2010). Sanchez & Robert (2010), indicate that mediating factors on portfolio control, regarding the portfolio success are the governance type, industry, geography, dynamics and project types.

Besides stakeholder engagement and controlling and reporting, one important aspect of portfolio management is value management. It ensures that investments in the project portfolio delivers the intended returns as steered by strategic objectives directed by stakeholders. Value management focuses on both tangible and intangible attributes. Two main guiding principles in portfolio value management are that the portfolio must ensure that investments in the portfolio components are aligned with the organisation's strategy and governance practices. And that the portfolio balances the value against overall risk (Project Management Institute, 2017). The difficulty of value management is the context in which the value is measured, as value is an indicator of the effect of an entity or offering and is seen in different ways (e.g. revenue, profit, reduced risk). High with regards to the organisation, is an entity that has significant impact on an organisation's environment and where impact is relevant for the organisation's strategic objectives.

To measure the value of entities, different metrics apply in portfolio value management. Three categories of metrics exist to measure different entities, *tangible* value metrics, *economic* value metrics, and *intangible* value metrics. Tangible value metrics are for example skills uplift, resource capacity, market share and client satisfaction. Economic value metrics are for example improved productivity, increased volume of activity and intangible value metrics are for example brand awareness, reputation, risk & compliance, and societal value (Project Management Institute, 2017). Components in portfolio value management are negotiation, return maximization, value realization, performance measurement and value reporting.

As shown in Figure 27, two feedback loops are present in the value management scheme. The feedback loop on the left side shows the first, internal, feedback loop regarding the required portfolio value and negotiated expected value. This is the value based on strategy, budget, environmental factors, and risk factors. The second feedback loop on the right, is more impact full as derived performance measures on the component level (see Figure 27) as well that are included and combined with environmental factors.

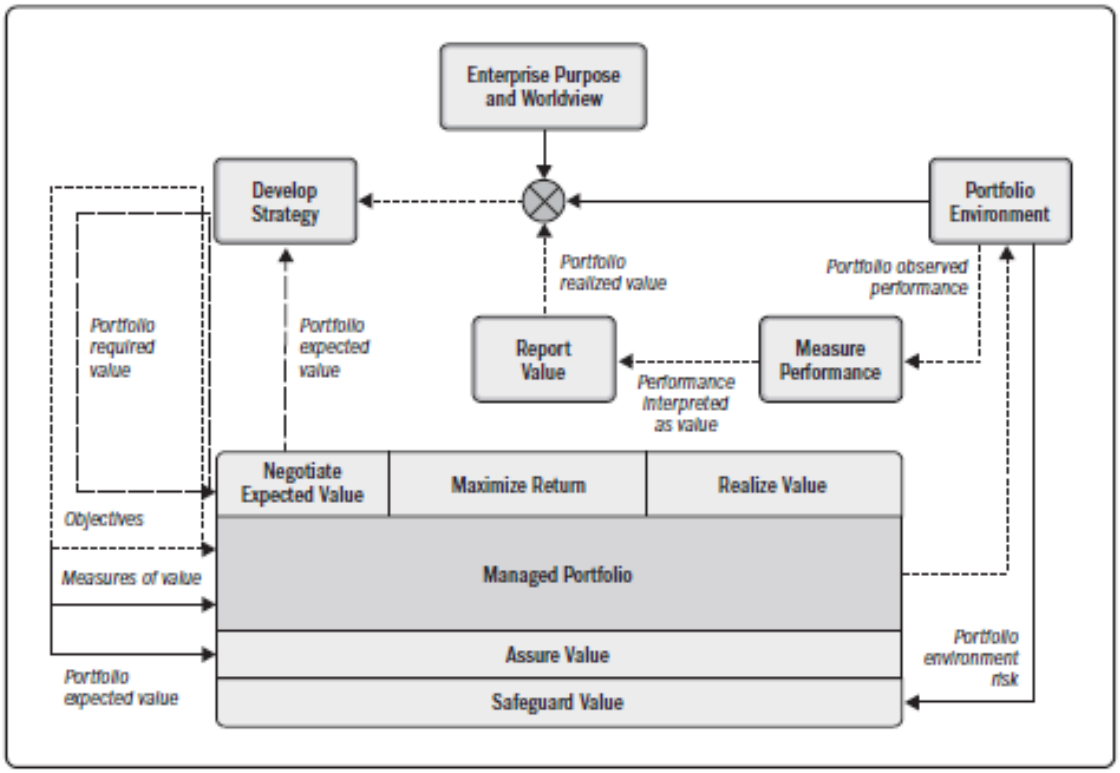

Figure 27: Portfolio control, value management activities (Source: (Project Management Institute, 2017, p. 78))

4.2 Project performance

More than half of the project portfolio efficiency and performance success is attributed to single-project performance factors. And critical success factors on this level are found as goal setting, decision-making, information availability on single projects (Martinsuo & Lehtonen, 2007). To go more in depth, this section will elaborate more on the individual project's performance and success.

4.2.1 Successful projects

In current markets where projects have become increasingly important, the definition of project success is difficult. Project success is linked to the quality of projects and thus to the triple constraint of time, cost and scope (Shenhar, Dvir, Levy, & Maltz, 2001; Tonnqvist, 2018). But besides, projects have business aspects as well, to result and have organisational performance that create profits, growth, improve market position etc. (Shenhar, Dvir, Levy, & Maltz, 2001). This is an operational mindset that is often ignored in project management literature. And project success has different definitions for different people, organisations, clients, and stakeholders. As PPM is aiming at the organisational strategic objectives, the selection of projects should focus on successful projects in the interest of the organisation. Project success may be determined by performance against trade associations, contractors, government, suppliers, banks, community groups, regulatory agencies or media (Shenhar, Dvir, Levy, & Maltz, Project success: A multidimensional strategic concept, 2001).

Shenhar et al. (2001) identified four dimensions of project success, that incorporate project efficiency, impact on the customer, business success and future preparing. These dimensions of success are measurable through different measures (see Figure 28). The business dimension addresses the impact on the organisation and is the core dimension in PPM. Business success focusses on providing sales, income, and profits. Besides, customer impact is measuring direct performance, and is one of the central dimensions to measure. Measures include functional performance, technical specification, customer needs and satisfaction, problem solving and usage. Project efficiency is not measuring performance and is a short-term success dimensions and cannot guarantee long-term success, measures are schedule goals and budget goals. (see Figure 28). The future dimension of success addresses the organisational and technological structure for the future. This dimension is the longest-term dimension. (Shenhar, Dvir, Levy, & Maltz, 2001)

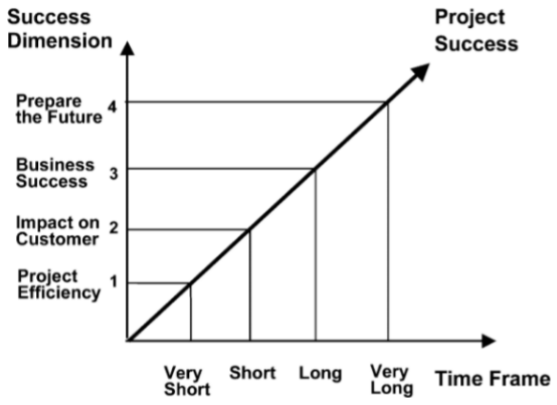

Figure 28: The time frame of project success dimensions (Source: Shenhar et al. (2001))

Reflecting these success dimension to the triple constraint of project management, the project efficiency is mostly reflected by the triple constraint incorporating schedule goals (time) and budget goals (cost). The scope constraint will thus mainly deliver success in the dimension of customer impact. Thus, the project efficiency dimension is more internal facing project success, and the customer impact is more external facing project success. But if those three constraints are optimally used and managed this will lead to long term business success, as customers will return as the customer impact dimensions score good and the company itself will be satisfied as the project efficiency is good. It seems therefore relevant to dive more in depth on each of the triple constraints and see how they connect to the AEC industry.

4.2.2 Time, cost, scope

Traditionally project success can be indicated by the three factors of time, cost and scope that determine the final quality of a project (see Figure 29). The model of the triple constraints, also called the "*iron triangle*" or "*golden triangle*", indicates the best way of evaluating projects in the AEC industry as well (Hassan, Adeleke, & Taofeeq, 2019). Benefits of the model of triple constraints is that project can be carried out with significant change, if one of the three factors is changed, the other factors should change appropriately to strive for the balanced success of the projects. The model of the triple constraints is important for decision-making and evaluation in the AEC. Balance among the three factors of the triple constraint is needed in order to complete projects and create benefits, on business success as well (Hassan, Adeleke, & Taofeeq, 2019). Within the triangle of triple constraints, prioritization can be applied, when product quality is prioritized, this means that the result, the delivery from the project, is more important than the time or cost of the delivery. If the timeline has priority, the end date of the project is most important. The result and costs are then of secondary or tertiary importance.

Figure 29: Project management triangle of the triple constraint (Source: adapted from (Blomquist & Müller, 2006))

The three factors for project success are often monitored extensively trough many measures and metrics, the project performance metrics. Combining these metrics with conventional business data analytics can constitute project Data & Analytics, which is of high value for the portfolio success as well if aggregated (Spalek, 2019). Focus on schedules, budges, resource allocation, specifications, work performance assessment must be extended with business and environmental factors as well, incorporating historic, real-time, and prescriptive insights. Seweryn Spalek (2019, p. 12) proposes a mind map showing only two of the three constraints of project management combined with business data analytics. Regarding the insights in the AEC industry specifically, this framework must be extended with scope as well and should thus comprise cost, time, and scope. The time and budget constraints are monitored extensively and many success factors and KPIs are established that enable Data & Analytics practices. But especially the scope constraint is important in the AEC industry, as projects do differ greatly. To further elaborate on the different constraint, each will be considered in more detail.

Time

As an element of the quality of project delivery, time consumption is important to evaluate. In this case, the question is if projects follow the schedule or if it did take longer than expected. This discussion is mostly about delays. In the AEC industry large projects across asset classes typically take 20 percent longer to finish than scheduled (see Figure 30). Construction productivity has declined in some markets since the 1990s and financial returns for contractors are relatively low and volatile (Agarwal, 2016).

Quote from interviews:

"Scheduling is an industry problem, all scheduling data we have should be analysed"

- Global Solutions Director, Project & Programme Management, Middle Eastern, 17-06-2020 -

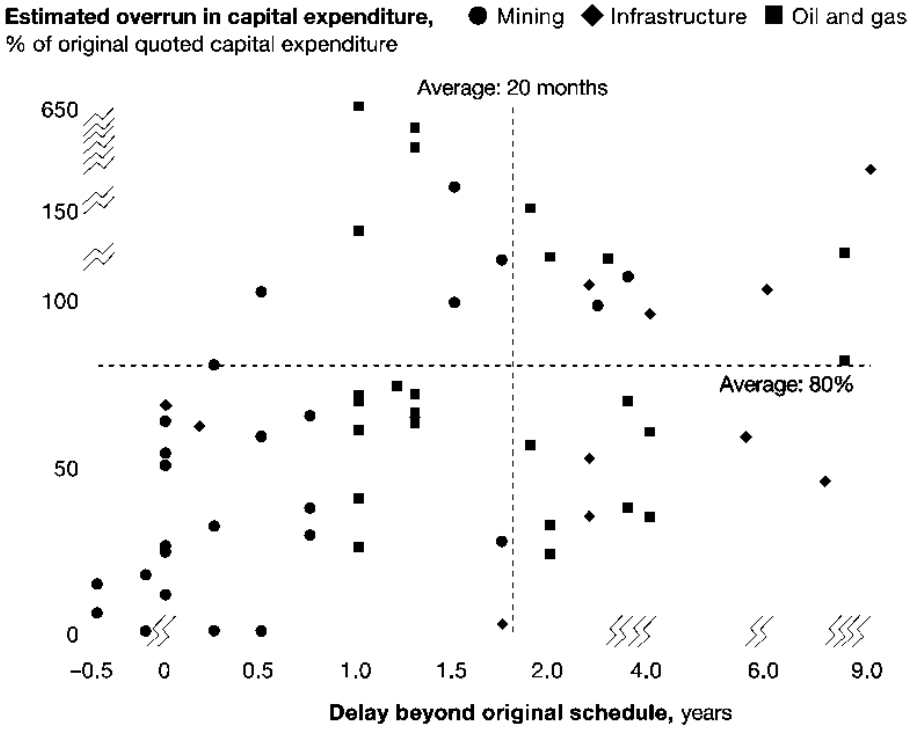

Figure 30: Time and budget overrun in AEC projects (Source: (Agarwal, 2016))

Especially in the development process for scheduling and planning, data analysis plays a crucial role. Data can be used for sequencing, duration estimation, resources requirements bills, and schedule constraints based on these elements are needed to create schedules. Models for execution and monitoring and controlling can be established through data analytics. The schedule data includes, milestones, activities, attributes, documentation of all identified constraints. The amount of additional data varies by application area. Work performance data contains data on project status such as which activities have started, their progress (e.g. actual duration, remaining duration, and physical percentage complete). Case study indicates that project performance data in the AEC industry is extensive and includes many measures on time, cost and scope, but measures in the area of the time constraint of project management are behind and could be extended (see Appendix IV. and Appendix VIII.)

With regards to data analysis for monitoring and controlling projects in the portfolio, data techniques include earned value analysis as part of earned value management (EVM). Schedule performance metrics (variance or performance index) can be used to assess the deviations from the planning. Another method based on iteration burndown charts (graphical representation of outstanding work and time) can be used to track the work that needs to be executed. Other analysis techniques include, performance reviews, trend analysis, variance analysis and what-if analysis which is more related to scenario planning and analysis. Project management information systems include scheduling software that provides the ability to track planned dates versus actual dates. Data analytics can potentially be used to also report variances to the planning and can be used in forecasting changes in the work planning.

Cost

It is being recognized that different stakeholders measure project costs in different ways and at different times, therefore a centralized perspective on the manner of project cost management must be applied to have a concise approach which is needed for analysis and evaluating the entire project portfolio. Activities in cost management include budgeting, estimating, financing, funding, cost control, but overall, the focus is on the distribution of cost over the resources that are required to complete the projects according to the requirements.

Earned value management is a method that has a tremendous potential in the AEC industry, especially when combined with Data & Analytics. EVM is based on best practices methods and is often used in civil engineering projects (Tonnqvist, 2018). The financial outcome is related to a result in EVM and opportunities are given to assess actual results and resources throughout the entire project life cycle. Results are evaluated in financial terms and are being compared to planned and actual costs. Benefits arise with the fact that during project execution clear insights and information of the proceedings are gained (Tonnqvist, 2018). Through variance calculation on costs and schedule an overview with both key figures show the accrued values over time.

Quote from interviews:

"Earned value method is interesting for project management practices"

- Programme Manager, Managing Board AEC firm, The Netherlands, 21-04-2020 -

Data analytics techniques that can be used for this EVM are based on alternatives analysis. Alternatives analysis should include funding options with different strategic perspectives (e.g. self-funding, equity funding, debt funding) and It can also include resource acquirement (e.g. making, purchasing, renting, leasing) (Project management institute, 2017). Moreover, data analytics practices thus include alternatives analysis, reserve analysis, cost of quality. Project management information systems can include spreadsheets, simulation software, and statistical analysis tools to assist with cost estimating through EVM, which will improve decision-making practices with evidence based information (Project management institute, 2017). To identify certain factors that influence the cost analysis, environmental factors can be exchange rates, multiple year currencies, fluctuations of currencies etc. And organisational assets can also be considered as influencing factors and can be found in existing formal and informal cost budgeting-related policies, procedures, and guidelines, historical information and lessons learnt repository, cost budgeting tools, reporting methods (Project management institute, 2017).

Historical project information can reveal insights that help with the development of estimates using parametric and analogous models. Historical information can reveal project characteristics to develop mathematical models to predict total project costs. These focus points may be retrieved from project reviews, evaluation reports of lessons learnt reports.

To conclude, the perspective on the success of projects, depends on the stakeholders as different ideas about the importance of the different factors leading to success are existent. Selecting objective measures that are measurable are subject to varying concerns. Other success factors include financial measures like net-present value (NPV), return on investment (ROI), internal rate of return (IRR), payback period (PBP), benefit-cost ratio (BCR). And non-financial objectives include completing movement of an organisation from its current state the desired future state, fulfilling contract terms and conditions, meeting organisational strategy, goals, and objectives. And moreover, achieving stakeholder satisfaction, creating acceptable customer/ end-user adoption, integrating deliverables into the organisation's operating environment, achieving agreed-upon quality of delivery and meeting governance criteria. (Project management institute, 2017).

Scope

The scope constraint in the AEC industry includes several aspects, under which organisation's culture, infrastructure, personnel administration, and marketplace conditions, contracting forms, project types, service or business types, stakeholders involved, location requirements (Hadjinicolaou & Dumrak, 2017). Moreover, the scope in in AEC projects is complex and existing of many different types of activities and factors. Documentation containing this constraint in early phase of the project are the project contracts with all parties involved, the scope baseline in the scope statement, the work breakdown structures (WBS), and WBS dictionary. Often the time constraint and budget constraint are two factors that need to be covered through contracting. Requirements have always been a concern in project management and have continued to gain more attention in the profession, in the AEC industry requirement management is an entire discipline. Controlling requirements and activities is part of the analysis to enhance business success. This has to do with the increased complexity of projects (Jerbrant, 2019; Tonnqvist, 2018).

4.2.3 Project CSFs and selection criteria

Many different CSFs on the project level in the AEC industry are investigated, the most important criteria identified appear to be a strong and good private consortium, have appropriate risk allocation and have an available financial market (Li, Akintoye, Edwads, & Hardcastle, 2005). But there is an infinite quantity of critical success factors available. Li, Akintoye, Edwards & Hardcastle (2005), set up general categorization for the CSFs available that include effective procurement, project implement ability, government guarantee, favourable economic conditions and available financial markets.

In another research, the different CSFs are categorized and tied to the phases of project life cycle management (identification, evaluation, commitment, preparation in organisation, and implementation) (see Table 10). Moreover, responsible bodies were identified for each phase and the belonging CSFs (Banihashemi, Hosseini, Golizadeh, & Sankaran, 2017).

Table 10: CSFs on AEC Projects per lifecycle phase, (Source: adapted from (Banihashemi, Hosseini, Golizadeh, & Sankaran, 2017))

PLM Phase	CSF	Responsibility
Identification	▪ Client's commitment to the needs of other stakeholders	▪ Client
	▪ Enacting required policies in supporting sustainability principles establishment in construction projects by governmental and professional bodies	▪ Government ▪ Professional Bodies
	▪ Clearly defined goals and prioritising all stakeholders	▪ Client/ PMT
Evaluation	▪ Evaluation Knowledge and awareness of sustainable project delivery in the PMT Dominance of constructive relationships among project stakeholders	▪ PMT ▪ Client/ PMT
Commitment	▪ Strong commitment to sustainable project delivery from project stakeholders	▪ Stakeholders
	▪ Emphasis on high quality workmanship	▪ The government ▪ Professional bodies ▪ Client/ PMT
Preparation in organisation	▪ Creating accountabilities, expectations, roles and responsibilities for the organisation Implementing effective health and safety protocols	▪ Project managers ▪ The government ▪ Professional bodies
Implementation	▪ Comprehensive contractors' portfolio investigation in terms of their level of awareness of the sustainability concept and their previous records of sustainable projects implementation ▪ Water and noise pollutions minimisation during execution ▪ Implementing a project monitoring and feedback methodology to evaluate the current state of sustainability and rectify any discrepancy and/or deviation	▪ Clients ▪ Project managers ▪ PMT

Other factors are identified through research into the interdependencies between projects and the project portfolio and are, timeliness, delivery to specification, delivery to quality, team effectiveness, business success, future readiness (Hadjinicolaou & Dumrak, 2017). In a literature review and questionnaire, critical success factors for specific AEC projects, focussing on green building projects are the support form senior management, skilled designers, skilled project managers, troubleshooting, project team motivation, commitment of project participants, strong plan in design and construction, adequate communication channel, effective control, effective feedback, and adequate financial budget (Li, Chen, Chew, Teo, & Ding, 2011). It is clear, that every research has a slightly different focus on CSFs, the goal here is to identify generic CSFs that do apply to the entire AEC industry.

As the CSFs discussed before are generic and loosely connected to academic project management literature, and not evidently established from the perspective of AEC projects and programmes, extensive field research in the AEC case firm has been executed. According to case study into evaluation documentation and lessons learned reports (see Appendix II.), different patterns are found that are transformed into critical success factors. Some patterns were found to have strong links, which are then assumed to be important CSFs, some patterns had less strong links and are assumed to be less important CSFs. Moreover, during the investigation into CSFs, interview turned out that the opposite of CSFs, root-causes for project failure, were investigated in certain R&D programmes within the AEC case firm. These root-causes have similarities with the CSFs, identified through the qualitative case study. Besides, through interview it turned out that the AEC case firm also identified CSFs itself. These factors are relatable to project management literature on the triple constraint of project management and to CSFs identified in other academic literature. The results of both the case study and the interviews are represented in Table 11.

Critical root-causes appear to be the capabilities of the project manager, contract issues, focus of the project (optimistic budget calculation/ strategic benefits), communication, risk management, client expectation, and scope management. Categories of CSFs can be identified that have relative impact on the success of project success. Comparing This means that the factors are of high importance in AEC projects. CSFs are not only identifying success factors, but as can be seen from the definition in 4.1.1, they just identify focus area that under specific conditions lead to success. Root-causes are found to be present in the same areas as success factors. Therefore, combining the three sources of factors provides a multi-faced evaluation of the CSFs.

The results from the case study often indicate the importance of contracting, contracting for project delivery, contracting for procurement, and contracting with different client types, contract with clear duties and obligations, and one of the root-causes in projects are contract management issues. Contracting in the AEC industry is important as it comprises many different agreements between all stakeholders involved. Contracting is the legal form of documenting that states and explains a formal agreement between people or bodies. And in the firms in the AEC industry are often named "*contractors*", which are companies that arranges to supply materials or workers for building or moving goods (Rawlinson, 2017; Merriam-Webster, 2020). Scoring criteria identified through the AEC case firm, also state the importance of the triple constraint of project management and indicate geographical and social factors. Contracting includes planning and budgeting and thus stakeholders. So, it can be assumed that contracting is key to satisfy all parties and bodies in AEC projects.

Table 11: Integrated critical success factors from the AEC case firm (Source: Authors own analysis)

Critical success factors based on case study 1	
CSF	**Relationship type**
1. Contracting for project delivery	Strongest
2. Contracting for procurement	Strongest
3. Procurement processes and procedures	Very strong
4. Contracting with client type	Strong
5. Stakeholder involvement in planning	Strong
6. Client involvement in project delivery	Severe
7. Contracting for duties and obligations	Severe
8. Client involvement in procurement	Severe
9. Stakeholder involvement with client type	Severe
10. Policies on design principles	Moderate
11. Planning involvement end user	Moderate
12. Procurement included in planning	Moderate
13. Tender processes and procedures	Moderate
14. Costs incorporated in budget Planning	Mild
15. Planning including communication	Mild
16. Relationship with client	Mild
17. Relationships and contracting	Mild
18. Planning project delivery	Mild
19. Subject matter experts and leadership skills	Mild
20. Responsibilities included in planning	Mild
21. Stakeholder involvement in planning phase	Mild
22. Tender including procurement	Mild
Critical success factors based on interview #4	
Root-causes of project failure	
1. Project manager not classified	
2. Contract issues	
3. Strategic project: calculated too optimistically	
4. Project manager not calculated	
5. Handover processes went wrong TM -> PM and PM -> PM	
6. Kick-offs are missing, incomplete or no commitment	
7. Risks not or not fully mapped out and not managed + shared with the customer	
8. Customer expectations insufficiently managed	
9. Scope creep	

10.	Lack of escalation
11.	Issues insufficiently shared internally and externally
12.	Project manager not classified
13.	Contract issues
14.	Strategic project: calculated too optimistically
Critical success factors project identified by case AEC firm	
Scoring criteria and related question	
1.	Project Cost: Did the project/activities cost more or less than anticipated?
2.	Project Duration: Was the project/activity delivered to schedule?
3.	Project Scope: Did the project deliver what it was expected to?
4.	Project team: Were there any impact or requirements on the project team?
5.	Location: Did the project have any impact on the local environment?
6.	Health & Safety: Was the project delivered without any problems?
7.	Company Reputation: Was the company's reputation enhanced/degraded by the project?
8.	Client Reputation: Was the client's reputation enhanced/degraded by the project?
9.	Relationships: Was there any impact on staff morale/turn over?

To further specify the underlying factors that are specific to the AEC industry and represent the relationship between these factors and the importance of these factors, Appendix II. shows the most relevant factors based on case study. Interpreting these results and reflecting these insights from the perspective of the triple constraints, most factors are interrelated to the scope constraint. The scope constraint is thus important and is characterising the projects the most. Different project characteristics that are important in the AEC industry are found to be the nature of the projects which can be new construction or renovation. But also, the type of building, regarding residential or non-residential buildings. Besides the client type (private, public), the bidding or tender process (open, selective, negotiation) the procurement methods (design-build, general contracting, design-bid-build, develop and construct, management contracting or others), and the contracting type (lump sum, unit price, gross maximum price, hourly rate price etc.) are important (Li, Chen, Chew, Teo, & Ding, 2011).

The AEC case firm has also identified selection criteria that it uses for project and client selection. These selection criteria also reveal directions for CSFs that are important for the AEC industry. Here again, two of the triple constraints of project management are indicated (cost and scope) and contracting and team characteristics are mentioned again (see Table 12).

Table 12: AEC case firm's selection criteria combined with critical factor perspective (Source: Author's own analysis)

Selection criteria	Relatable critical factor
Only work for those markets where opportunities for a sustainable and profitable business are present	Cost
Only bid for opportunities a profit can be realised and payments are ensured	Cost and contracting
Only provide services when delivery can be ensured	Scope and capabilities
Always seek to command a premium on market price based on our differentiation and the value delivery	Cost and leadership
Only put to work selected, trained, and certified Project Managers that can be responsible for projects	Knowledge and skills
Every project starts with a handover between the Pursuit Leader and the Project Manager	Scope
Project must have a plan for optimal profit that takes into risk and opportunity	Cost and scope
Only work with a signed agreement and actively manage contracts and risks, this includes scope changes	Contract and scope
Ensure that the Line Manager, Project Manager and Finance execute robust monthly project reviews	Knowledge and skills
Ensure that every project will have a disciplined close out to capture lessons learnt and client feedback	Knowledge and skills

4.3 Conclusion

To answer sub question 2: "*What financial and non-financial project factors determine the success of a project portfolio*?", the success of the entire project portfolio is dependent on several factors. The individual project performance is the most important factor (>50%). Besides, the strategic fit, the balance and optimization of the projects in the portfolio, the synergies and interdependencies of the projects, stakeholder management and the integration mechanism are important for successful portfolios. On the individual project level CSFs and selection criteria are investigated. In the AEC industry the inclusion of time, cost and scope are the most important factors. Moreover, contracting in the AEC is considered as key to success as this covers all aspects of project management. Besides, the project team knowledge, skills and abilities, health and safety, the project environment, client satisfaction and communication are important into monitoring, reporting, and controlling internally and externally.

Linking the CSFs to the PPM framework, the most important is to start capturing project performance data and categorize this data according to the triple constraint of project management. The time constraint can in this case be measured through gathering data from schedules, resource usage, and work performance data. The cost constraint should be measured through budgeting data and calculating ROI, IRR, NP and should strive to implement and gather data via the EVM methodology. The scope constraint must measure and categorize mainly project types, service types offered, stakeholders and location characteristics. The measures from the triple constraint of project management can also be used in the stochastic forecasting phase. Besides, the CSF on team composition with the right knowledge, skills, and abilities is covered through the pre-screening phase. Here it is determined on overarching risk factors what persons should be involved in the portfolio decision-making. Health & safety issues are covered through the screening phase in the selection and evaluation process. Here social and sustainability criteria can be set up to align with health and safety standards. The integration mechanism is covered in the optimal portfolio selection phase and is dependent on the optimization objectives of the company.

5 DATA & ANALYTICS FOR PPM

The previous chapter identified critical success factors, and data that is crucial as input for the digitized PPM framework. This data is of high value and needs to be collected, organized, stored, and analysed to gain insights from it and drive decision-making. This chapter introduces Data & Analytics in general and indicates how it can add value in PPM. Therefore, first Data & Analytics is explained and the connection to the value of big data is elaborated. Second, the presence of big data in the AEC industry is considered and data management and data analytics is discussed. Third, analytics methods are identified and categorized, and methods and techniques are connected to PPM practices, specifically to the PPM core process phases. Finally, the application of data analytics is connected to the project performance measures and metrics and methods and techniques that are expected to gain insights on the factors of the triple constraint of project management are identified.

5.1 Why Data & Analytics

Data is defined as facts or information and statistics collected together for reference and analysis, especially when examined and used to find out things or to make decisions (Oxford Dictionary, 2020; McAfee & Brynjolfsson, 2012). And big data are extremely large data sets that may be analysed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions (Oxford Dictionary, 2020; McAfee & Brynjolfsson, 2012). Data thus plays a crucial role in businesses and is recognized as a vital enterprise asset.

Data is at the bottom-line of the knowledge pyramid (see Figure 31). This knowledge pyramid describes the creation of insights, knowledge, and wisdom from a data perspective. Data are facts about the world, often letters, numbers, or other symbols. Signals that are physically structured are gathered as data. These signals come from many sources, and the amount of sources is increasing with the rise of industry 4.0 and Internet of Things (Jennex, 2017). Raw (primary) data, which are individual facts, figures, signals and measurements that is placed in context are known as information (Rowley, 2007; Jennex, 2017). Information is thus organised, structured, categorized, useful, condensed, or calculated data. If meaning is added to information, knowledge is created (Rowley, 2007). Knowledge is an idea, learning, notion, or concept, that is synthesized, compared thought-out or discussed. When knowledge is accompanied by insight, wisdom is created (Rowley, 2007). Wisdom is the understanding, integration, and application of accumulated data (Rowley, 2007). Information and knowledge thus hold the key to competitive advantage (McAfee & Brynjolfsson, 2012; Gandomi & Haider, 2014; Spalek, 2019; Jennex, 2017).

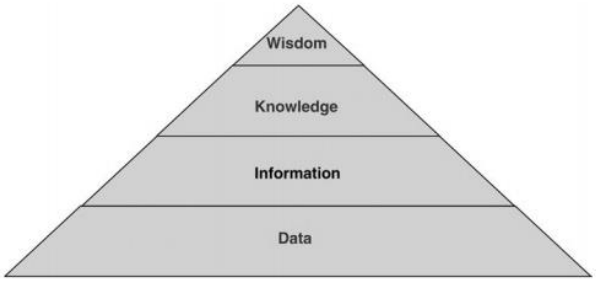

Figure 31: DKIW Pyramid (Source: (Rowley, 2007, p. 164))

Decision-making is tremendously improved by organisations that own reliable, high quality data about their services, their clients, their products, and their operations. Without a rigid approach to data management, it will not be possible to organise data and no insights can be gained from it. Big data offers the opportunity to measure and thus know radically more about business and thus improve decision-making and performance based on knowledge and insight (McAfee & Brynjolfsson, 2012). Big data is huge and complex, and it does not allow traditional systems, data warehousing and tools to process and work on it. Especially through the growth of technologies that capture data, data generated by machines, humans and also nature is increasingly growing (Spalek, 2019; Ishwarappa, 2015).

The AEC industry deals with significant data arising from many projects that include multiple disciplines. The Building Information Model (BIM), is a digital data model, based on various tools and technologies that connects information from representations of physical and functional characteristic of the built environment. It includes planning, design, construction, operation, and maintenance, and represent physical and functional characteristics of any project. Also cost and scheduling is integrated in standardized spatial design parameters in 3D (Bilal, et al., 2016). A BIM file can reach 50GB for a 3-story high building model and the files in this model have any form but are valuable for the performance of the industry (Bilal, et al., 2016).

Without rigid approaches to handle data, it would not be possible to gain insights from it. The mechanism or process to acquire data, clean the data and aggregate and present it is known as data management. And with the growing amount of (big) data and the growing demand to use this data, data management is gaining popularity (McAfee & Brynjolfsson, 2012; Ishwarappa, 2015; Gandomi & Haider, 2014). To analyse existing data, and use the data for creating insights and knowledge, the data should be processed in a certain way. Also, the potential of Data & Analytics should be clear. Machines and computers connected through the Cloud create large amounts of data associated with their daily tasks. Moreover, the IoT, interacting with humans, will add additional sets of information.

The application of data analytics has value for all types of projects or programmes and can thus be used as well for the portfolio level. Decisions are being made on all projects and must be informed by information. This includes projects that are large, medium, or small but also high-tech and low-tech projects, or projects that deliver services or are more creating products. But also the complexity and the sector of which the project is being executed are not determinative or excluding the use of Data & Analytics (Spalek, 2019). But the type of analytics used that delivers value varies substantially according to context. In the business world, data analysis and data visualization are important, organisations need robust data analysis to make better decisions and improve strategic execution. The key is to have the right processes in place to collect the right data and ensure that the data is of good quality (Spalek, 2019).

5.2 Project Data and Analytics

Now that the value of Data & Analytics is clear and that CSFs and selection criteria are discussed (see Chapter 4), translating these findings into measurable information is needed. The first step in this process is identification of performance measurement categories that are crucial in the AEC industry. The second step is to collect the project performance data from both internal sources and external sources. The final stap is to define critical performance indicators and transform them into calculatable KPIs (Cheung, Suen, & Cheung, 2004). According to the AEC case firm, an extensive amount of data is currently available (see Appendix IV.)
General information, financials, billing information and risk information is gathered through project performance management systems. But according to interview 7 (see Appendix VIII.) , this information is only used for single loop learning, and not for double loop learning (see 3.1.1).

Reflecting on the CSFs and selection criteria in the AEC industry and the data that is being gathered, more in depth analysis on project performance measures indicates that the focus on gathering data from measures related to the triple constraint of project management is not equally distributed. Most of the data points gathered are related to the cost constraint (56%), and large share is related to the scope constraint (39%). This implies that only a very small fraction of the gathered data points is related to the time constraint (5%) (see Figure 32). Especially gathering data on the time constraint and running analytics om time data has high potential in project performance improvement (Spalek, 2019). These analytics can help by creating what-if scenarios, help schedule development, run simulations and perform reserve and alternative analysis (Project management institute, 2017). The value of developing and using systems that include cost, schedule, and scope metrics to manage projects and large, programmes effectively is of high potential.

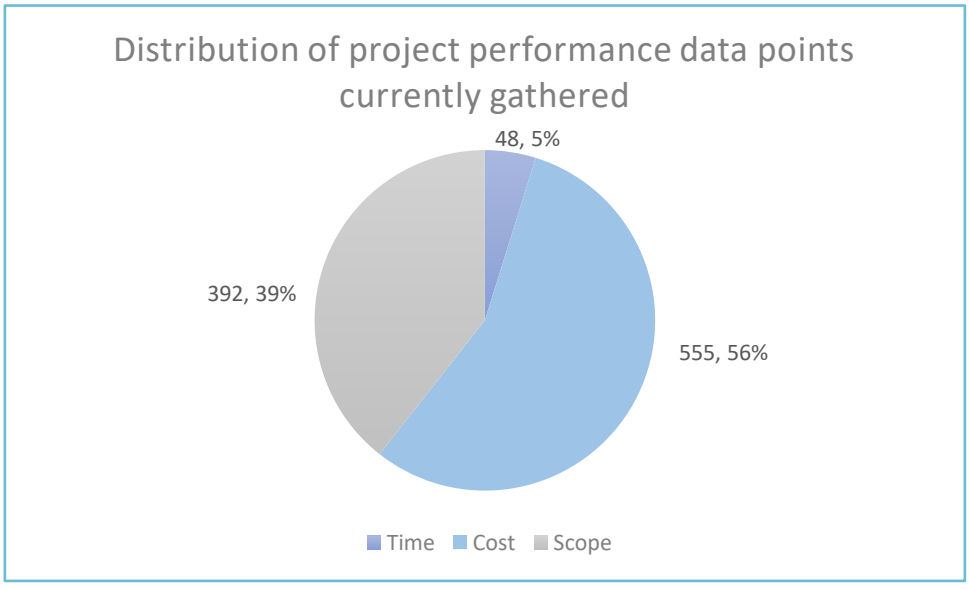

Figure 32: Distribution of project performance data points in the AEC case firm

Firms in other industries (e.g. defence and finance and banking) use integrated data management and analytics for long periods of time already and is mainly done in construction projects. Competitive advantage is established through electronic integration of the project performance management data with supply chain, budget, and contract data (Spalek, 2019).

The core principles that underly the integration of data sources, is the process of extracting, transforming, and loading data (ETL). This process is the basis for collecting data from several sources, transforming it into a suitable format for analysis that aligns with the capabilities of the organization and storing the data in the data base or warehouse that is used (Spalek, 2019), in this case for dashboarding and driving decision-making.

Quote from interviews:

"Cost management data is complete, there is no centralized controlled time data base"

- Business Director, Project & Programme Management, Middle Eastern, 16-06-2020

5.3 Data Management & Analytics

Two main processes underlying handling of (big) data to disclose its potential value and drive decision-making, are data management and Data & Analytics. Data management includes the process of acquisition and recording, the process of extraction, cleaning and annotation and the process of integration aggregation and representation (Gandomi & Haider, 2014). "*Data management is the development, execution and supervision of plans, policies, programmes and practices that deliver control, protect and enhance the value of data and information assets throughout their lifecycles*" (DAMA, 2017, p. 17).

Data management has several goals under which, guiding the information demand and requirements of organisations including all stakeholders that deal with this information (clients, employees, and partners). Data management often incorporates the data management life cycle workflow, including multiple phases, collection, processing, storing, analysing, visualising/ sharing, and deletion. But also protecting and ensuring the integrity of data assets is part of it. Besides elements of data management are about the quality of data and information. Moreover, ensuring the privacy and confidentiality of data, authorization on access, misuse, or the use and reuse of data. To conclude everything is about effective data handline to add value to the organisation (DAMA, 2017). To establish a foundation for Data & Analytics, data management practices, standards and procedures must be in place. Data engineering is the practice that focusses on data processing and storing and provides the infrastructure for handling data (Bilal, et al., 2016).

Data & Analytics includes the process of modelling and analysis and the process of interpretation where it is about the retrieving or extracting knowledge to drive decision-making (Bilal, et al., 2016). Data & Analytics can be text, number analytics, audio analytics, video analytics, and social media analytics. Depending on the application, data is based on historical records or new information is created that is used for real-time analytics. Moreover, the data is retrieved or created from internal or external sources (Bilal, et al., 2016; Spalek, 2019).

Data & Analytics initiatives stimulate businesses as they create competitive advantage. They help increase revenues, operational efficiency, marketing, customer satisfaction, respond time to emerging market trends and organisational safety (Spalek, 2019). Data & Analytics knows three general ideas to strive for, simplification, unification, and providence of self service. Challenges with Data & Analytics are having the right process, the right data and good quality of the data.

The main aim to apply Data & Analytics in PPM is to visualize related resources and show trends and insights on business data combined with external data. Also assessing with setting up analytical frameworks to test and optimize during trade-offs regarding resource allocation, sequencing, and portfolio value, is an important objective. In the end building recommendations for the desired future state of the project portfolio is the goal with support in decision-making. There are many deviations in companies' PPM frameworks which implies that current frameworks do not include all relevant factors.

In the rapid changing technology business environment, traditional, normative PPM processes are not applicable anymore (Gandomi & Haider, 2014; Spalek, 2019). (Big) Data & Analytics as we know it these days, does exist for a long time and has related fields with different names throughout the time. Statistics, data mining, predictive analytics, business analytics, knowledge discovery, Data & Analytics, data science and now thus big Data & Analytics (Bilal, et al., 2016). First, statistics is used to collect, analyse, and draw conclusions from data with using tools and techniques. Second, data mining is the process of automatically exploring and analysing larger volumes of data to discover patterns and rules and is based on statistics but also on pattern recognition techniques and machine learning, which are both types of learning procedures that find regularities in data (Bilal, et al., 2016; Spalek, 2019). Data mining is used in the AEC to identify key factors for project delay, improve project delivery, prevent injuries, modelling of judicial reasoning and predicting outcomes of litigation (Bilal, et al., 2016). And third, machine learning, a form of artificial intelligence (AI), enables computational systems to learn from data automatically based on classification, clustering, association, and numeric prediction. The underlying techniques are regression techniques, classification techniques, clustering techniques, natural language processing, and information retrieval (Bilal, et al., 2016).

Several analytical methods exist which are categorized according to complexity and maturity. Some basic analytical methods are statistical analysis, data mining and regression modelling. More advanced analytical methods are clustering, machine learning and deep learning. State of the art methods are for example quantum computing (Spalek, 2019; Bilal, et al., 2016).

Different levels in Data & Analytics are identified as descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics (see Table 13). Descriptive analytics focuses on the collection and organisation of data to reflect on the organisational interest of the data to specific situations. Decision-making based on descriptive analytics often use the measures to follow up with upsizing, downsizing or redistribution of certain activities and resource allocation. Change in the future measures is anticipated (Bilal, et al., 2016; Spalek, 2019). Diagnostic analytics are comparable to descriptive analytics, but differ in the fact that results are automatically being compared to a predefined standard, indicating positive or negative results and thus inform or instruct people to change the path of action but not assigning specific direction or guidance on the action. Predictive analytics uses measures or data to predict how a future scenario or status can. This is often based on predefined settings and interests or trends. Often internal and external information is used to create more accurate estimates. Predictive analytics is sometimes called Analytics 2.0 and when employed effectively, it creates competitive advantage for an organisation (Spalek, 2019). Future readiness is strengthened by early signals or trends and can identify challenges for the organisation early so the organisation can prepare for it.

Information is used to change the firm's perspective. This can return and stimulate the change of the organisation and the business practices (Spalek, 2019). At the highest level, prescriptive analytics, data can give insights and guide entire organisations on how to act or in the case of PPM how projects should be chosen and executed to create successful businesses. Multiple sources and layers of data are needed in a way that multiple scenarios can be compared and the outcomes can be optimized computationally (Spalek, 2019). In PPM, Data & Analytics practices should strive for developments towards predictive or prescriptive analytics – what will happen? And what should we do? - and should establish solid descriptive and diagnostic analytics to enable reaching competitive advantage from it.

Quote from interviews:

"What do you know today that you wished you knew a year ago, we use the past for present context, to use in the future."

- Business Analyst, Business Transformation, UK, 02-06-2020 –

Table 13: Overview of types of analytics (Source: adapted from (Spalek, 2019, p. 68))

Analysis type	Question answered	Purpose	Functions to be covered	Responsible
Descriptive analysis	What has happened?	Establish current state performance through historical analysis	Dashboard KPI Performance benchmarking Insights/ segmentation Fact based assessment	PMO Data analyst PPM responsible Business managers
Diagnostic analysis	What has happened compared to our set standard?	Establish current stat performance through historic analysis and compare	Dashboard KPI Performance benchmarking Insights/ segmentation Fact based assessment	PMO Data analyst PPM responsible Business managers
Predictive analysis	What will happen?	Predict outcomes, propensity, customer behaviour, preference, or entity	What-if scenario development and forecasting Predictive classification of risk	PMO Data analyst PPM responsible Customer feedback
Prescriptive analysis	What should be done?	Analytical method to show implications or impact of a series of decision options	Stimulate organisational financial/ ops impact across a series of strategic options Develop optimal path against a set of potential choices	PMO Data analyst PPM responsible Finance

5.4 Analytics methods and techniques for PPM

First, regression techniques, estimating relationships between a dependent and independent variable, are used in the AEC industry to estimate the cost of design, predicting cycle times, identifying delay factors, predicting partnering success of contracting parties, and exploring relationships between behaviour and safety (Bilal, et al., 2016). Second, classification techniques are used to emulate decision-making, based on previous made decisions and results.

These techniques include, logistic regression under which, Classification techniques under which naïve Bayes, decision-trees, and support vector machines and artificial neural networks, genetic algorithms, latent document analysis, document classification (document analysis, image-based classification, predicting overrun potential, safety analysis) (Bilal, et al., 2016). Third, clustering techniques find groups that have specific characteristics and is different from classification techniques in the sense that this technique is unsupervised and identifies categories itself based on characteristics. Clustering is used in the AEC industry to cluster or link deficiencies, and construction case retrieval to identify accidents (Bilal, et al., 2016). Fourth, natural language processing, connecting computational models with linguistic abilities (reading, writing, listening and speaking), is used in the AEC industry to develop ontologies from construction contracts, automated compliance checking, and tagging, separating, and sequencing of regulatory documents (Bilal, et al., 2016). Last information retrieval (IR), systems that organise collections of documents and that handle complex and unstructured data, are used in the AEC industry to reuse construction knowledge in projects, CAD exploration, technical document retrieval, and managing construction documents (Bilal, et al., 2016).

Table 14: The spectrum and types of analytics (Source: adapted from (Spalek, 2019, p. 120))

Basic analytics			Advanced analytics			State of the Art
Statistical analysis	**Data mining**	**Regression modelling**	**Clustering/**	**Machine learning**	**Deep learning**	**Quantum computing**
Analysing data sets to identify patterns, trends, and uncover relationships between variables	Data mining Sifting through large amounts of raw data to identify trends and patterns (can be automated)	Establishing a mathematical model to represent the relationship between multiple variables eventually seeking to enable predictive analytics	Data mining method for grouping large data sets, advanced computing algorithms	Using artificial intelligence to generate and apply sophisticated and adaptive algorithms to data sets, with limited or no human interaction	Variation of machine learning that allows for pattern recognition in unstructured data sets	Capable of exponentially faster and more complex data analysis than traditional computers. Powerful enabling technology for machine learning and artificial intelligence

As described earlier different analytics techniques and maturity levels exist. Basic analytic methods are statistical analysis, data mining and regression modelling. More advanced analytics are clustering, machine learning and deep learning. And state of the art methods is categorized as quantum computing (see Table 14). Within the AEC industry correlation, descriptive statistics, regression, time series modelling, hypothesis testing, machine learning, deep learning, predictive analytics, and prescriptive analytics is used throughout different businesses. Machine learning consists of several techniques, under which regression techniques, classification techniques, clustering techniques, natural language processing techniques and information retrieval techniques. Combinations of several techniques is possible as well. (Bilal, et al., 2016)

Comparative approaches (e.g. q-sort methods and pairwise comparison) are methods that define different weight of predefined criteria and results in alternatives for choices. The effect of each individual alternative is then assessed and matched to the objectives, after which benefits and disadvantages are identified (Bilal, et al., 2016). Guidance in selecting projects can be done through using comparative scales and analytical hierarchy processing. Advantages are found in the quantitative and qualitative character of these techniques; assessment criteria are being used. Disadvantages are the amount of comparisons that are being made, therefore this method is not suitable for large project portfolios (Bilal, et al., 2016).

Time analytics or time series analysis can be used on time data points. This comprises methods and techniques to make predictions on future values, based on observed data points. This some form of regression analysis and is often used in forecasting (Box, Jenkins, & Reinsel, 2011). Alternatives analysis is more used for resource allocation and benefit management and can help schedule development. Moreover, it can drive decision-making and can help optimization processes (Project management institute, 2017). Reserve analysis is often used as evaluation tool for reserve checking regarding, time, scheduling, risks, and can help preventing delays and cost problems. It focuses on the contingency reserve and unforeseen costs (Project management institute, 2017). What-if scenario analysis can be performed to sketch scenarios and evaluate them. This can help predicting the outcome of certain actions. The more data points are being used, the more detailed and varying scenarios can be created, with at the same time optimizing the level of detail of the scenarios and indicating positives and negatives. Especially when combined with decision-trees, this is a strong type of analytics. Simulation analysis techniques are focussing on resources and risk and uncertainty. This can also help with scheduling and drive decision-making practices (Project management institute, 2017).

Optimization models focus on selecting the maximum benefit in terms of maximum net present value. Therefore, mathematical programming is applied to enhance the optimization process and include interdependencies in projects. Moreover, technical and market interactions, constraints and programme considerations are included in the calculation. Extensive input data is required for the optimization model and the models often have lack of risk considerations (Ghasemzadeh & Archer, 1999; Morris & Pinto, 2007). Based on mathematical optimization approaches, selecting potential projects to create maximum overall benefit. This is Including criteria regarding resource dependencies, constraints, precedence dependencies, risk, timing, technical and market interactions, and programme considerations. The combination of decision support systems with an interactive display of results enhances the ability to adjust the portfolio based on nonquantifiable judgements. Disadvantage is the need of extensive amounts of detailed financial data (Ghasemzadeh & Archer, 1999; Morris & Pinto, 2007).

Projects in the organisational portfolio are quantifiable (PMI, 2017). Decision methods for project portfolio management, thus selection, evaluation, and prioritizing projects in the project portfolio, is divided in two generic categories. Qualitative, quantitative or combinations of both methods is being applied (Ghasemzadeh & Archer, 1999). Qualitative methods are more related to strategic goals and indicate directly what is to be achieved. Qualitative methods are less quantifiable than quantitative methods. The use of specific project characteristics for portfolio selection is context dependent. The chosen methods, techniques require different measures. But to compare projects for the portfolio in an equitable way, in the portfolio selection process equivalent selection criteria must be used to enhance transparency and equipollent rating. Difficulties arise when trying to reach consensus on the to be used methodologies, metrics, and measures. Within the AEC industry, quantitative values including cost and time measures are available but qualitative measures are needed and are more potential in this industry to use in advanced and complex projects. Models exist that focus on economic return, market research, portfolio matrices, comparative approaches, scoring models, or portfolio support systems (Ghasemzadeh & Archer, 1999).

Project portfolio matrices are used to evaluate an organisation's strategic positioning. Therefore, the strategic orientation of organisations must be predetermined thoroughly before individual project is addressed to enter a project portfolio (Ghasemzadeh & Archer, 1999). With evidence-based decision-making, especially regarding choosing a model for project portfolio management practices, the need of large amounts of data is an obstacle. Sound theoretical bases in modelling is needed and the generation of suitable data as input for the model is required. To prevent overload, balance must be achieved simplifying the PPM framework and the need to generate strong computational outcomes with theoretical foundation (Ghasemzadeh & Archer, 1999).

Quantitative modelling methods for project selection and portfolio processes are commonly used and mathematical and financial optimization are denominators of all methods (Kester, Hultink, & Lauche, 2009). These methods have in common that they assess and represent selection decisions as evidence-based approach. These methods are theoretically well-defined, but have practical shortcomings, namely the presence of speculative data, the fact that real option analysis is academically relevant but not practically relevant due to its complexity, the fact that organisations that only focus on financial aspect perform worse in practices, the belief of bounded rationality is in reality not true (Kester, Hultink, & Lauche, 2009).

5.5 Data visualisation and dashboarding

Data Visualization capabilities and services can offer great benefits to business practices, from better overview to possible new business opportunities. Data visualisation and dashboarding is part of monitoring and is another term of reporting (in a digitized and dynamic way). Data Visualization does not only involve the creation of a dashboard, but includes previous steps aimed at preparing the data. Because of this, it is important to establish effective governance and standards to maintain good levels of data quality and security. Moreover, establishing a baseline helps building a powerful yet easily scalable solution for a variety of data sets. Data visualization is the process of interpreting concepts, ideas, and facts through graphical representation, to understand the underlying data insights. First, better customisation: people can see the level of detail that they need to successfully achieve their goals (executive needs, EPMO needs, PMO needs, project manager's needs). Second, more extensive information: it is easier to manipulate the data to reach the insight needed. Third, easy communication and trigger for the organizational dialogue with up to date information that often originates from dynamic sources and real-time data sharing sources. Fourth, the access of dashboard enables everybody within the company to understand the value of large and complex amounts of data. This is important for successful digitization of PPM practices as well. (Spalek, 2019)

In the AEC industry the large enterprise projects are significant element of the overall organisational operations. Therefore, operational executives, must be apprised by the performance of the portfolio. Project with high strategic value must therefore be assessed and monitored on status. Status indication can be done through connecting identifying colours like green, orange, red. Often dashboards are being used that contain information about the portfolio and project performance. Important content of an advanced portfolio dashboard is shown in Table 15. Dashboards should contain different screens, and representation modes that combine graphical views, list views and scorecard views.

Table 15: Proposed PPM dashboard elements (Source: Author's own analysis)

Portfolio performance dashboard elements
Project status (green, yellow, red)
Financial KPIs (EVM, ROI, IRR, NPV)
Business objectives (milestones achieved)
Timescale (overall initiative, and project)
Key stakeholders (name, stake, contact)
Project cost (money or level of effort)
Issues and risk identification
Critical success factors
Critical interdependencies (status)
Scope change statement (quantitative and qualitative)
Accomplishments
Resource dependency attributes (personnel, manpower, machinery and equipment, material)
Learning dependency attributes (country, project type, client, technology, contract type, deliverable system, partnering companies)

5.6 Conclusion

In this chapter the third sub question is investigated, *"How can Data & Analytics be applied for decision-making in PPM practices in the AEC project environment?".* The value of data in project management and portfolio management in the AEC industry is emphasized, It is clear that data management maturity is at the foundation of creating value out of data and the AEC industry deals with significant data arising from many projects. The value of the project data is increasing throughout the organizational hierarchy and is most valuable at portfolio level. Analysing this data gives insights to the organization, and the entire range of descriptive, diagnostic, predictive and prescriptive analytics is applicable in PPM. Throughout the core process many different analytics techniques can be used. In the stochastic forecasting phase, time series analysis using project characteristics like cost and duration and macro-economic variables can help predicting the right times for investments in different business lines of the company and can help predicting upcoming projects, after which the company can respond to resource allocation internally. In the pre-screening phase, classification techniques can do an initial selection to evaluate the importance and complexity of the decision-making issue. Thereafter, different management levels can be appointed to make portfolio decisions. In the individual project analysis, q-sort, pairwise comparison, decision trees and matrixes and bubble charts can be used. In the screening phase multicriteria decision-making can be used as well as classification and regression techniques. Optimization can be done through linear programming, q-sort, and multivariate regression. And final adjustments can be made with the support of sensitivity analysis, matrix-type displays etc. Machine learning techniques from the analytics field including time series analysis, classification, and clustering techniques, have high potential. With connecting these potentially high valued techniques to the specific phases of the PPM core process, the way of using Data & Analytics is practiced and contextualized. Most value can be derived through starting with improved descriptive analytics through visualization and dashboarding. This opens the organizational dialogue in the decision-making process. Important elements of PPM dashboards are identified.

6 INFLUENCING FACTORS ON DIGITIZED PPM

The conceptual framework presented in Chapter 0, that is driven through the success factors and data as described in Chapter 4 with the support of Data & Analytics practices as described in Chapter 5 is theoretical. This chapter elaborates on different factors that prevent the implementation of digitized PPM and identifies barriers to Data & Analytics practices in the AEC industry. First, the concept of digitalization and the technologies behind digitalization is explained. Secondly, trends and opportunities through digitalization are described. Third, general barriers to implement PPM in organisations are discovered. Fourth the project management maturity of the AEC industry is discussed. Fifth the data management maturity of the AEC industry is discussed. And finally, barriers obstructing Data & Analytics are described including the concept of standardization and automation.

6.1 Digitalization in the AEC industry

There is a difference between "*Digitization*" and "*digitalization*". These concepts are often used to the process of changing data in a digital form that can be easily read and processed by a computer in which the information is organised into bits. Digitization is the specific computerized process of converting analogous information into digital data and digitalization process how social life is changing and being reshaped to align with digital information, communications and infrastructures (Kreiss, 2016). This restructuring of domains of social life is known as the fourth industrial revolution or industry 4.0. Other industrial revolutions were about mechanization (1st), electrification (2nd) and computerization (3th) (Schwab, 2016). Data is created in tremendous amounts nowadays. It is expected that this and this increasing trend will continue and even rise increasingly using digital technologies and the speed of innovations that are built on data. An example that contributes to this dramatic rise and production of data on massive scale is the internet of things (IoT), due to the many signals collected and communicated to monitor, control, and to adapt to the human social needs. The number of sources of data is soaring as the fourth industrial revolution (Industry 4.0) is now underway (Spalek, 2019).

The speed of development and technological breakthroughs has not earlier been met in precedents and is exponential. Disruption is taking place globally and the impact of the transformation changes entire systems of production, management, and governance (Schwab, 2016). Also, within the AEC industry digitalization is taking place, and the industry is ready for disruption (Agarwal, 2016). But the AEC sector is one of the slower adopters of new technological innovations and processes. This is seen in project planning practices, contract management, innovation performance management, and supply chain practices (Agarwal, 2016). The reason for this is that the AEC industry is not extensively investing in digital technologies. Moreover, R&D spending are compared to other industries relatively low and spending on information technology (IT) is lacking behind as well.

Besides, technical challenges that are specific to the AEC industry play an important role in the pace of digitalization. First, the industry operates in many different sectors and thus has a high variety of work and activities (e.g. airport engineering versus oil pipes). Second, geographical dispersion due to globalization, challenges companies to operate in many different locations with all its consequences (e.g. cultures, politics, economies, societal factors). Third, the interaction and interdependencies with other organisations and construction firms or subcontractors. (Agarwal, 2016)

Other challenges are due to the complexity and size of projects, there is a growing demand for sustainable solutions that are environmentally accepted, and a lack of highly educated people in the technology field with leadership skills is present. The AEC industry traditionally has a mindset that focusses on incremental improvements instead of radical steps. This conservative mindset has its roots in the idea that every AEC project is one of a kind and is thus not scalable, there is a strong resistance towards adapting to new technologies in the industry. (Agarwal, 2016)

Quote from interviews:

"Engineers have a conservative attitude and want to innovate on the products or services, they normally don't take the time to reflect and improve on processes. As our people might be less voluntary to provide insights themselves, we could use Data & Analytics to retrieve insights via IT. The social abstinence to keep track on project performance reviews is than captured through automation and Data & Analytics."

- Programme manager, Managing board AEC firm, The Netherlands, 21-04-2020 -

Internal and external challenges related to digitization in the AEC industry are thus linked to project portfolio management in broad sense. Internally, challenges are shortfalls in accountability, talent management, reinventing the wheel, failure to adopt to new technologies and problems utilizing resources. External challenges are, fragmented value chains, extensive subcontracting, complex portfolios, competitive pressure and coping with complexity. (Agarwal, 2016)

To overcome these challenges, some actions should be considered. First clear vision, mission and a well-thought-out roadmap must be established including predefined goals and milestones. Second, a solid educative trajectory for project and programme managers must be offered to change the mindset to a more progressive one, especially focussing on the long-standing industry workers. Third, a new IT infrastructure must be built to facilitate the new data flows, enhancing global accessibility, reducing fragmentation of data. Fourth, the urge of quick decision-making, less bureaucratic attitudes and improved risk mitigation must be understood and put into practice. Fifth, hierarchical organisational structures must switch to ecosystem like structures that are more organic and revise roles and responsibilities, so that delivery them have higher accountability. And lastly, an enterprise wide, project performance management system must be established allowing for standardization and automation with minimum changes once established. (Agarwal, 2016)

Quote from interviews:

"Oracle EBS is the old version of the ERP system and Orcale ERP cloud is the new version. These two together are now being used in 65% of the firm. These source systems are now being rolled out to all regions. Sales Cloud is now 100% rolled out. HCM and ERP will be rolled out in the EU in the coming year, then 85% will be online. Only China and Latin America not yet. Then the entire company is on one ERP system. Requests from the ELT can be retrieved immediately. Regions are then no longer necessary to request data."

- Global Director IT, Business Intelligence, Global, 28-07-2020 -

Besides these actions, five ideas for enhancing the digital disruption in the AEC industry are offered. The ideas are the introduction and improvement of higher definition surveying and geolocation, 5D building information, digital collaboration and mobility, the internet of things and advanced analytics, and future-proof design and construction (Agarwal, 2016).

The first idea of higher definition surveying and geolocation is needed to discover discrepancies between ground conditions and geological surprises in earlier stages, so that project scopes and design is adapted. Geological setbacks and information deficiencies are the major reasons for project delays and budget over runs (Agarwal, 2016). The second idea of using next generation 5D building information modelling (BIM). 5D BIM platforms offer the opportunity to identify, analyse and record the impact of changes in projects on scheduling and costs. 5D BIM improves ROI and decreases the project life cycle regarding time (Agarwal, 2016). The third idea of digital collaboration and mobility stimulates the industry to change from paper blueprints, design drawings, procurement, supply chain orders and progress reports etc. to online, real-time sharing of information. Therefore, online platforms that are cloud-based and mobile-enabled, must integrate activities and work from the industry (Agarwal, 2016). These activities incorporate design management, scheduling, materials management, crew tracking, quality control, contract management, performance management and documents management for example. The fourth idea of implementing the Internet of Things (IoT) and advanced analytics must enhance the production or creation of digitized information or data and must improve measurement and processing of this data (Agarwal, 2016). The fifth idea of future-proof design and construction aims at new building materials, processes, and techniques that enhance trends regarding green constructions, cost efficiency, supply-chain agility and improved durability and strength. To steer organisations in the AEC industry towards these digitized solutions, first a change in mindset must be attained. Therefore, transparency and risk sharing in contracts must be enhanced, the orientation in projects must be on return-on-investment, change management must be embraced and simplicity and intuitiveness in the design of new solutions must be the starting point (Agarwal, 2016). Also, project owner and developer must mandate and measure with a digital technology focus.

Opportunities of Data & Analytics in the AEC industry are biggest in resource optimization as data-driven decision-making enhances utilization as best course of actions could be described. There are several broad range, non-core services in the AEC industry that gain advantages of big data and Data & Analytics identified by Bilal et al. (2016), incorporating generative design, clash detection and resolution, performance prediction, visual analytics, social networking services and personalized services. But also, facility management and energy management profit from Data & Analytics (Bilal, et al., 2016).

From these fields that gain advantages, performance prediction and visual analytics have potential for PPM practices driven by Data & Analytics. Performance prediction models are management systems that facilitate decision-making, these models use a large number of variables and their great combinations, in which they influence each other as well as overall model performance, and are developed using simple statistical approach (like linear regression) to computational intelligence techniques. Visual analytics combine automated reasoning and visualization to solve complex analytical problems through perceiving, understanding, and reasoning.

Personal views and interactive exploration of data is made easier through visual analytics and enhances human knowledge, creativity, and intuition in decision-making. It also improves distribution and communication of relevant information among stakeholders. This is thus of high potential value for PPM practices, through establishing the "*boardroom of the future*" where interactive dashboard monitors the ongoing and incoming projects and their performance or promises and needs.

Quote from interviews:

"Simplicity tools and systems must be developed to enable board room of future, establishing an aggregated view with PPM data"

- Global Solution Director, Portfolio & Programme Management, Europe, 11-05-2020 -

Besides these benefits, emerging trends and opportunities arise when combining big data with other technologies. Big data and BIM revolutionize the construction industry through improving the project delivery process and provide actionable insight about aspects of deliverables. Moreover, combining big data with cloud computing, the internet computing paradigm which offers accessibility on demand so that shared resources are provided, offer advantages as well. Business models that are built on IT infrastructures, platforms, or software, provide access to computers, networks, operating systems, databases, applications etc. There are several combinations of big data and certain IT applications that are identified to have potential in the AEC industry. These combinations are big data and BIM, cloud computing, IoT, Smart Buildings, Augmented reality (Bilal, et al., 2016). But there are pitfalls identified that hinder the rollout of big data application. First, data security, privacy and protection are areas that need to be developed and often cost time. Second the data quality of AEC industry data sets is lacking behind, which causes incomplete, inaccurate, unreliable, or difficult to access data. Third the costs that have to do with management of big data in the AEC industry are relatively high. Last, the connectivity with the internet for certain applications that use big data is low in the AEC industry and needs first to be enhanced.

Thus, insight in data revealing interdependencies and interconnectivity between projects and data monitoring and reporting project characteristics that help businesses increase revenues, improve operational efficiency, optimize marketing campaigns and customer service efforts, respond more quickly to emerging market trends, feel safer as organisation, and create sustained competitive advantage (Bilal, et al., 2016; Agarwal, 2016). Integration of different sources of data including internal project performance data and external data that focus more on political, (macro-)economic, social, technological, environmental, and legal. And Data & Analytics helps to uncover these trends and insights. The data that is produced within an organisation is depended on the maturity level of project management practices and this is connected to the maturity level of information and knowledge management. According to an investigation by Agarwal (2016), the AEC industry is among the least digitalized industries (Agarwal et al., 2016). Many organisations are aware of the potential value of digitalization in their industry and understand the value of tools and technology but lack support of implementing and integrating technological innovations and do not know how to set-up the social construct around it. This counts as well for the PPM processes. As the transition towards a digitalized organisation should be non-invasive, change and development starts in lower hierarchical levels like project level.

6.2 Barriers to PPM application in organisations

Many organisations are engaged in multiple projects at the same time, which causes challenges on several aspects. These challenges have to do with planning, organizing, and controlling the projects. Especially projects with different scopes, timelines, and complexities, create resource conflicts and problems with throughput time (Caniëls & Bakens, 2001). Moreover, interdependencies, and balancing of scarce resources, causes information and project overload. Project overload is associated with over-commitment, i.e. too many projects in relation to the existing level of resources (Engwall & Jerbrant, 2003). This causes a negative impact on the project performance regarding time schedules and quality and moreover, it inhibits the decision-making process (Caniëls & Bakens, 2001). Managers of multiple projects must focus on more than the triple constraints of projects; they must manage interdependencies and interaction between projects. Therefore activities e.g. planning, scheduling, monitoring, control, and resource management of multiple projects are carried out simultaneously. Valuable information is needed for management of multiple projects simultaneously (Caniëls & Bakens, 2001). Focus areas in multi-project management practices are identified as resource allocation issues, managerial problems in terms of delay, stress and loss of overview, differences between the single project environment and the multi-project environment, planning and control (Caniëls & Bakens, 2001). The existence of a multi-project organisational setting can be strategical or can be unintended, but in both cases an integrated management control and reporting systems should be in place for the general management.

There are general barriers to implementing PPM in organisations. Important barriers are identified as: immaturity of project management processes, lack of broad organisational support, difficulty to agree on a common approach to prioritize projects, and lack of executive sponsorship (Hadjinicolaou & Dumrak, 2017). For the AEC, especially the unavailability of systems that provide timely data to measure success, inadequacy of projects to justify PPM, undefined organisational strategy, lack of information on resources, lack of broad organizational support due to fragmentation, and lack of organisational unit responsibility are important (Appendix VIII.).

To be more specific and looking at failures, when implementing IT project which is the core of this problem with PPM as well, factors are identified and connected to stakeholders that are involved with the implementation. On the executive management level, lack of top management support, wrong resource allocation (priority issue), lack of business case for the project are the main factors of failure. On the senior management level factors for failures are identified as weak project management skills, ineffective scheduling, planning and management, the lack of change control during the project, and communication problems among the stakeholders. On the operational level a lack or requisite knowledge and skills is the biggest issue and besides, weak commitment by teams is a factor as well. Externally the involvement of clients is identified as a barrier and subject matter experts are often overscheduled. Besides a lack of documentation with requirements and success criteria causes failures (Kappelman, 2011). Hadjinicolaou & Dumrak (2017) investigated benefits and barriers in PPM to business success among 8 different industries. It appeared that the benefits of implementing PPM in the AEC industry were highest on all assessed beneficial factors compared to other industries (Hadjinicolaou & Dumrak, 2017), but at the other hand, also the barriers of implementing PPM in the AEC industry were ranked lowest, which is thus indicating the potential of PPM (see Table 16).

Table 16: Ranked benefits and barriers of implementing PPM in AEC industry (Source: adapted from (Hadjinicolaou & Dumrak, 2017)

#	Benefit	Barriers
1	PPM have facilitated for repeatable success	Lack or organisational unit responsible for the managing process
2	Resources are allocated optimally	Lack of information on resources
3	PPM has maximised resource usage	Unavailability of systems that provide timely data to measure success
4	PPM has led to improved time to market	Impact on existing organisational processes and systems
5	PPM has led to increased cost savings	Lack of business case to show value of portfolio management
6	PPM has led to increase in profits	Organisation's business strategy no well-developed or communicated
7	Demonstrated value to key stakeholders	Lack of executive sponsorship
8	Ensure working on the right projects	Inadequacy or projects to justify PPM
9	Project redundancies have been eliminated	Internal politics and culture of resistance to change
10	Projects are better aligned to business strategies	Lack of broad organisational support
11	Gaps in the portfolio have identified and been managed	Immaturity of project management processes
12	Poor projects are killed	Higher priority organisational and change management issues to address
13	Investments in the right areas	Difficulty to agree on a common approach to prioritize projects
14	Decision making has improved	Shifting business in priorities
15	PPM has reduced organisational risk	IT infrastructure not in place to support portfolio management

6.3 Project management & Data management maturity

Maturity is describing the quality of thinking and behaving, the state of being fully developed or the time in when money invested is ready to be paid (Khoshgoftar & Osman, 2008). Maturity models are often used in process improvement or technical improvements. Processes and technologies are always interrelated with other knowledge and skills domains, and maturity models connect those domains in a framework, mostly related to capability maturity models. The maturity models create a foundation for the development of strategies, roadmaps, plans and actions. Besides, they can be used to benchmark capabilities on the industry level, but also internally within large, fragmented organisations. The main aim of using those maturity models is to apply a common language, be consistent, manageable, reliable, and predictive. Maturity models can also be used as diagnostic tools to identify current states of development. But after all, maturity models, are being used to bridge the gap between business and certain capabilities. Many different investigations, associations and institutions develop standardized maturity models. (Khoshgoftar & Osman, 2008; Cooke-Davies & Arzymanow, 2003; Pennypakcer & Grant, 2003)

Therefore, it is difficult to select the model that is best suitable. Due to the fact that this thesis is about project portfolio management, which is a sub-field of the academic project management field the project management maturity of the AEC industry is a focus point which will assess the status of project management maturity, and thus project portfolio management maturity. Moreover, since the focus here is on digitalization and data, and since data is at the core of setting up a digitized PPM framework, using Data & Analytics, Data management maturity is also a factor that needs to be assessed to evaluate on factors that influence the digitized PPM framework in the AEC industry.

6.3.1 Project management maturity in the AEC industry

Different project management maturity models exist, most are based on the model from the project management institute (PMI) and the PMI's guide to the project management body of knowledge (PMBOK). Besides, SEI capability maturity assessment applies a five-level approach. Frameworks are nowadays still based on those two models, and apply a 5 or 6 level scale, including phases ad hoc, abbreviated, organised, managed and optimized. More modern maturity models include, managing successful programmes (MSP) (see Appendix VIII.), PRINCE2, and OPM3 (Khoshgoftar & Osman, 2008). According to a research by Cooke-Davies & Arzymanow (2003), the AEC industry scores relatively high on the factors assessed in project management maturity models, and industries like the pharmaceutical industry, the oil and gas industry, the telecom industry and financial and banking industry are behind. The organisational culture, knowledge and skills, leadership and authority skills, pervasiveness, people, and information is up to date. (Cooke-Davies & Arzymanow, 2003)

When looking into the newer models, such as P3M3 (Portfolio, Programme & Project Management Maturity Model) and models focussing on software, such as CMMI (Capability Maturity Model), it is observed that the AEC industry is somewhere at the organised (level 3, out of 5) on the maturity scale (see Table 17). To evaluate this with regards to the framework in Chapter 3, the three pillar of People, Processes and Technology are discussed.

First the people level indicates that people in the AEC industry are on a managed or optimized level (4 or 5) regarding certification and knowledge and skills. Second, the process pillar is evaluated on a managed level (4), as project success is well defined, project metrics are used by management in decision making, and many standard operating procedures (SOPs) are defined that contribute to uniform defined processes. Lessons learnt reports are gathered but are not intensively consulted and feedback is not enough being used for continuous improvement. Project success and cost management is measured, and performance is improving, but the schedule performance is behind. Third, to evaluate the technology pillar, many different tools are used in project management practices. Templates and SOPs are in place, collaborative tools are present, and servers to share information are set-up. Also, enterprise project management tool are roles out in the organisation from the case study. But PPM tool and technologies are not yet in use. This sets the technology pillar on a managed level (level 4). Combining the three pillars in the maturity evaluation thus sets the organisation from the case study on a level 4 on general (see Appendix IX.). This implies that there is room for improvement, and this improvement is specifically pointing into the direction of using data on a larger scale to making business improvements. Moreover, also the use of enterprise wide PPM tools is suggested.

Table 17: Project management maturity matrix (Source: Author's own analysis)

	Level 1: Ad hoc	Level 2: Abbreviated	Level 3: Organised	Level 4: Managed	Level 5: Optimized
People	No PM background	Somewhat PM background	PMP certification	PMP, PgMP, MSP certification	PMP, PgMP, MSP certification
Processes	Processes are disorganised, chaotic, and ad hoc. Project success on individual heroic effort Cost schedule and scope problems	Some PM processes for individual projects Project success largely unpredictable (success due to management) Cost and schedule problems	Standardized processes across projects Project success predictable Coordination and integration among groups Improved cost and schedule performance	Project success is more uniform Established project metrics are used by management in making decisions Well-defined processes	Feedback from PM process enables continuous improvement Project success is norm and cost, and schedule performance is improving Data is used to evaluate & select process improvements
Technology	Excel, word, email, phone, conversation	Individual project tools	Templates, collaboration tools, MS project server, Sharepoint server	EPM and PPM tools	EPM and PPM tools

6.3.2 Data & Analytics maturity in the AEC industry

Incorrect data or data with bad quality causes bad decisions. Therefore, the proper amount of data, the processing of data and the analysis should be carried out in a good way. Data management maturity is comparable to the project management maturity in the previous section. But in contrary to the standard models and frameworks that exist in project management, Data & Analytics maturity is often evaluated through combined frameworks as the focus and attitude to Data & Analytics is less generalizable and needs to be tailored to the specific context in which the maturity is evaluated. An overview of different data maturity frameworks and models is displayed in Appendix IX. Differences are observed in the domain types of the models and can include knowledge, capabilities, processes, competencies, technology etc.

Aligning the maturity model with the focus on Data & Analytics in the AEC industry, specific domains including data, analytics processes, technology (IT), people, organisation and governance, value proposition and learning are important. Considering these domains, an overall data management maturity on a repeatable or defined level (level 2/3) is achieved. This implies that awareness of the value of data and quality is present, that consistent tools and technology usage is emergent, that roles and responsibilities to support process execution is in place, that centralized data management initiatives are raised and that documentation of artefacts, job description and standard processes are created. But data management capabilities are being scaled, and data quality must be increased through replication, procedures, and policies. Moreover, the establishment of organisation wide KPIs in the data management performance of the firm must be developed.

6.4 Barriers and resolutions in obstructed Data & Analytics

Syweryn Spalek (2019), identified eight barriers that are preventing analytics to gain insights from big data. First, difficulties in identifying starting points for data gathering and analysis are observed (Spalek, 2019). Therefore, the focus should be on analysing available, structured data and on the use of experience and best practices that were successful, so that senior level management can be involved and investments are done in Data & Analytics practices and technologies. Second there is the barrier that have to do with technologies. Mostly storing the data, computing, and running Data & Analytics software are problematic. Therefore, the organisations must be selective in the data they store, and only collect data that is valuable for business purposes. Moreover, alternatives of data gathering and collecting must be evaluated and the focus must be on scalable and continuous software and hardware usage (e.g. cloud). Third, challenges in linking the correct analytical techniques to the different data sets are present. The solution for this is selecting the right method that fits to the type of data and first within the project and data management maturity of the organisation. This maturity is also the fourth challenge, that has to do with the organisational maturity. When this maturity is lacking, gap analysis must be performed in certain areas (e.g. project or data management) and improvement must first be made before continuing the Data & Analytics transformation and practices. Fifth, lack of stakeholder buy in is often observed, which aims for good communication about benefits and risks and in dept anticipation to put emphasis on the opportunities of big data. This last point is indicating the sixth challenge, and this incorporates the understanding of the value of big data and analytics. Awareness must be created, and specific goals and objectives must be clearly identified that are aligned with organisational goals. Moreover, bottom-up input from subject matter experts and the use of data visualization tools must be stimulated to provide enthusiasm on a corporate level. The seventh challenge indicated, is about the responsibility and role definition around Data & Analytics practices. This is often not designated extensively, which causes unclarity and decreases efficiency and productivity in the transformation and innovation in the field of digitalization. Therefore, clear executives' role must be defined focusing on digitalization and data specifically. But also, on the lower level management and in operational management levels, teams must delineate roles among their project members. Lastly, data specific challenges are observed, including biases, sources, variables, and collection methods. This must be accepted and must not be conceived as barriers but must be limited in the impact it can make on the Data & Analytics practices. (Spalek, 2019)

Not least because digitalization is in general behind some other industries and because of the organisational mindset. But also cost reductions using AI may be over-emphasised. Costs will be made in terms of paying people with expertise to translate activities into code at both ends. Moreover, there is a significant skill gap in the workforce to overcome and make Data & Analytics a reality and competition will increase as technology is established (Lamb, 2018). Also, technical issues arise that need to be resolved to implement the emerging Data & Analytics practices that are based on artificial intelligence-based technologies. Data & Analytics experience the same pitfalls of interoperability as other technologies that need interconnectedness and seamless data sharing. And data structures are very much dependent on the quality of the data is contains. Overhauling existing infrastructures without guaranteed high quality data has a too speculative economic value. (Lamb, 2018)

Maturity of technology and its technological network externalities is an important barrier that obstructs implementation of information technologies within companies in the AEC industry. Two factors that influence the dependencies on network externalities are the installed base, the number of users of a particular good together with complementary goods, additional goods and services that enable or enhance the value of another good (Schillings, 2013). Here especially the use of a centralized enterprise wide IT system to support PPM practices is the issue. The more spread out the use of the system is, the more value can be gained from it as more data is shared and insight is created. Standardization and the level of automation, inter-institutional and international interoperability is crucial. In the IT field, this is reflected in the compatibility of software usage and human input to this software solutions. This signifies that not only technological maturity, but also the maturity of standards and practices are part of the obstructing barriers. Standards, policies, and legislation may also influence the adoption. The development and curation of standards, policies and best-practices is also driven from outside official standardization channels by industry, trade, and community organisations (Lamb, 2018). This problem is an industry wide problem, as most AEC firms struggle with the same needs, and issues (see Appendix VIII.). An holistic understanding of value delivering ecosystems, life cycle management of products and services and data management, security and privacy issues is needed. Moreover, the industry is pending technology hardening, changing business models, operating procedures/ processes (including standardization), changing societal constructs, and regulatory and governance mechanisms. (Schillings, 2013)

6.5 Conclusion

This chapter identified factors in the AEC industry that influence the application of Data & Analytics to assess the potential of the framework, therewith the fourth sub question*: "What factors influence the application of Data & Analytics in PPM in the AEC industry?"*, has been answered. The most influential factors are the status of digitization in the AEC industry, project management maturity and data management maturity of the AEC industry. Besides, organizational, technological, and behavioural factors influence the application of digitized PPM using Data & Analytics. These factors include the lack or organisational unit responsible for the managing process, lack of information on resources, and unavailability of systems that provide timely data to measure success. Table 18 summarizes and categorizes the most important factors on digitizing PPM in the AEC industry. The most tangible barriers that are found in Data & Analytics practices and working with big data are refuted with resolutions that are formulated as managerial implications.

Table 18: Influencing factors on digitizing PPM in the AEC industry (Source: Authors own analysis)

Area of interest	Specific factor
Digitalization in the AEC	- Increase computerization - Increase data production through IoT - Slow adoption new technological innovations and processes - Lack of investment - Work and activity vary across sectors - Geographical dispersion due to globalization - Increase interaction and interdependencies with other Organisations and subcontractors
General barriers to PPM	- Complexity and size of projects - Lack or organisational unit responsible for the managing process - Lack of information on resources - Unavailability of systems that provide timely data to measure success - Impact on existing organisational processes and systems - Lack of business case to show value of portfolio management
Project management maturity	- Certification of people (knowledge and skills) - Standardization of processes - The use of predictive performance measures (EVM) - The use of data - The use of (collaboration) tools
Data & Analytics maturity	- Awareness of the value of data - Centralization of IT systems - Standardization of processes - The use of performance measures and metrics - Roles and responsibilities & collaboration - Self-service level - Quality of the data
Data & Analytics barriers	- Difficulty identifying an appropriate starting point - Technological barriers (storage, computing, data analytics software) - Challenges in pairing data with an appropriate analytical method - Organizational immaturity - Lack of stakeholder buy-in - Management inability to understand the value of data analysis - Lack of responsibility and clearly defined roles - Data-specific challenge, including biases in data and data collection methods

7 DISCUSSION AND CONCLUSION

The research in digitizing project portfolio management (PPM) in the Architecture, Engineering & Construction (AEC) industry through the application of Data & Analytics, has contributed to filling knowledge gaps in literature about the lack of context and practice in PPM frameworks. A conceptual framework has been developed, for monitoring, reporting, and controlling PPM practices in the AEC industry. The framework consists of the three pillars, people, processes, and technology. Adherent to the framework, CSFs are identified on both the portfolio level and the individual project level. Prerequisites regarding data management practices and specific analytics methods and techniques are connected to process phases in the framework. Practical implications that influence the implementation of the framework are identified and resolutions are discussed.

7.1 The PPM framework

The main research question: *"How does a PPM framework for monitoring, reporting and control look like to improve project portfolio decision-making practices in the AEC industry, using Data & Analytics?"* has been answered through the conceptual framework, the determinants for success, the application of Data & Analytics and the factors that influence the application of Data & Analytics in PPM. Formalizing the entire process and setting up a governance structure that supports Data & Analytics and proposing a technology set-up enables digitized PPM. Through integrating the success factors and identifying and offering resolutions to the barriers this research guides the transformation and initiation of digitized PPM.

The three pillars of the framework, people, processes, technology with the specific content thus form the foundation for PPM and are considered as crucial characteristics for a PPM framework. With that the first sub question: *"What are the characteristics that are crucial for a PPM framework?*", is answered. The first pillar, concerning people, incorporates a governance structures that enables organisations to facilitate data-driven PPM and stakeholders that play an important role in digitized PPM are identified and assigned with roles and responsibilities. The concept of a project management office (PMO) has a tremendously important role in those organisations. The PMO is a centralized office, responsible for data flows. Especially in large, fragmented organisations, such as in the AEC industry, a centre of excellence is needed. Therefore, the establishment of an enterprise project management office (EPMO) is needed. The EPMO is responsible for identifying, analysing, coordinating, negotiating, monitoring, and controlling portfolio components; supporting component proposals and evaluations; facilitating prioritization; authorization; termination of components; and facilitating the allocation of resources in alignment with organisational strategy and objectives. To absorb the fragmentation in the AEC industry, the PMO on divisional or regional level is required to support the EPMO. The second pillar is describing the formalized core processes of PPM decision-making, and through this process the data, measures and requirements that are needed to drive evidence-based decision-making are clear. Important phases in the core process are pre-screening, individual project analysis, screening, optimizing, and adjustment. Especially in the AEC industry, were projects are often won by tender procedures, the core process of PPM must be extended with a preceding stochastic forecasting phase. This stochastic forecasting phase is needed to enhance the adaptiveness of the entire selection, evaluation, and optimization process, combining internal and external

information. The pre-screening phase should be used as a first filter, using "*overarching risk*", to assign portfolio decisions to the right management layer (EPMO or PMO). In the individual project analysis phase, micro-economic analysis should be carried out, measures including ROI, IRR, NPV and EVM are considered. In the screening phase, financial and non-financial analysis must be performed. And in the optimization phase resource management and benefit management are used to constitute the optimal combination of different types of projects that fit within the organizational capacity. Lastly, portfolio adjustments can be made to align risk, size and running time of projects. The third pillar, involving technology focuses on information technology (IT) that is required to facilitate the people and processes with data and enabling monitoring, reporting and control. Important in the AEC industry is the combination of business data and analytics and project performance data and analytics. Currently financials, marketing, operations, supply chain and environmental data is used to monitor business success, but information from project planning, budgeting and scope is siloed. Data from schedules, resources, work performance must be gathered and combined with KPIs available from budgeting including ROI, IRR, NPV and EVM. Moreover, the data from the scope constraint must be analysed through clustering and classification techniques. The technology pillar describes how fragmented data in AEC organisations is brought together through integrating multiple internal and external sources of data that are mostly cloud-based and must be stored in a data warehouse. The set-up of this data warehouse of integrated systems, consist internally externally of public databases with macro-economic data and environmental data.

Adherent to the framework CSFs are identified on the portfolio and project level. Business success is mostly recognized as being economic successful and being future ready and is in PBOs driven by project portfolio success. A major factor in project portfolio success, accountable for more than 50% of the success, is the aggregated individual project success, which is determined by the triple constraint of time, cost, and scope. Most of the required data from the cost constraint is already available in the project performance management system. The scope constraint data is present, but not yet analysed, but Data & Analytics practices in the time constraint is less mature. Besides other factors that determine the success of AEC projects, are found to be contract management, procurement processes and procedures, tender management, stakeholder management (internal and external) and knowledge and skills in the project management field.

Good data management practices are a prerequisite, as the AEC industry deals with significant data arising from many projects. The value of the project data is increasing throughout the organizational hierarchy and is most valuable at portfolio level. Analysing this data gives insights to the organization, and the entire range of descriptive, diagnostic, predictive and prescriptive analytics is applicable in PPM. Throughout the core process many different analytics techniques can be used, under which statistical techniques, data mining, regression modelling, clustering, and machine learning. Machine learning techniques from the analytics field including time series analysis, classification, and clustering techniques, have high potential. With connecting these potentially high valued techniques to the specific phases of the PPM core process, the way of using Data & Analytics is practiced and contextualized. Most value can be derived through starting with improved descriptive analytics through visualization and dashboarding. This opens the organizational dialogue in the decision-making process. Important elements of PPM dashboards are identified.

However, when establishing a conceptual framework, there is a requirement to include factors that influence the application and implementation of digitized PPM through Data & Analytics. Organizational, technological, and behavioural factors are present. First, radical change through digitization is transforming socio-technical systems, and management practices in every industry. But the AEC industry is lacking behind in terms of digitization. This visible in project management practices, contract management practices, and innovation performance and supply chain practices. Time and resources are wasted whilst bespoke solutions to problems are being developed. Second, there is a lack of knowledge which may lead to poor decision-making and the industry is not fully realizing the full values of data assets. This status of digitalization is the biggest factor influencing digitized PPM through Data & Analytics. Third, data management maturity is part of this status of digitalization, and progress can be made to enhance this. Fourth, organisational culture, responsibility for processes and systems, defined strategies, executive and financial sponsorship and support and difficulties with change management influence the application of digitized PPM through Data & Analytics. Fifth, project management maturity is not yet optimized which also has to do with the lack of data usage.

7.2 Scientific implications

This research on PPM and Data & Analytics contributed to the academic literature through integrating two academic fields, which provides a broad perspective on the trajectory and implementation of innovative organizational change through a management framework that is not only focussing on people, but also on comprehensive processes and technology. The research is established through extensive literature review, including a large body of literature running from the fundamentals of PPM to state-of-the-art literature on PPM and Data & Analytics which was published a few months prior to the delivery date of this research. With this, the basic principles have been used as a starting point and modern findings and innovations have been integrated. The delivered framework is logical and has high potential value in theory, which is confirmed by experts from the industry. PPM facilitates for repeatable success, helps resource allocation, improves time to market, ensures investments in the right areas and leads to increased cost savings. Through developing this framework on three pillars, the gap in literature on practice has been amplified. Another gap in literature that has been addressed is the context in which current PPM framework are lacking empirical knowledge. This research contributed with adding empirical knowledge in two ways, first extensive literature review has indicated that digitalization through using digitized data and analytics has high potential value in the field of PPM. This does not only apply to the AEC industry but is applicable to many industries. Second, context for PPM has been studied empirically in a broader sense for the AEC industry. The core process has been extended and phases are now specified and worked out in detail that fit within the needs of the AEC industry. Through field research in the form of multiple case-studies within a project-based AEC firm, the status of both academic fields is evaluated. Through qualitative research in the form of document analysis, specific factors that are of high value to business success, through the project portfolio and individual projects are found. These insights do contribute to the academic literature in terms of specifying CSFs that can be translated into selection criteria and eventually KPIs. Most importantly, context knowledge has expanded to such an extent that the way in which data is handled in the AEC industry has been highlighted, making it clear which data is important in PPM.

7.3 Managerial implications

Though, it is evidently clear by a thorough analysis of factors influencing the practice and implementation of the digitized PPM framework, that there are a number of barriers that must first be overcome in order for this framework to be successful in the AEC industry. But since these barriers are identified, and accordingly resolutions are offered, specifically for the AEC industry, getting over these barriers through acting upon the recommendations is manageable and advised. Moreover, the digital transformation in the AEC industry on-going and building out the Data & Analytics capabilities is at the core and centre to ensure the generation of the most useful insights from the rich data that this industry and its clients owns. To do this, building out the Data & Analytics capabilities by training staff, developing new and exciting analytics use cases, sharing data across business units and regions to allow data exploration, and creating a culture of data sharing with a analytics community in its core. This also implies that people must integrate data management and data analytics practices in project management. Starting with assigning roles and responsibilities from a data perspective must be done, the introduction of data stewardship to drive innovation through data in projects is advised. Also, the set-up or the change of the EPMO, and making this the general expertise centre for handling project related data-streams is part of this. Besides the use of professional tools supporting PPM capabilities must be investigated on an enterprise wide level. To drive this, first a centralized data lake must be set up to enhance enterprise wide data sharing.

7.4 Limitations and future research

First, most findings are generalizable for the AEC industry but might not be generalizable for other industries. The framework is most generalizable for fragmented large international organizations. But the adherent CSFs and other factors might not be generalizable as relevance and the balance between different project performance measures might vary. Therefore, specific project factors for different industries should be investigated. Second, Triangulation during the research, including the use of several different sources and research methods, strengthens the validity of the research. However, a more extensive verification of the conceptual framework would be necessary before further building on this framework. Third, during the research, a lot of information was obtained for the different case studies, however this information provided superficial insight into the theories and practices in the AEC industry as this information was mostly qualitative. Research of a more quantitative nature mainly focused on the project performance data to be used in the PPM framework is missing and would improve the completeness of the framework. Fourth, the framework is theoretical and is not tested in practice, complexity of the analytics methods and techniques are not evaluated and might be complex when applied for large amounts of projects. Therefore, the framework and methods and techniques must be tested with real data. Moreover, macro-economic variables should be investigated for each industry to reveal trends and opportunities in the stochastic forecasting phase of the PPM process. Finally, barriers are identified and included technological barriers, but the research did not focus on overcoming these technological barriers. This should in future research be investigated extensively. Besides, other barriers that have to do with legal or political implications were out of scope in this research and must also be investigated. (see Appendix X.)

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Appendix I.

Projects

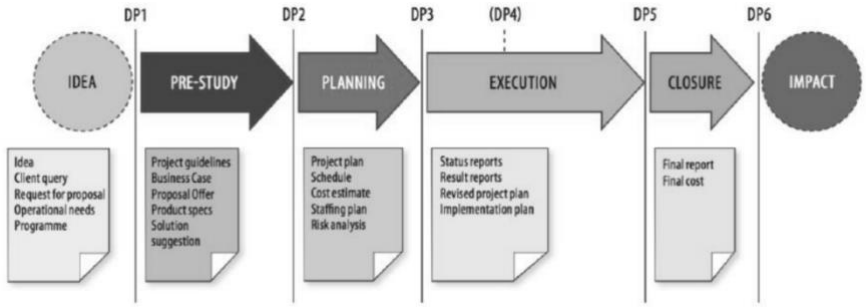
A project is a work form with a strong focus on results. Projects are part of a bigger context and are tools for delivering business goals and operational benefits (Tonnqvist, 2018). “A project is a temporary endeavour undertaken to create a unique product, service, or result” (Project Management Institute, 2018, p. 6). As part of an organisation, projects are temporarily restructuring the responsibilities and decision paths to optimize organisation to achieve objectives and produce deliverables. Objectives are outcomes towards work is directed, they are strategic positioned. Different perspectives exist on objectives, it can be a purpose to be achieved, a result to be obtained, a product to be produced or a service to be delivered. Deliverables are the results of completed processes, phases or projects and can be tangible or intangible. An important project characteristic is that they are unique. Unique in the sense of a product (enhancement), a service or capability (improvement), a result (insight, knowledge) or a combination of product, services, and results. Project have repetitive elements regarding the deliverables and activities or processes and involve individuals, groups, a business unit, or multiple organisational units from multiple companies. (Zandhuis & Stellingwerf, 2013)

Research shows that with the increasingly complex and changing environment, businesses with structured and practice-based processes and project management have better performance in several areas. They produce better deliverables as planning, definition and estimations are carried out better. The running time is shorter due to reuse of knowledge and practice. Uncertainty is decreased through proactive management processes. And they achieve higher customer satisfaction. (Zandhuis & Stellingwerf, 2013).

In the project environment, constraints have an impact on the decision-making processes in project management. Constraints are obstacles in a system that be limitations towards reaching a goal. A wide variety of constraints exist, they can be physical or immaterial. Within project management literature, the triple constraint of time, cost and scope are often bespoken. The constraint of time refers to the amount of time available to complete the project, the constraint of cost refers to the financial limitations and the scope constraint refers to all the work that must be carried out to produce the project’s result for meeting the requirements. Constraints are categorized in seven basic types, market, resources, material, supplier, financial, knowledge and policy constraints. (Zandhuis & Stellingwerf, 2013)**.**

Throughout the different project management stages, different activities are carried out. In the initiation phase, the project charter is developed. In the planning phase, the project (management) plan is developed, in the implementing phase the project work is executed, in the controlling phase the project work and changes are being controlled and in the closing phase the project is finalized and delivered and lessons learnt are being collected. The scope of projects, in other terms having defined objectives that are formulated in a concrete way, is progressively elaborated throughout the project life cycle. Change is expected throughout the project and processes are implemented to keep change manageable and controlled.

For portfolio management, the initiation phase of projects contains idea generation as antecedent that makes it possible for management to assess and prioritize the project idea alongside other project ideas, queries of customers and investments and the initiation of pre-study (Tonnqvist, 2018; Project Management Institute, 2018).



It describes, respectively the decision-making process to initiate a project. The idea generation phase is not part of the project itself. At the end of the project life cycle, after the closure phase, the impact phase ensures the desired benefits that are realized once the project is finished (Tonnqvist, 2018; Project Management Institute, 2018). The two additional phases (idea and impact) are important as they are creating context to the project and function as supportive phases (Tonnqvist, 2018; Project Management Institute, 2018). In the idea phase no project owner of project manager has been assigned. Decision criteria to start a project and pass the decision-point are based on the strategic value of projects imprimis. Other decision criteria are profitability, risk level, feasibility, adaptions to legal requirements, critical resource need. Positioning projects to strategic value and economic value can categorize projects in four categories, mandatory (low economic, low strategic), infrastructural (low economic, high strategic), rationalizing (high economic, low strategic), and value increasing (high economic, high strategic). Infrastructural projects are often needed for long-term survival.

When looking at the AEC industry specifically, within the project life cycle, construction projects contain fragmented and complex multi-tasks, architectural, procurement, engineering, construction phases. Projects in the AEC industry are complex and thus need rigorous coordination (Profeanu, 2019).

One part of project management is the knowledge management, it focusses on the handling of information an insight. Knowledge management is to obtain benefits in the direction of improved performance, advancement, sharing lessons learnt, integration and organisational continuous improvement. The knowledge management life cycle describes a process that organises documentation, resources, and individual learning. Phases in the knowledge life cycle are, creation, storing, sharing, using, checking, and updating. With regards to Data & Analytics this knowledge management life cycle is important as information or data us the key resource to drive Data & Analytics. Within the AEC industry, the knowledge lifecycle is used as well in terms of the data lifecycle. In the AEC industry the data lifecycle consists of planning phase, collection/ creation phase, processing phase, storing phase, analytics phase, sharing phase, and deletion phase. Besides, stakeholder management, guiding the project team and using the right processes in time are the main activities.

Programmes

A programme is a group of related projects, subsidiary programmes, and programme activities that are managed in a coordinated manner to obtain benefits not available from managing them individually (Project Management Institute, 2018). The projects in a programme have an overall goal. Programme components can be projects, programmes, or other activities. Programmes have a scope that go beyond the scopes of its programme components. And therefore, programs produce benefits for the organisation if the results and outcomes are organised and managed in a coordinated way. Through management of programmes, the company can adapt to organisational and environmental circumstances. High-level plans are thus needed that focus on finding interdependencies and progress information of the programme's components. (Project Management Institute, 2017; Tonnqvist, 2018). Programmes enhance capabilities, support change, develop and maintain assets and offer new products or services (Project Management Institute, 2018). On the component level, programmes are also used to guide planning (Project Management Institute, 2017). Equivalent to the project manager, programmes are being managed by the programme manager. The programme manager is ensuring that benefits are being delivered by coordinating all activities from the programme's components. Especially monitoring the progress of components that are subject to their interdependencies is an important task. Other tasks are ensuring the overall goals, budgets, benefits, and schedules. Benefits of programmes over separate projects is increased governance, better overview, decrease complexity by splitting up. In the AEC industry, programmes are often developed to spread extensive investments, to phase processes and efficiently create time planning and schedules, so that some projects run parallel and some are chronologically ordered (Project Management Institute, 2018; Tonnqvist, 2018). Within programme management, performance domains are distinguished as strategy alignment, benefit management, stakeholder engagement, governance, and life cycle management. These domains can potentially represent suitability in the organisational portfolio. The performance domains focus on the entire programme's dimensions. The overview from these performance domains defines the optimal approach for the individual programme components and is based on interdependencies. Interdependencies are found in output expectations regarding benefit and support in strategy, benefit monitoring, outcome and benefit communication, activity coordination, risk responses, governance structure development (Project Management Institute, 2017). Two main characteristics that differentiate project programmes from project portfolio are relatedness and time (Project Management Institute, 2017). Work in the portfolio is diverse and independent, while work in a programme is interdependent on all components. And programs are time-bound, or temporary, while a project is not constrained to specific time and can be continuous. Due to the complexity of programmes, internal and external influences can have significant impact on the success of a programme. Extensive analysis of enterprise environmental factors external to the programme are being carried out to evaluate select, design, and set up management of a programme. Various analysis forms are being used to assess potential and validity of programmes. Examples of analysis are comparative advantage analysis, feasibility studies, SWOT-analysis, assumption analysis, and historical information analysis (Project Management Institute, 2017). These results also indicate portfolio potential regarding project or programme selection and evaluation for the entire portfolio. During the initiation phase of programmes, a benefit register is developed and lists the planned benefits for the programme and is built on programme business cases, the strategic plan, and other relevant objectives. The benefit register contains a benefit roadmap, measures, KPIs, risk assessment, progress indicators, targets and milestones,

persons, groups and organisations, and a description of tracking and communication processes (Project Management Institute, 2017). Another register is the stakeholder register and should be established beforehand and should be maintained during the programme life cycle. Key programme stakeholders include the programme sponsor, steering committee, managers, team members, organisations, PMO, customers, suppliers, agencies, individuals, and other groups (Project Management Institute, 2017). The stakeholder registers from the initiation phase of the programme disclose insights, regarding the complexity of the stakeholder environment. When historical data is compared from several projects, the composition of stakeholder registers of tender programmes can be used as reference. The governance performance domain consists of two types of artifacts that additionally disclose valuable information for portfolio selection. The programme business case serves as a formal projection of the expected deliveries and the programme charter authorizes the use of organisational resources to the programme management team (Project Management Institute, 2017). Within programme management, the programme life cycle is equivalent to the project life cycle but consists of three phases instead of four. Phases are the definition phase, the delivery phase, and the closure phase.

Appendix II.

Case study 1:

Project evaluation and lessons learnt reports - “Identify project success factors and issues”

Documents coded:

Table 19: Overview of evaluation reports and lessons learnt reports used for coding (Source: Author’s own analysis)

Document number	Document label ATLAS.TI	Name of the document
1.	D13	Lessons learnt FK
2.	D14	PGM Aviation lessons learnt
3.	D18	4.Project Close out Template Nokia
4.	D19	12 lessons learnt for DF
5.	D20	170323 Lessons learnt for DF
6.	D27	Arcadis HMC Lessons learnt April 2017 Final
7.	D30	Project E
8.	D31	Project F
9.	D32	Project I
10.	D33	Project L
11.	D34	Project S
12.	D35	Project V
13.	D36	Project Z
14.	D37	General points
15.	D38	Lessons learnt Fitness for Purpose
16.	D39	Lessons learnt – reasonable skill and care September 2017

Open coding codes:

152 codes have been used, analysing the documents

Table 20: List of codes used for (open) coding (Source: Author’s own analysis)

List of open coding codes				
Accessibility	Controls	Health and safety	Performance	Schedule
Acquisition	Coordination	Historical	Planning	Scoping
Archival	Core-activities	ICT	Planning phase	Services
Asset Management	Corporate	Improvement	Policies and standards	Solicitors
Authority	Cost	Info management	Politics	Specification
Back-up	ross-sectional	Innovation	Portfolio	Stakeholder involvement
Baseline	Data	Insurance	Positioning	SOP
Benchmarking	DBE	Investment	Processes and	Strategy
Benefit management	Debriefing	Isolation	Procurement	Structural
BIM	Decision-making	lack	Profiling	Sub-contractor
Bond	Defective	Leadership skills	Progress	Subject matter experts
Budget planning	Delay	Lease agreements	Project	Success
Capabilities	Delivery	Lessons learnt	Project management plan	Successful
Centralized	Design principles	Liability	Project records	Successful project
Change management	Development	Liaison	Qualification	Supply chain
CIS	Disclosure	Line management	Quality	System integration
Claims and disputes	Drawing	Liquidation	Quantity surveyor	Team
Clear insights	Due diligence	Location	Reasons lost	Tender
Client	Duties and obligations	Market to opportunity	Recruitment	Terms and conditions

Close out	Early engagement	Middle Eastern	Red Amber Green system	Third party
Collaboration	Economic climate	Monitoring	Refurbishment	Tools
Commercial point of view	Efficiency	New builds	Relationship	Transparency
Commissioning	End-user	Operate and maintain	Reporting	Triangular
Communication	Experience	Organisation	Requirements	Triple constraint
Competition	Finance	Organisational learning	Resource management	Value engineering
Conflict	Flexibility	Organisational silo	Responsibilities	Vendor
Construction	Follow up actions	Outbid	Rewarding	Vertical management structure
Consultants	Gate-way	Outsourcing	Risk	WBS
Continuity	Governance	Overvaluing	ROI	Workarounds
Contract	GS1 coding	Payment	Scaling	Worked well
				Working climate

Code-documents table and relative frequencies (80/20-rule: 53 most occurring codes):

The code-document table (see Table 21) shows the relative frequency that codes occur in the set of documents. The higher the frequency, the more important the code is considered in general, based on the lessons learnt reports. High frequencies indicate that the code is relevant in successful project delivery, but it cannot be concluded what relationship the code towards successful project delivery has. This can either be positive or negative or can either have an inhibiting or reinforcing character. This can later be defined through logical thinking or through the Code Co-Occurrence table. In the AEC industry, contracting is clearly and important critical success factor. Besides, planning, information management, the client, procurement, stakeholder involvement and delivery is important.

Table 21: Relative code frequencies in documents (Source: Author's own analysis)

Code #	Code description	Relative frequency in documents
1.	Contract	7,46%
2.	Planning	3,96%
3.	Information management	3,65%
4.	Client	3,50%
5.	Procurement	3,50%
6.	Stakeholder involvement	3,50%
7.	Delivery	3,04%
8.	Processes	2,89%
9.	Policies and standards	2,59%
10.	Cost	2,44%
11.	Responsibilities	2,44%
12.	Project records	2,13%
13.	Design principles	1,98%
14.	ICT	1,98%
15.	Communication	1,83%
16.	Services	1,67%
17.	Budget planning	1,52%
18.	Duties and obligations	1,52%
19.	Early engagement	1,52%
20.	Collaboration	1,37%
21.	Consultants	1,22%
22.	Leadership skills	1,22%
23.	Performance	1,22%
24.	Clear insights	1,06%
25.	Reporting	1,06%
26.	Scoping	1,06%
27.	System integration	1,06%
28.	Claims and disputes	0,91%
29.	End-user	0,91%
30.	Liability	0,91%
31.	Requirements	0,91%
32.	Team	0,91%

33.	BIM	0,76%
34.	Efficiency	0,76%
35.	Overvaluing	0,76%
36.	Project	0,76%
37.	Schedule	0,76%
38.	Strategy	0,76%
39.	Archival	0,61%
40.	Bond	0,61%
41.	Construction	0,61%
42.	Coordination	0,61%
43.	Decision-making	0,61%
44.	Gate-way	0,61%
45.	Innovation	0,61%
46.	Outsourcing	0,61%
47.	Relationship	0,61%
48.	Resource management	0,61%
49.	Tender	0,61%
50.	Third party	0,61%
51.	Value engineering	0,61%
52.	Authority	0,46%
53.	Change management	0,46%

Code Co-Occurrence table:

The code co-occurrence table shows the amount of connections between different codes. Through colouring the relative frequencies, the co-occurrence is observed. Figure 33 shows clearly what relationship between codes are often observed, and what relationships are less often observed. The strongest links between codes are coloured red and the weakest (or no link) are coloured green (highest value=10, lowest value is 0). Thereafter, more in-dept investigation is carried out for the strongest links. Table 22 shows several of the strongest relationships between codes. The relationship is further investigated by reading the pieces of coded text again and to see if there are generic relationships between the two codes, these relationships are briefly written down in the table.

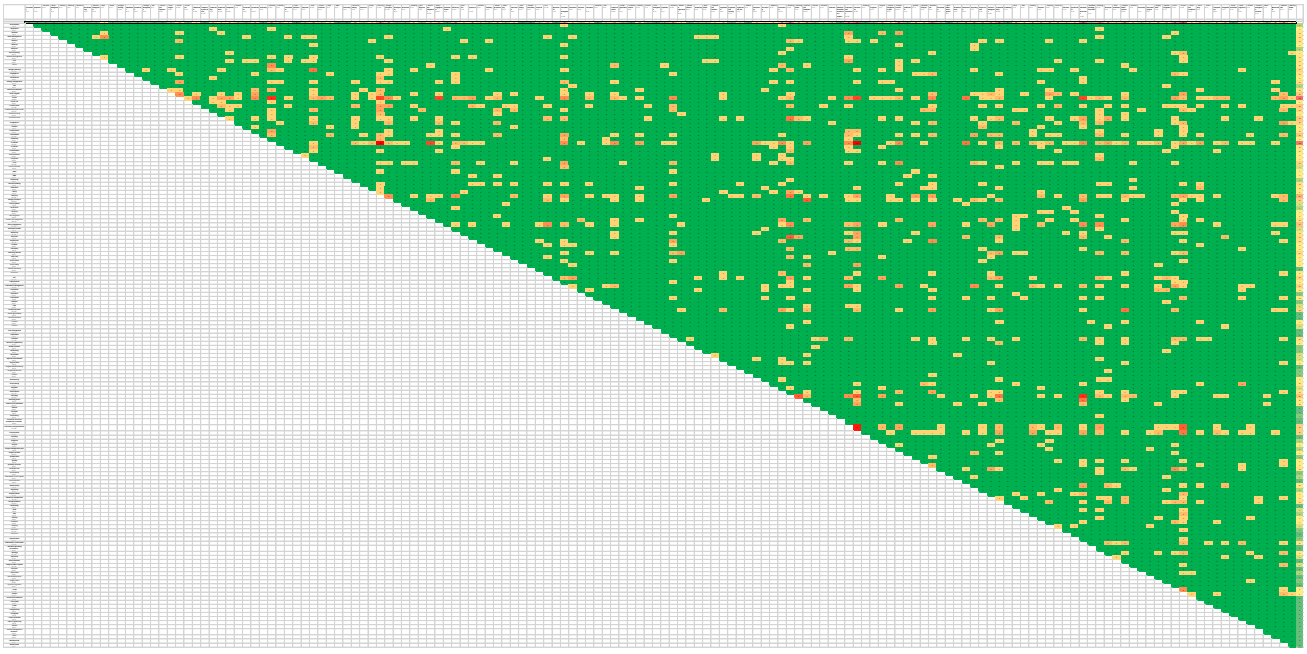


Figure 33: Code co-occurrence results (Source: Authors own analysis)

Highest value = Red (10)

Lowest value = Green (0)

Table 22: Critical success factors and links to explanation (Source: Authors own analysis)

Strongest (10)	Very Strong (9)	Strong (8)
Contract - Delivery	**Procurement - Processes and procedures**	**Contract - Client**
Visibility/ transparent procurement	*Stakeholder engagement*	*Agreement client and contractor*
Agreement client and contractor	*Efficiency and productivity*	*Transparency*
Vendor management	*Scale misjudgements*	*Relationship (triangular client/ contractor/ end user)*
Performance bond not in time	*Recruitment issues*	*Third party involvement*
Competing obligations	*Flexibility*	**Stakeholder involvement - Planning**
Specification design standard		*Specification, procurement, evaluation*
Contract terms		*Design development activities*
Requirements		*Design principles and standards*
Contract - Procurement		*Identification experts*
Rigorous execution plan (WBS-scope/CBS-contract packaging/ABS-facility management		*End-user authority*
Visibility/ transparency		
No standards		
Relationship (triangular client/ contractor/ end user)		
Contract type specification		
Delay order and payment		
Very Severe (7)	**Severe (6)**	**Moderate (5)**
Client - Delivery	**Policies - Design Principles**	**Costs - Budget Planning**
Agreement client and contractor (mature conversations needed & closeout meeting)	*Development standards framework*	*Scheduling*
Transparency	*end user*	*Value engineering*
Team offering	**Planning - End user**	*Experience*
leverage capabilities (combination)	*reliance and responsibilities authority*	**Planning - Communication**
Value proposition > technical skills	*end user*	*Liaison meetings*
Contract - Duties and obligations	**Procurement - Planning**	*Responsibilities (project lead & subject matter experts)*
Importance of project records (performance bonds, chain of evidence)	*Transparency*	**Relationship - Client**
Conversant to scope	*reliance and responsibilities authority*	*Relationship (triangular client/ contractor/ end user)*
Insurance checking		*Third party arrangements*
Onerous/ competing obligations (check legal besides technical)	**Tender - Processes and procedures**	*Connectivity*
Client - Procurement	*BIM usage*	**Relationship - Contract**
Transparency / visibility		*Engagement*
Relationship (triangular - client/ contractor/ end user)		**Planning - Delivery**
Delay order and payment		*Transparency*
Flexibility		*Effectiveness*
Experience		*Asymmetry*
Leadership skills and engagement		*Coordination*
Stakeholder involvement - Client		**Subject matter experts - Leadership skills**
Interaction		*Exercise skill and care*
Relationship (triangular - client/ contractor/ end user)		*Client knowledge*
change management		*Choice programme lead*
Communication partner/ associate		*Location experts*
		Responsibilities - Planning
		Reliance and responsibilities authority
		Role definition
		Stakeholder involvement- Planning phase
		Authority
		Tender - Procurement
		Scale misjudgements
		BIM usage
		Strategy versus visionary approach

Lessons learnt Critical Success Factors:

Within the set up or the lessons learnt report templates, Critical Success Factors are a management term for an element a project or organisation needs to achieve in order to reach its goals and thus be deemed a success. These Critical Success Factors can be used to facilitate the identification of Lessons Learnt as the project is scored against them. Arcadis Projects will be scored against the following Critical Success Factors:

CSF	Question
Project Cost:	Did the project/activities cost more or less than anticipated?
Project Duration:	Was the project/activity delivered to schedule?
Project Quality:	Did the project deliver what it was expected to?
Project Staff:	Was there any impact on staff morale/turn over?
Local Environment:	Did the project have any impact on the local environment?
Health & Safety:	Was the project delivered safely?
Arcadis Reputation:	Was Arcadis' reputation enhanced/degraded by the project?
Client Reputation:	Was the client's reputation enhanced/degraded by the project?
Relationships:	Was there any impact on staff morale/turn over?

Managing Successful Programmes:

Principle	Description
Remaining aligned with corporate strategy	A programme is typically a large investment that should make a significant contribution towards achieving corporate performance targets, maintaining good links with sometimes volatile corporate strategy
Leading change	In a programme, leading change includes giving clear direction, engendering trust, actively engaging stakeholders, appointing the right people at the right moments, and living with a measure of uncertainty
Envisioning and communicating a better future	A programme is relevant where there is a need to achieve transformational change. In order to achieve such a beneficial, future state, the leaders of a programme must describe a clear vision of that future and then communicate it consistently
Focusing on the benefits and threats to benefit realization	The programme should be aligned to satisfying strategic objectives by realising the end benefits. Thus the programme's boundaries, including the projects and activities that become part of the programme, are determined to enable the realization of these end benefits and the effective management of any risks related to that realization
Adding value	A programme only remains valid if it adds value to the sum of its constituent projects and major activities. If it is found to add nothing then it is better to close the programme and allow the projects to proceed, coordinated independently by corporate portfolio management
Designing and delivering a coherent capability	The programme will deliver a business architecture or final capability. This should be released into operational use according to a schedule delivering maximum incremental capability (and therefore benefits) with minimal operational impact
Learning from experience	A programme should review and improve its own performance during its life. Good governance requires managing the different themes with regular adjusting and adapting on the basis of experience and results so far

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Appendix III.

Case study 2:

Annual reports - “Identify company strategy, risk and success factors over period of 10yr”

As PPM is closely related to corporate strategy and the organisational focus, alignment of a PPM framework depends on the context. To better understand the switching context of the AEC industry the context of the case of Arcadis is analysed for the past 10 years. This is done through analysing 10 years of annual reports.

Documents:

Document number	Document label ATLAS.TI	Name of the document
1.	D1	Annual report Arcadis 2010
2.	D2	Annual report Arcadis 2011
3.	D3	Annual report Arcadis 2012
4.	D4	Annual report Arcadis 2013
5.	D5	Annual report Arcadis 2014
6.	D6	Annual report Arcadis 2015
7.	D7	Annual report Arcadis 2016
8.	D8	Annual report Arcadis 2017
9.	D9	Annual report Arcadis 2018
10.	D10	Annual report Arcadis 2019

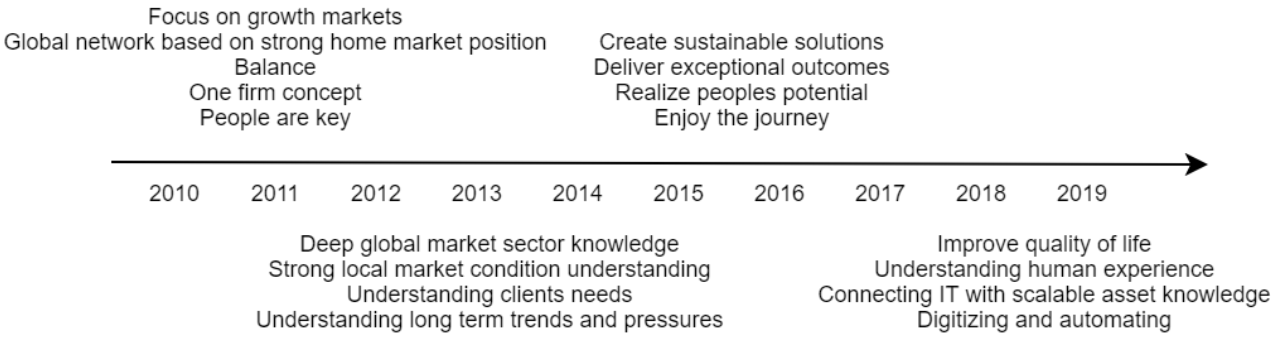
Categories:

1. Organisational values
2. Organisational vision
3. Market positioning
4. Corporate strategy
5. Long term growth drivers & mega trends
6. Key client trends & stakeholder engagement factors
7. SWOT
8. Key business success factors
9. KPIs

1. Organisational values

* Integrity:	Performing work to the highest professional and ethical standards and establishing trust by openness, honesty, and responsibility
* Entrepreneurship:	Driving initiatives to develop business opportunities that create value and use our resources in the best interest of the clients
* Agility:	Reacting fast to market conditions, being responsive to client needs and employees, being eager to perform
* Sustainability:	Performing in an environmentally responsible way, through social and economic advancement
* Client focus:	Being entrepreneurial, agile and creating value for clients, achieving high performance
* Collaboration:	Valuing the power of diversity and global capabilities, delivering excellence
* People first:	Taking care, creating safe and respectful working environment enabling people to grow, perform and succeed
* Client success:	Bringing insights, agility, innovation and value through co-creation

2. Organisational vision



3. Positioning

2010

Differentiation:
- The services in consultancy, design, engineering and management services
- Commitment to clients and the benefit they gain form knowledge and the collaboration of professionals
- Solid client relationships and thorough knowledge of local market condition, allowing for competition on regional level
- Deliver global services to multinational clients, particularly in environmental services,

2011

as well as the water and real estate markets, where few companies can compete globally
- Solid risk management, new types of contracts requiring a broad, multidisciplinary service offering

Largest design and consultancy firm in the world:

2012
- Balanced portfolio of geographies, clients, types of work and business lines
- Organic growth through a focus on client outcomes and internal synergy
- Shift towards activities higher in the value chain
- Value adding acquisition and divestment of low margin businesses

2013
- Stable financial performance with good access to financial markets
- Focus on operational excellence, margin discipline, cash flow and working capital
- Strong leadership and management, health and safety focus, great culture and passionate and talented staf

Active across the entire value chain:

2014
- Market sector insight
- Market sector capabilities
- Client relationship over entire asset life cycle
- Understanding changing needs of clients and market sector

2015
- Combining technology, consultancy and management skills

Leading global design & consultancy firm for the natural and built assets

- Active across the entire value chain

2016
- Global presence
- Local market understanding
- value adding solutions and technology

2017

Strong and well balanced global market position:
- Global presence
- Local market understanding
- value adding solutions and technology

2018

Full service, design and consultancy, spanning entire asset life cycle
- In depth sector knowledge
- Global presence

2019
- Combining technology, consultancy and management skills
- Pairing digital capabilities
- Design principles on sustainability

4. Strategy

People & Culture, Innovation & Growth, Focus & Performance:
- Voluntary staff turnover< market
- Engagement score improving annually
- Top-five brand awareness in market we serve
- Top-quartile performance for client experience
- Organic growth surpassing GDP growth in our markets
- Digital adoption by our people and our clients
- Significant contribute to UN sustainable development goals

Leadership, balance, growth:
- Superior growth and profitability
- Quality, innovation and operational excellence
- Focus on high added value services
- Employer of choice
- Balance as key differentiator

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

Sustainable growth, performance, collaboration:
- Continue expansion into higher growth market sectors and higher margin solutions
- Differentiate through talented and passionate people, unique capabilities
- Expanding the core, focused growth, and mergers and acquisitions
- Being recognized as being the best in everything through continuous improvement
- Leverage capabilities and global footprint

5. Long term growth objectives & mega trends

6. Key client trends

*Employee engagement:	The Company's ability to engage and retain high-quality staff
*Tax policies and compliance (paying fair taxes):	The Company's approach to paying fair taxes across the globe, and adherence to local tax laws and regulations
*Business ethics:	The way the Company approaches business ethics and acts with integrity, both internally and towards its stakeholders
*Environmental non-compliance:	The extent to which the Company complies with environmental laws and regulations
*Privacy (and personal data protection):	The Company's approach to safeguarding (stakeholder) data, and adherence to privacy laws and regulations
*Direct economic value generated:	The Company's ability to generate revenues

*Direct economic value distributed:	The Company's financial return to society (employee wages and benefits, dividends, taxes, etc.)
*Risk management framework;	The quality of the Company's control framework, designed to identify and manage risk exposure
*Client experience:	The outcome of the interaction between Arcadis and its customers over the duration of their relationship
*Innovation:	The Company's ability to provide innovative solutions, and its ability to develop and apply technological solutions

7. SWOT

2015

Strengths - Strong health and safety culture - Balanced geographic portfolio - Leading global architecture firm CallissonRTKL with number one ranking in retail design - Diversified client base of multinational and key national clients and local clients - Strong cash flow; healthy balance - Senior, diverse, experience leadership team	**Weaknesses** - Revenue decline in North America due to exposure to competitive environment - Brand name recognition
Opportunities - Expanding our core business including serving multinational clients and emerging market clients worldwide with the full range of solutions - Growth markets: Infrastructure, Buildings, Big Urban Clients Value propositions: Business Advisory, Program Management and Design - Climate change, water and sustainability Performance Excellence, including the expanded use of Global Design Centers - Mergers and acquisitions: acceleration of consolidation in our industry	**Threats** - Government austerity programs leading to fewer investments in Infrastructure and Water in some mature markets - Shift from Design-Bid-Build to Design & Build in certain markets Low oil and commodity prices impacting natural resources, particularly Brazil and the Middle East - Economic volatility impacting emerging markets - Clients aiming to shift more risk to suppliers

2016

Strengths - Strong health and safety culture - Balanced geographic portfolio - Leading global architecture firm CallissonRTKL with number one ranking in retail design - Diversified client base of multinational and key national clients and local clients - Offering wide range of design and consultancy services	**Weaknesses** - Difficult to optimize capacity in some markets - Limited diversification in North America and Asia - Higher working capital in the Middle Eastern, Latin America, and Asia - Mix of cultures from acquired companies
Opportunities - Selling full range of services to multinational and key national clients - Benefiting from increasing investments in infrastructure by Big Urban Clients - Growing demand for solutions that help clients becoming sustainable - Exapnding use of Global Excellence Centers - Growing demand for digital technologies - Marketing Arcadis and CallissonRTKL brands globally	**Threats** - Shift from design-bid-build to design & build in certain markets - Low oil an commodity prices impacting demand, particularly in North America, Brazil and Middle eastern - Economic volatility impacting markets - Clients shifting more risk to suppliers - Increased protectionism in certain markets

8. Key CSFs (strategic)

- Balanced portfolio of geographies (developed and emerging), clients (public and private), types of work and business lines;
- Organic growth through focus on existing core markets and clients, three priority markets and four priority value propositions;
- Buildings capabilities that cover the complete asset life cycle;
- Water capabilities that cover the full water cycle;
- Acquisitions and structured post-merger integration processes that add value; divestment of low margin businesses;
- Stable financial performance with good access to financial markets;
- Focus on operational excellence, margin discipline, cash flow and working capital;
- Strong leadership and management, a health and safety focus, a great culture and passionate and talented staff.

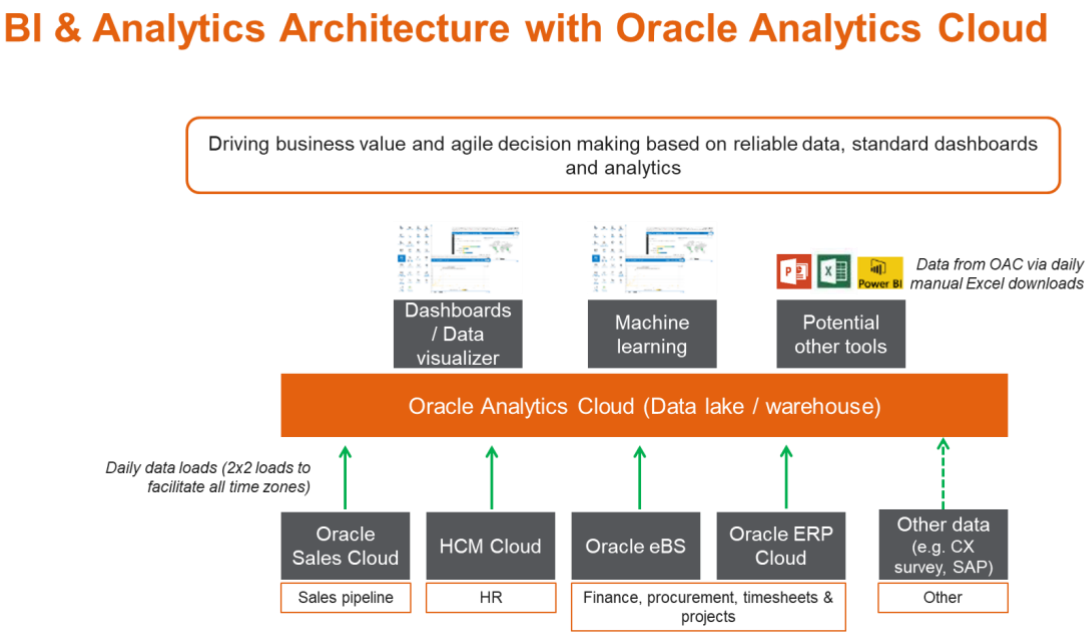
Appendix IV.

Case study 3:

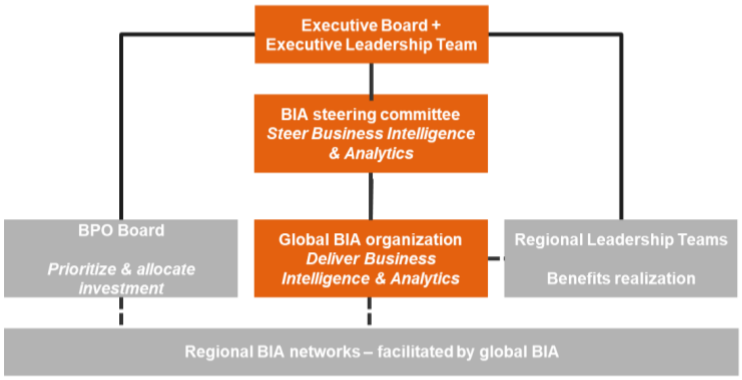
CRM & ERP project data – “Identify available project data”

Document number	Type	Name of the document
1.	Interview	Rene Putman
2.	Powerpoint	Data bases Arcadis
3.	Excel	Project performance data

BI Analytics Architecture:



Business Intelligence & Analytics governance



BIA steering committee

- Key accountability: steer BIA decision making on strategic themes, portfolio management and roadmap for BIA global and regional (budget, risk, change requests)
- Decision making on major releases to the business

Global BIA network organization

- Design, implement and continuously improve Business Intelligence, reporting and analytics in support of business performance
- Deliver high quality and reliable analytics platform to enable standard reporting and (predictive) analytics based on a single version of the truth

Project review regime:

Project review assessment questions:

- How is the client relationship and what are the client expectations?
- What are the major scope considerations and did any of those change in the contract negotiations?
- What are the deliverables and schedule? What are the critical resources including third party suppliers for the project?
- How are we going to earn the revenue, are there any special incentive/ penalty schemes and what are out options to improve the margin?
- How are the risks and opportunities featured into the bid, what are the main lookouts during the delivery phase?

General:	Financials: (Project based KPIs)	Billing and collections	Risks:
Project name **Project number** **Overall health** **Project status** **Project type** **Project manager** **Customer** **Start date** **Finish date** **Organisation**	Task number POC Gross Revenue Net Revenue Labor Cost Non Labor cost Multiplier Margin Contract status	Billed amount Gross revenue amount Work in progress Last invoice date	Risk number Summary of risk Owner Type of risk Priority Status Need by date Date of creation

Questions:

1. Are the client's objectives, expectations, level of satisfaction and/ or concerns understood and what is the concern if any, of not meeting these?
2. Have any concerns of 3rd party stakeholders (public, regulators, subcontractors, professional team) been identified and how are they being managed?
3. How has the contracted scope of services changed, if at all, and is a change order being pursued?
4. What are the opportunities to grow the contract through the provision of additional Arcadis services?
5. What are the technical challenges in service delivery and who is supporting?
6. Are there any quality concerns and who is supporting?
7. Are there any schedule concerns and, if so what could the impact be on the projects?
8. What is the status of the budget and its percentage complete?
9. Is the current forecast margin and financial indicator sin line with or better than the original budget and is there a margin improvement strategy in place?

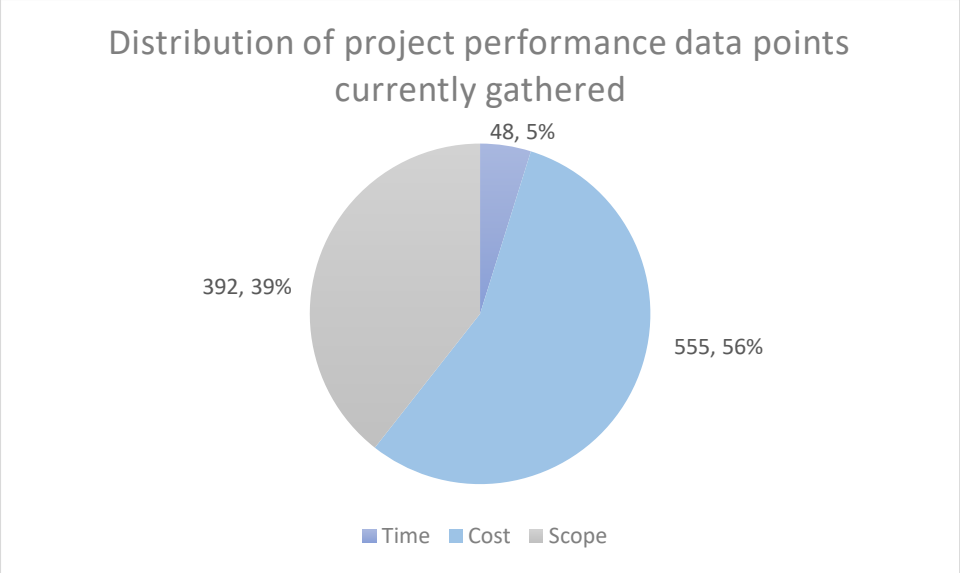
10. What is the ambition on sustainability? How do we provide sustainable solutions?
11. What is the status of DRO? What actions are necessary to improve DBO and DUO?
12. Explain any current or upcoming resource needs and issues
13. Are there any key risks not captured in the questions above, and if so what is the plan to mitigate?
14. Is there a required HASP (Health and safety plan) If so, are there any updated addendums required for upcoming work?
15. Does the review regime need to be changed to reflect the outcome of this review, and if so, what is/ are the main reasons for the change?
16. Who is the licenced professional that is signing all reports, drawings, and documents, is the registration current?

Project performance data available:

Analysis has been carried out to evaluate the distribution of data points being gathered on project performance data. These data points are categorized according tot the triple constraint of project management and the specific data field are counted.

Time (4)	#data points	Cost (58)	#data points	Scope (36)	#data points
GL Calendar	19	Budget Forecast	14	Organizations	10
Enterprise Calendar	19	Budget Project Budget	14	Arcadis Organization Employee	0
Budget Hours Metrics	5	Currency Code	2	ARCADIS - Organization Project Owning	30
Forecast Hours Metrics	5	Project Budget Version	7	ARCADIS - Organization Project Review Approver	24
TOTAL	48	Project Finance Responsible	4	Billing Customer	24
		Project Forecast Version	7	Contract Customer	24
		Project Revenue Forecast	2	Ultimate Customer	24
		Financial Resource	12	Project	40
		Non Labor Resource	4	Project Agreement	7
		Resource Class	2	Project Classification	12
		Planned Resource	1	Project Contract	22
		Actual Performance ETC Metrics	7	Project Flexfields (sustainability)	0
		Actual Performance ITD Metrics	23	Project Issues and Risks	6
		Actual Performance MTD Metrics	14	Project Line Manager	4
		Actual Performance QTD Metrics	12	Project Location	3
		Actual Performance YTD Metrics	10	Project Manager	9
		DRO Ago Metrics	2	Project Assistant	3
		Fact - Project Billing	12	Project Portfolio Director	3
		Billing ITD Metrics	16	Project Role	4
		Billing MTD Metrics	15	Project Status	5
		Billing QTD Metrics	15	Project Status History	18
		Billing YTD Metrics	15	Project Workplan	7
		Fact - Project Budget	17	Employee	9
		Fact - DRO Measures	11	Job	2
		Budget ITC Metrics	17	Work Type	1
		Budget MTD Metrics	8	Supplier	2

		Budget QTD Metrics	8	Resource Assignment	2
		Budget YTD Metrics	8	Task	29
		Fact - Project Commitment	1	Task Flexfields	14
		Fact - Project Cost	15	Task Hierarchy	21
		Fact - Actual Performance Metrics	41	Fact - Project Review	6
		Actual Performance AGO Metrics	15	Fact - Project Risks	1
		Cost Ago Metrics	9	Fact - Project Status History	1
		Cost ITD Metrics	8	Fact - Project Workplan	4
		Cost MTD Metrics	6	Project Review	18
		Cost QTD Metrics	6	Project Review Regime History	3
		Cost YTD Metrics	6	TOTAL	392
		Fact - Project Forecast	17		
		Forecast ITC Metrics	17		
		Forecast MTD Metrics	8		
		Forecast QTD Metrics	8		
		Forecast YTD Metrics	8		
		Fact - Project Funding	1		
		Fact - Project Order Intake	7		
		Order Intake ITD Metrics	3		
		Order Intake YTD Metrics	3		
		Order Intake QTD Metrics	3		
		Order Intake MTD Metrics	3		
		Fact - Project Revenue	8		
		Revenue Ago Metrics	19		
		Revenue ITD Metrics	9		
		Revenue MTD Metrics	7		
		Revenue QTD Metrics	7		
		Revenue YTD Metrics	7		
		Fact - Project Revenue Forecast	16		
		Fact - GL Adjustments	12		
		Fact - Sub-Ledger WIP	6		
		TOTAL	555		


Distribution of project performance data points currently gathered
48, 5%
392, 39%
555, 56%
Time
Cost
Scope

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Appendix V.

Case study 4:

Client selection criteria - “Identify initial client assessment criteria and procedure”

Document number	Document label ATLAS.TI	Name of the document
1.	D1	Annual report Arcadis 2010
2.	D2	Annual report Arcadis 2011
3.	D3	Annual report Arcadis 2012
4.	D4	Annual report Arcadis 2013
5.	D5	Annual report Arcadis 2014
6.	D6	Annual report Arcadis 2015
7.	D7	Annual report Arcadis 2016
8.	D8	Annual report Arcadis 2017
9.	D9	Annual report Arcadis 2018
10.	D10	Annual report Arcadis 2019

Documents:

Content analysis:

High Risk

- Private Individuals: it can be difficult to get background information on private individuals through publicly available sources. Example – “John Smith” (private individual)
- Sole ownership of entity by an individual: like private individuals, it can be difficult to get information on closely held companies. Similarly, for companies owned by a single individual, the acts of the individual might be attributed to the company and vice-versa (i.e., the company is the alter-ego of the individual).
- ‘Offshore’ entities/overseas companies with limited transparency: Companies set up in tax havens, free economic zones or where inquiry into their operations is restricted make it difficult to gather information. Example – a company registered in a tax haven (private company registered in Luxembourg) or where inquiry is difficult (Belize, Nigeria, China, etc.).
- Companies/market sectors with highly charged political or reputational issues: Working for clients engaged in these areas may bring brand or reputational harm to Arcadis by association. Example – companies involved in tobacco or cannabis production or animal testing.
- Companies or projects where the ultimate beneficial ownership or source of financing is not known: When we don’t take reasonable steps to identify the ultimate beneficial owner or source of financing, Arcadis risks violating sanctions laws if it later transpires that the company or an individual behind it is subject to sanctions.
- Clients with known integrity issues: We must be able to gauge the severity and possible impact of those issues on Arcadis if the client could face criminal, financial, or reputational problems. Example – client undergoing known criminal, fraud, or other significant investigation.

Medium Risk

- Government clients: depending on the transparency of the location and the strength of the procurement process, government clients may pose risk. Consider, for example, working for a Governmental department of a grey listed country or a country that rates highly on the Corruption Perception Index of Transparency International.
- Private/closely held companies with more than one shareholder: it can be difficult to get information on private companies from public sources.
- Contractors: depending on the transparency of the information available and the strength of the procurement process, contractors may pose risk.

- High turnover of key personnel: This could be a signal of deeper internal problems. For long-term, existing clients, it also could require Arcadis to rebuild the trust in the relationship.
- Clients that do not fit into any category: if you are unsure of which category your client may fall, you should consider them a medium risk for purposes of due diligence.

Low Risk

- Clients in highly regulated industries: these clients typically have a lower integrity risk because of the government oversight that is exercised over them. Example –International financial institutions (World Bank).
- Clients that are publicly traded on a major international exchange: these clients typically have lower risk because of the stock exchange regulation exercised over them. Example – NYSE, NASDAQ, Euronext. This does not include "over-the-counter" type markets.
- Our "Top 200" Clients: our Top 200 clients have undergone review in the Go/NoGo process. We also typically have an existing relationship, pro-actively managed by a dedicated Account Leader, that has been stable, productive, and valuable for both parties

Arcadis Fit	
1	Have you read the guidance note on selecting and deselecting clients? If not, please refer to the link provided in the smart tip. **(1)**
2	How well does this client fit with our values (transparency, integrity, sustainability)?
3	How does this client fit the Arcadis strategy (sector plans, regional plans, etc.)?
Opportunity and Financials	
4	What profitable revenue do we expect from this client in the coming 3 years?
5	What is the quality of our relationship with this client?
6	What is the (expected) invoice approval and payment behavior of this client?
Risk (2)	
7	Are there any restrictions around working for this client? (e.g. reputational risk, human rights, environmental issues, possible Conflict of Interest, working in black/grey listed countries or for sanctioned companies or individuals, etc.)
8	*To be added May 2020* Will any of the client's personal data be processed in the delivery of this service/project/program? If yes, go to the PIA Tool processor (link in smart tip) to register and assess privacy impact of your service/project/program and add the PIA number (automated code) in the response box below. **(3)**
9	Have you consulted the functions (e.g. legal, finance, risk, H&S, sustainability) in answering the above?

Appendix VI.

Case study 5:

Strategic pursuits wins and losses - “Identify critical factors in the bidding process for projects”

Documents coded:

Document number	Document label ATLAS.TI	Name of the document
1.	D40	Empier loss
2.	D41	GDOT loss
3.	D43	GSP loss_crossrail
4.	D44	GSP loss_jaguar land rover
5.	D45	GSP loss san fransisco airport
6.	D46	HS2 loss
7.	D47	PANYNJ loss
8.	D48	Bayer win
9.	D49	Chevron win
10.	D50	GSP success ccr
11.	D51	GSP success exxonmobil italy
12.	D52	GSP success ey
13.	D53	GSP success_HS2
14.	D54	GSP success mars inc
15.	D55	Ionity win

Open coding codes:

152 codes have been used, analysing the documents

Accessibility
Acquisition
Archival
Asset Management
Authority
Back-up
Baseline
Benchmarking
Benefit management
BIM
Bond
Budget planning
Capabilities
Centralized
Change management
CIS
Claims and disputes
Clear insights
Client
Close out
Collaboration
Commercial point of view
Commissioning
Communication
Competition
Conflict
Construction
Consultants
Continuity
Contract
Controls
Coordination
Core-activities
Corporate
Cost
ross-sectional
Data
DBE
Debriefing
Decision-making
Defective
Delay
Delivery
Design principles
Development
Disclosure
Drawing
Due diligence
Duties and obligations
Early engagement
Economic climate
Efficiency
End-user
Experience
Finance
Flexibility
Follow up actions
Gate-way
Governance
GS1 coding
Health and safety
Historical
ICT
Improvement
Info management
Innovation
Insurance
Investment
Isolation
lack
Leadership skills
Lease agreements
Lessons learnt
Liability
Liaison
Line management
Liquidation
Location
Market to opportunity
Middle Eastern
Monitoring
New builds
Operate and maintain
Organisation
Organisational learning
Organisational silo
Outbid
Outsourcing
Overvaluing
Payment
Performance
Planning
Planning phase
Policies and standards
Politics
Portfolio
Positioning
Processes and
Procurement
Profiling
Progress
Project
Project management plan
Project records
Qualification
Quality
Quantity surveyor
Reasons lost
Recruitment
Red Amber Green system
Refurbishment
Relationship
Reporting
Requirements
Resource management
Responsibilities
Rewarding
Risk
ROI
Scaling
Schedule
Scoping
Services
Solicitors
Specification
Stakeholder involvement
SOP
Strategy
Structural
Sub-contractor
Subject matter experts
Success
Successful
Successful project
Supply chain
System integration
Team
Tender
Terms and conditions
Third party
Tools
Transparency
Triangular
Triple constraint
Value engineering
Vendor
Vertical management structure
WBS
Workarounds
Worked well
Working climate

Code-documents table and relative frequencies (80/20-rule: 53 most occurring codes):

Table 23: Code-document table and relative frequencies

#	Code	Occurrence in Loss	Occurrence in win	Total
1.	**Client**	5,17%	8,87%	7,02%
2.	**Tender**	5,75%	5,42%	5,58%
3.	**Delivery**	2,87%	5,42%	4,15%
4.	**Location**	2,87%	5,42%	4,15%
5.	**Competition**	4,60%	2,96%	3,78%
6.	**Team**	3,45%	3,94%	3,69%
7.	**Experience**	2,87%	3,45%	3,16%
8.	**Early engagement**	2,30%	3,94%	3,12%
9.	**Commercial point of view**	4,02%	1,48%	2,75%
10	**Strategy**	3,45%	1,97%	2,71%
11	**Subject matter experts**	3,45%	1,97%	2,71%
12	**Collaboration**	1,15%	3,94%	2,55%
13	**Clear insights**	3,45%	1,48%	2,46%
14	**Consultants**	3,45%	0,99%	2,22%
15	**Follow up actions**	4,02%	0,00%	2,01%
16	**Reasons lost**	4,02%	0,00%	2,01%
17	**Worked well**	4,02%	0,00%	2,01%
18	**Responsibilities**	2,30%	1,48%	1,89%
19	**Investment**	1,72%	1,97%	1,85%
20	**Processes and procedures**	0,00%	3,45%	1,72%
21	**Resource management**	3,45%	0,00%	1,72%
22	**Leadership skills**	2,87%	0,49%	1,68%
23	**Design principles**	2,30%	0,99%	1,64%
24	**Capabilities**	1,72%	1,48%	1,60%
25	**Stakeholder involvement**	0,58%	2,46%	1,52%
26	**Cost**	0,00%	2,96%	1,48%
27	**Market to opportunity**	2,30%	0,49%	1,40%
28	**Decision-making**	1,15%	1,48%	1,31%
29	**Relationship**	1,15%	1,48%	1,31%
30	**Information management**	0,58%	1,97%	1,27%
31	**Performance**	2,30%	0,00%	1,15%
32	**Quality**	0,58%	1,48%	1,03%
33	**Contract**	0,00%	1,97%	0,99%
34	**Efficiency**	0,00%	1,97%	0,99%

Appendix VII.

Table 24: Overview of key words used and important literature (Source: Author's own analysis)

Words	Related articles found	Writers	Used for
Project portfolio management	Portfolio Management for New Products	Cooper	General information on PPM
Project portfolio management processes	Key attributes of effectiveness in managing project portfolio	Peerasit Patanakul	General information on PPM
Construction project portfolio management & Project portfolio management AEC	An integral framework for portfolio selection Prioritization of project proposals in portfolio management using fuzzy AHP PPM & GIS Project dependencies 3-dimensional model Prioritization and selection contractor companies Stochastic forecasting project streams Integrating sustainability MCDM method for ppm Customer integration in PPM	Ghasemzadeh & Archer Chatterjee, Hossain, & Kar, Hashemizadeh & Ju Bilgin, et al. Wu, Zhang, & Xu Hosseininia & Dehghani Shojaei & Flood Yung & Siew Ryan & Abbasi Voss	Theory building for framework & Identifying criteria and variables Theory building for framework & Identifying criteria and variables
Innovation in PPM	The integration of ideation and project portfolio management—A key factor for sustainable success Augmenting innovation project portfolio management performance: the mediating effect of management perception and satisfaction Innovation Portfolio Management as a Subset of Dynamic Capabilities: Measurement and Impact on Innovative Performance	Wilderich Heising Lerch and Spieth Hélène Sicotte,	Scoping topic Scoping topic Scoping topic
Different approaches in PPM	Behaviour of internal stakeholders in project portfolio management and its impact on success	Claus Beringer	Identifying influential factors in ppm
PPM in different industries	The Impact of Project Portfolio Management on Information Technology Projects.	Sergio Ricardo Calderini	Scoping topic
PPM in R&D firms	Decentralization integration and the post-bureaucratic organisation the case of R&D. Towards a 'New Project Management' movement? An international development perspective	Stephen Hill Robert Picciotto	Creating the context (focus industry) Specifying context
Adaptability in PPM	Role of single-project management in achieving portfolio management efficiency	Miia Martinsuo	Strengthening the importance of the topic and research in this field.

	Dynamic capability through project portfolio management in service and manufacturing industries Project Portfolios in Dynamic Environments: Sources of Uncertainty and Sensing Mechanisms	Killen & Hunt Ivan Petit	Creating more focus on subtopic Creating more focus on subtopic
Data analytics for PPM	Data analytics application series Digital innovation in the service industry	Spalek Aithal & Aithal	Adding technological perspective Perspectives on IT applications
Adaptability project portfolio management	Role of project portfolio management in fostering both deliberate and emergent strategy The use of effectuation in projects: the influence of business case control, portfolio monitoring intensity and project innovativeness. Critical success factors integration sustainability in project management	Kopman; Kock; Killen & Gemünden Nguyen; Killen; Kock Banihashemi; Hosseini	Link to strategic management & emerging strategy Strategy perspective on PPM CSF and PMS in PPM
Project portfolio management development	Towards a new project management movement	Picciotto	History and development in the PM field
Project portfolio management	Configurational explanation for performance management systems' design in the project-based organisation The moderating effect of programme context on the relationship between programme managers leadership competences and programme success	De Rooij Shao	Design factors for PPM in consultancy industry Management level perspective

Literature findings overview

Author	Method and data	Findings	Future research
Teller et al., 2012	Questionnaire study with 134 firms	In complex project portfolios (where projects have interdependencies), PPM formalization is even more important than less complex	Formalization of PPM needs to take into account the context and nature of the portfolio
Chatterjee, Hossain & Kar, 2018	MCDM using fuzzy set analytical process hierchy process. And input from 15 project management experts.	Prioritization of project proposals in portfolio management. Criteria commercial, selection risk, project owners, project bid competition, additional factors, internal operating issues + sub-criteria	Method execution on big data sets in fuzzy stochastic situations with random parameters and interrelationships among criteria.

Hashemizadeh & Ju, 2019	MCDM analytical hierarchy process. 5 active projects, 29 proposed projects, 4 experts.	Project portfolio criteria, strategic, technical and communal. Evaluation on organisation, quality, human resources and planning	Explore other areas or other criteria for ppm.
Bilgin, et al., 2017	Questionnaire study 280 construction professionals in turkey	Project interdependencies in PPM. Criteria: status, risk scores, resource dependency attributes, learning dependency attributes, outcome dependency.	Numerical testing for validation of the tool using large data sets.
Wu, Zang & Xu, 2016	Literature review and case study	3-dimensional model for PPM. Project phase dimension, management layer dimension and project type dimension are important.	Further exploration concerning the influence of ppm interplay in achieving PPM success.
Hosseininia & Dehghani, 2017	Literature and MCDM using AHP	Project portfolio management processes in two groups, monitoring and controlling and aligning process group. Parties involved indicated and criteria. Risk, organisational evaluation, economic criteria, business political criteria, financial criteria, technical criteria.	Using financial and risk information parameters assess criteria hierarchy.
Shojaei & Flood, 2017	Time series data, 12 years. Data base with 2816 projects. Quantitative correlation analysis	Bidding process is important for PPM. External focus is needed. Stochastic forecasting project streams before internal metric usage. Time series on cost, frequency and macroeconomic variables. Variables identified.	Combine the generator of streams of future projects with a sample portfolio to show the model's capabilities
Yung & Siew	Casestudy with 3 projects and 24 scenario's	Integrating sustainability in construction project portfolio management. Screening phase methodology with financial and non-financial variables. Economic (profit, expenditure risk or debt, aid from government), Environmental (energy, waste, water, emissions, incidents, design criteria, land, material, compliance) and Social (leadership, supply chain, health and safety, training).	Expanding on the sample size, adjusting for existing projects, interactions among them and resource competition.
Ghasemzadeh & Archer, 1999	Literature review	Integrated framework for project portfolio management selection with different phases; pre-screening, individual project analysis (data-base comparison), screening, optimal portfolio selection, portfolio adjustment.	Research into the generic requirements for decision support in PPM. Modelling techniques, how to simplify some of the more useful techniques to make them acceptable. Finding suitable data, connecting economic models, examining scope of strategic decisions outside the portfolio framework.
Ryan & Abbasi, 2018	Literature review	Multi-criteria Decision-Making for PPM. Key challenges are sensitivity, analysis, treatment, dependencies, decision-traceability, simplicity, quantitative and qualitative, number of projects, trade-offs, group decision-making, mutual link between projects and strategic level.	Study on managing the entire process, find approach to identify method for activities based on organisational factors. Best fit investigation.
Voss, 2012	Literature study	Possible interfaces between CRM and PPM with focus on strategy development, value creation multichannel integration, and performance assessment.	En empirical validation of the conceptual model and the model's further development. Test propositions with quantitative study.
Zika-Viktorsson et al., 2006	Questionnaire study in nine firms	Project personnel often experiences project overload due to various multi-project	Multi-project setting as a work to context is relevant to how work is experienced as well as to performance.

		issues, and this overhead has various negative consequences	
Cooper and Edgett, 2008	Reference paper	Methods for PPM practices, selecting, evaluating, prioritizing	The importance of data integrity in PPM
Peerasit and Patanakul, 2015	Case study, PPM practice relative to the market. Theoretic sampling.	The effectiveness and impact of PPM is limited. Therefore, strategic alignment is needed together with adaptability, visibility, transparency.	Relationship between PPM effectiveness and organisational effectiveness. In addition, the relationship between PPM effectiveness and project team effectiveness should be investigated
Wilderich and Heising, 2012	Sound review literature. Verified for Relevance and face validity by a series of ten interviews con-ducted with practitioners from various industries.	At the front end of projects, opportunities are discovered, ideas are created, and the foundation for later project, portfolio, and, eventually, corporate success is laid. Holistic view of project portfolio management.	Managers to adopt a holistic view and include the front-end activities in their managerial consideration. Focus areas: the strategic setting of ideation, the formalization and institutionalization of the ideation process, integration mechanisms, stakeholder management, and ideation culture.
Lerch and Spieth, 2014	Theoretical sampling, computer assisted telephone interviewing.	Challenge of efficiency and effectiveness. Transparency, formality, management perspective and design elements are key.	Empirical research is needed to establish holistic framework. Assess internal and external variables. Research on cross-sectional data is needed.
Sicotte, Drouin and Delerue, 2015	Survey data from a sample of 923 firms.	Multidimensional construct for innovation in PPM. Intrapreneurship, adaptability, strategic renewal, value chain, technical leadership.	Dynamic capabilities, long term practice measure over time. Including organisational performance variables.
Beringer, Jonas and Kock, 2012	Empirical study of 197 project portfolios.	Stakeholder behaviour and management is key in PPM. Engagement of stakeholders is phase specific. Role clarity is measure of PPM maturity.	Investigate quality of the stakeholder engagement. Role clarity within organisational context. Emphasis on the project managers as interface to the projects in a portfolio. And also, external stakeholders of the portfolio.
Martinsuo and Lehtonen, 2006	Literature research and questionnaire survey with 279 firms verifying.	Information availability from project level, goal setting, systematic decision-making for efficiency.	Project portfolio practices, in the single project contribution to the entire portfolio. Project management factors to be identified. Standardizations, metrics, resource sharing and ownership. Maturity to efficiency.
Calderini et al., 2005	Based on a survey, we developed a new framework of PPM adoption and identified groups of organisations at different stages of the adoption of PPM. Correlated PPM adoption levels.	Processes of PPM with software and IT to automate process. Three stage classification schemes. Centralized view, financial, risk, interdependencies, constraints, categorization, selection, accountability, optimization, software. Project benefits, dependencies, value is needed.	--
Hill, Martin and Harris, 2000	Analysis of a sample of companies in R&D based on survey.	R&D is less decentralized than accounts suggest. Flexibility is required and integration withing functions is needed.	--
Picciotto, 2019	International development perspective, literature review. And development experience.	Limitations of management by objectives. Adaptable approaches are needed in complex and turbulent environment. Experiments can contribute to sound decision-making at the higher plane of strategy formulation	Investigation in context, evaluation criteria, stakeholder performance, multidisciplinary approaches and interdependencies.

		and policymaking. Efficiency, efficacy, relevance, impact and sustainability.	
Martinsuo and Lehtonen, 2006	Literature research and questionnaire survey with 279 firms verifying.	Information availability from project level, goal setting, systematic decision-making for efficiency.	Project portfolio practices, in the single project contribution to the entire portfolio. Project management factors to be identified. Standardizations, metrics, resource sharing and ownership. Maturity to efficiency.
Kopmann, Kock, Killen and Gemünden, 2017	Sample of 182 firms. Cross industry medium to large firms in Germany. Multi item scale.	Organisational adaptability is created through emergent strategies that constitute independently from deliberate top-down strategy. Strategic control systems are opportunity for emerging patterns.	Effect of emerging strategy recognition in more depth to illuminate the mechanisms involved. Inclusion from additional perspectives from top and lower management. Bottom-up perspectives as well. Employee voice behaviour. Planned emergence. Multilevel research.
Nguyen, Killen, Kock and Gemünden, 2018	The paper contributes to research and practice by empirically investigating the antecedents to the use of effectuation decision-making logic in project and portfolio management through a multi-level model.	Project management approaches are evolving to be more flexible and adaptive to meet the challenges associated with an increasingly complex and dynamic environment. Effectuation, decision-making logic. Portfolio governance inhibit the use of effectuation. Project innovativeness increases effectuation.	Exploration of the role and characteristics of the project manager. Applying a longitudinal design which could explore whether effectuation and causation are applied in different stages of a project. . Future research could explore whether the type of decision-making logic changes over the course of a project lifecycle (longitudinal).
Spalek, 2019	Literature research.	Data & Analytics based on project management metrics can enhance portfolio management.	Factors, data, measures, metrics need to be identified. The lack of practice and context determines the performance of PPM processes.
Aithal and Aithal, 2019	Literature review and conclusions. Categorization.	ICCT can enhance digital service innovation. Applications of ICCT identified and the management of ICCT in tertiary sector.	--

Appendix VIII.

Interview Notes:

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
1.	Global Solutions Director	Project & Programme Management	Middle Eastern	>12 years	Introduction programme management, PM problems, lessons learnt reports and data handling	17-06-2020

- Project and cost management
- Stopped physical project delivery
- PM is service
- Involved in:
- residential pm building orientated
- supervision and engineering

- PgM capability uae building oriented
- Scheduling is an industry problem
- Primavera not pulling together specific data
- Materials are better able to analyse
- project location
- client
- benchmarking schedule data?
- No principles
- We want to be premium based consultant
- All scheduling data we have should be analysed
- early engagement
- identifying, developing and harvesting
- Schedule thing is really important
- Large document initiation phase--> simplified
- PMP- PM tools is more important
- streamlined reporting
- pdf document with lot of documentation
- Schedule management
- More pm orientated
- People focus
- Toolkit
- Minimal requirements
- DC harris
- SOP is communicating
- Leaner quicker, innovative,
- From digital perspective
- project blame contracter
- Project delays
- Change management in design phase
  - ➔ efficiencies can increase
- Bettter efficiency lacking consistency
- opining regio, stakeholder, client
- Product market combination perspective

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
2.	Programme Manager	Managing Board ANL	Netherlands	>22 years	Introduction programme management, review Spalek (2019) framework, management implications	21-04-2020

- Project review template and data
- Think about global/ NL levels
- Project review data is a complex process and sensitive to fraud. Institutions in the netherlands are keen on that
- >€10.000 loss is bleeder intervention
- Root causes are identified (will be send by mail)
- MEPC programme --> rob mooren
- Maybe contact Toon gerards
- And Norbert van Haaften
- Project sally is interesting
- Oscar van der Vaart
- Hackaton IBM-->application
- Earned value method is interesting for project management practices
- Cost development in time can be monitored and can be used potentially for Data & Analytics practices
- Engineers have a conservative attitude and want to innovate on the products or services, they normally don't take the time to reflect and improve on processes. Try also to think about incorporating societal factors in your research, as this can be inhibiting factors.
- As our people might be less voluntary to provide insights themselves we could use Data & Analytics to retrieve insights via IT. The social abstinence to keep track on project performance reviews is than captured through automation and Data Analytics.
- Tip for framework: incorporate the decision-making process. Leadership and power and the individual opinion plays an important role in the selection of clients. More evidence based decision-making processes are needed.
- Regarding scope, collaboration and stakhollders can be an important input with data

- Key-clients/ local clients
- Make every project count

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
3	Project Leader	Project & Cost and Commercial Management	Netherlands	>3 years	Project data handling	16-04-2020

- Risk management
- Control tasks

- Developing new processes
- SAP project registration
- Comparing cloud projects
- Medium risk
- Netherlands
- Facebook algorithm
- Databases excel risk reports
- ----------
- Project management: start and inspiration for risk sessions
- Extern project management: support risk management
- Tender management: start and inspiration risk management
- System-oriented contract management: Help risk lists for projects where few risks have been formulated
- Construction risks for estimation: risk lists
- Tools and systems need to be developed for time saving, high quality and transparency, systemic use of data and knowledge, saves time for human consideration
- ----------
- **Obstacles in Data & Analytics:**
- Standardization
- Specific terminology (people are not aware)
- Cause-effect control measures must be developed
- Database is incomplete (shortage on data or bad quality)
- Keeping the system in the air is more expensive than the yields
- Business models must be changed and include risk management approaches
- Systems must be user friendly and have good appearance

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
4	Senior Project Manager	Managing Board ANL	Netherlands	>28 years	Project success factors	21-04-2020

Project Bleeder interventions

Root causes:

1. Project manager not classified
2. Contract issues
3. Strategic project: calculated too optimistically
4. Project manager not calculated
5. Handover: TM -> PM and PM -> PM
6. Kick-offs are missing, incomplete or no commitment
7. Risks not or not fully mapped out and not managed + shared with the customer
8. Customer expectations insufficiently managed
9. Scope creep
10. Lack of escalation
11. Issues insufficiently shared internally and externally

Solutions:

1. Ensure a good match between assignment and PM level
2. Know your contract + legal engagement
3. Re-plan at the start and in the meantime (reviews)
4. Re-plan budget
5. Apply guideline project launch
6. Apply guideline project launch + method of collaboration
7. Guideline TAW Risk management
8. Record contractually
9. Contract management + awareness in the project team: -> issue log + additional work
10. Awareness lacking capability → call for help
11. Guidelines project review

Intervention actions

- Deep dive in contract and billing situation if necessary
- Go to the client to negotiate (not by mail)
- Ask for help and escalate before it's too late.
- Deep dive in contract risk and long negotiations with the clients turned out to be successful by developing a compensation system.
- Define the cost to complete to gain insights into future costs and define measures to prevent overruns.
- Finalize and submit a claim to the client as soon as possible.
- Document the claim to the client with the support of the legal department and organise a meeting between the client and the Project Director to come back to a more constructive relationship.
- Design different strategies to get extra work/scope approved
- Get feedback on these strategies from other project managers.
- Involve steering committee in decision making
- Listen to client's expectations of deliverable result / focus on contract terms
- Summarize mutual understanding of scope and collaboration with client, before presenting scope creep and opportunities.
- Focus on finalizing project as soon as possible
- PM keeps close look at the performance of the team members focusing on doing the right things in these last few weeks
- Line up legal: schedule 2-weekly meeting
- Avoid no cure no pay situation with client.
- Escalate timely to Line Manager to align and organise support.

10 tips to prevent project loss

1. If the lead time increases costs will increase especially for project management: start discussion as with the client as soon delay starts
2. Hand over during project execution is costly: follow hand over procedure and be aware of additional costs and related financial provision
3. Focus on cost to complete by planning out the remaining activities in detail and look for alternative (cheaper) solutions like GEC
4. In case of upcoming conflict with the client start internal escalation and arrange meeting between LM of the PM (client) and LM of PM (Arcadis)
5. Offer additional support to PM to improve financial overview and controll
6. Look at the loss from a more strategical level and ask questions, like what will happen if we stop the project
7. Reread the contract, the scope and the risk register carefully
8. Connect with the legal department to check on contract conditions
9. Re-align with client on expectations
10. Be aware of scope creep and discuss regularly with the project team

Reasons for scope change:

Additional meetings with the client.	More alternative options worked out than offered.
Additional meetings with third parties, for example to gather basic information or to consult with residents or other stakeholders, authorities or governmental parties.	More extensive reporting than provided in the original proposal.
Meetings with more persons.	Additional mapping material supplied (number, scale) or processed.
Work (on request) carried out in more detail.	Higher quality of the design documents and reports (glossy instead of black and white or different dimensions)
Information provided too late by the client.	Extra lead time, which means more / longer project management is needed.
Information provided in a fragmented way by the client.	Extra lead time, which requires more supervision.
Extra rounds for comments by client leading to extra concept reports.	Extra supervision due to a contractor that underperforms.
Interim comment from third parties (not provided).	Interim rate adjustments.
Interim changes in (technical) starting points / assumptions.	Extra lead time, so part of an assignment must be executed at higher rates.
More reports delivered.	Higher construction costs than foreseen, so more project mangement is needed.

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
5	Senior Consultant	Project & Programme Management	Netherlands	>23 years	Project success factors	17-04-2020

- Ambition ANL
- Bleeder interventions
- Data analytics
- MEPC analytics globally person?
- 10 principles
-

We only work for those markets where we see an opportunity for a sustainable and profitable business.

We only bid for opportunities where we can make a profit and get paid.

We only make promises that we can deliver.

We always seek to command a premium on market price based on our differentiation and the value we deliver.

We believe only selected, trained and certified Project Managers can be responsible for our projects.

We believe every project starts with a handover between the Pursuit Leader and the Project Manager.

We believe every project must have a plan for optimal profit that takes into consideration risk and opportunity.

We actively manage our contracts and risks, and only work with a signed agreement, this includes scope changes.

We ensure that the Line Manager, Project Manager and Finance execute robust monthly project reviews.

We ensure every project will have a disciplined close out to capture
lessons learnt and client feedback.

Contract	**Contract Type**	**Time & Materials, Cost Plus Fixed Fee**
	Contract Language	Standard ARCADIS contract terms (low risk)
	Other High Risk Criteria	None
Client	Client Relationship	Existing client with good / non-contentious relationship
	Project Visibility/Profile	Routine project work
Financial	Project Budget	New Opportunity, project budget not established
	Payment / Cash Flow	None apply
Performance	Geographic Complexity	Project staffed by local office personnel
	Health & Safety	Routine or Office-based scope
	Schedule	Project is in Opportunity/Pursuit stages or just initiated
Scope / Technical	Scope Definition	Well defined, exclusions noted
	Technology/Work Type	Routine work/technology and complexity

- Deliver to result
- Arcadis way
- Monthly project reviews
- Global monitoring and control is needed
- Monthly audits
- People first
- Focus performance
- Growrth innovation
- Rob Moores
- North america
- Review reports --> learning
- Lessons learnt (QHSE)
- Lost get order order
- Offerte data base

- Distance between the global head office NV Amsterdam & business lines or regional firms

- Gartner, 2015; Halper, 2016; Larson & Chang, 2016

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
6	Global Solution Director	Portfolio & Programme Management Solution	Europe	>20 years	Introduction programme management, framework review, data handling, industry trends	11-05-2020

- Johnson and Johnson
- engineering property services
- real estate
- financial management
- project delivery
-
- transition different teams
- Right governance
- November workshops
- PPM struggle we don't know what it is
- Our company moved away from PPM, now capital investment planning
- Cashflow
- Not looking at other aspects
- Construction/ managing projects
- PPM language familiar in organisation
- engineering property services
-
- 40 groups interest in portfolio
- 1-3 regions
- 200 functional groups
- consensus approach
- 21504ISO PPM
- J&J team
- data is not available
- only in large projects
- project standards
- PM standard programme MSP (managing successful programmes) is UK based
- Managing successful programmes.
- action: pmbok.
- BAA britisch airport authority
- challenges: requests 4billion pounds capital spends
- creation areas annuallly 2 billio
- only 50%
- benefit management approach
- Project TOTO
- eddil christy
- head of buildings
- PgM globally
-
- Simplicity tool must be developed to enable board room of future
- Best value out of my spend
- Multiple projects
- Changes are required?
- Bottom line--> interesting
- Clients / client profiling
- Data available?

- Establishing aggregated view ppm data
- business operations
- division points not clear
- Engineering property service
- developing slide 8 process
- front end loading
- degrees of review
- optimize solution
- determine final benefits
- decision is already been taken
- mps receive-go ahead- optimize-deliver
- ideation phase
- jsk
- principle driver egin prop serv. objective is to spend the budget over year
- cashflow and spend
- optimizing portfolio ensure max value

- alphabed

- capital increase data center network
- property developer
- or core business

- j&j business operation
- engineering property services is different part

- hypothetically

- clients:
- J&J
- HSBC
- City bank
- JSK

- malony jsk arcadis project director
- martin court hspc
- phil darby

- hspc introduce to people

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
7	Global Director BI-IT	Business Intelligence	Global	>13 years	Business intelligence, project data handling, IT system configuration	28-07-2020

CRM system = Oracle sales cloud --> sales pipeline
ERP system = Oracle analytics cloud

KPIs in the oracle analytics cloud
Dashboards
Finance driven

Oracle HCM cloud
Oracle EBS and ERP cloud --> finance, procurement, timesheets, projects

<u>Interview:</u>
Business Intelligence Director

Questions

1. What are the activities of BI Director?
2. Which systems are being used within Arcadis?
3. What project / programme data is used in the systems?
4. What analysis / methods are used with the data?
5. How do you deal with internal and external data?
6. What data is presented in the dashboards you use regarding project management?
7. Are other KPIs (non-financial) KPIs also being monitored in the dashboard, like sustainability?
8. How do you measure scope for the client are their any KPIs for the scope?

1. The role of the BI director is internally focused, including sales and business development, and project services. Relevant information for project managers and operations leaders is gathered and analysed, but also finance and procurement analysis. These are retrospective activities. So, we are mainly working with descriptive analytics. The predictive analytics are performed more by the project managers. Function BI director is mainly looking at the KPIs together with the region and working towards predictive analytics. Linking internal and external data in the data lake. How can we link certain skills from the predictive side to the data that we have internally available?
2. A few years ago, we introduced Oracle Analytics Cloud. The Oracle HCM cloud contains all HR data for employees, etc. Oracle EBS is the old version of the ERP system and Orcale ERP cloud is the new version. These two together are now being used in 65% of Arcadis. These source systems are now being rolled out to all regions. Sales cloud is now 100% rolled out. HCM and ERP will be rolled out in the EU in the coming year, then 85% will be online. Only China and Latin America not yet. Then the entire Arcadis company is on one Erp system. Requests from the ELT can be retrieved immediately. Regions are then no longer necessary to request data. There are then a lot of dashboards that are used in the region.
3. The platform we use for all dashboards and functions that we operate there. Mainly finance-related KPIs are used. Project managers have little insight into their project status based on this data. Only financial insights are used to inform project managers about performance. At the moment a pilot is being run in the UK where it is predicted whether the project will be profitable or not. Employee attrition is also being tracked, to monitor which employees can potentially leave. Oracle sales cloud is the CRM system that our customers are in and the sales pipeline for upcoming work.
   To show what data is available within our systems I will show you around through some field. This is the project manager view this are all the projects he has under control. Project, customer name, contract value. Latest reviews, from here he can zoom in on who has spent hours writing on his project. Here you can see over time, which hours have been written. Project number, period, which people have written time, in this you can see how costs have developed. How profitable are projects, on a regional basis etc. can be tracked, but no predictive analytics are being used here. Project manager can see how his project has developed. But this shows little future. Project review session was done. Projects are passed on once a month. Is the project going well or are there certain concerns? Project review module reports this. The fields you use as fixed fields, name, type of service, what kind of service can I send you. Project review data is not included. Project polls. Talking more about the data we have available, type of service, type of contract and client are stored here. We capture lessons learnt reports as well, so we can learn from this. Top 200 dashboard for an account leader can show what are the projects that play for a customer. Account leader is more responsible for the inside of the work. If there are a lot of different projects for a customer, it can be decided not to accept a project anymore
4. All data in it is sent daily to the Oracle Analytics Cloud to the data warehouse and is being refreshed. All customers, pipeline, timesheets, project costing are incrementally loaded to the data warehouse. Mostly descriptive analytics are used, we visualize data on this dashboard the different work areas are shown. This also includes financial administration and project information. Little analysis are being run on the hours spend by employees on the project, no root-causes for example project delays are being identified on this level, as we don't see the details but only financial data. Thus the project manager himself should explain why project have delay. Project review sessions are kept once a month, where all obstacles and are being discusses, and it is being checked if projects are on track. Project review modules can show root causes. Expectations and forecast data are being compared, when outliers are observed, we notice this and the project manager can be contacted.

5. We try to connect data contained in this Oracle warehouse with Freek's data lake which consists Client data. With these systems we know what the financial performance of our customers is, about the profitability of our projects, project managers can see how their projects are doing. But also what about outstanding working capital or invoices that are outstanding to customers. Now we look at how we can gain more insights through advanced analytics. Combination with other sources gives even more insights.
6. Project management dashboard shows what is available for all projects. This is the pretty ugly version of all the projects we have (PPM dashboard). This contains data dump that finance teams in the region use. Project names (thousand), project number, customer type (ultimate customer / contracted / customer billing or all the same), organisation name (lead), status of projects, contract types (lump sum / time / material). Project manager. Project director, start and end date. Project reviews regime, last review. Project forecast, health and safety plan. Financial KPIS are project budget, turnover, baseline cost calculation, non-labour cost, net revenue, budget labor cost (total budgeted costs), multiplier and margin. Forecast has the same KPIS but for the future. Here you can see which costs are adjusted if more hours are incurred. Current labor cost. Another block with all labour costs (all hours incurred in this area) COSTS per hour per employee, including time sheets. Inception today, specifically current month. Progress reports are not available here.
7. Sustainability is still vague, what should be monitored regarding sustainability? Arcadis is defining the term sustainability. It is not clear what Arcadis sees as part of sustainability. Flex field show on project level some minimal health and safety plans, this mostly linked to the type of projects. This does account as well for sustainability. We try to connect our core strategic values to our project, for example we try to identify how much CO2 is being produced with a project. When it gets more clear about what we want to measure, we want to monitor this on the lower (project) level in the organisation. What type of service we serve to the customer. Core value propositions are monitored. What should the project manager provide as input for this system? We don't know yet
8. In the proposal phase we are very concerned with what we do with this customer. Categorization of projects within Arcadis is being done, but we do not run analytics on this, but we want to gain more insights on this through machine learning. Advanced analytics and my responsibility must come together in this case to gain more insights. IN the UKL predictive analytics are being used for the make every projects count project in Arcadis, I will connect you with this client. Maybe The project review data base is not connected to the ERP/ CRM system which has some kind of categorization regarding size, stakeholders, subcontractors etc.. The Project review regime, indicates what risk group the project is in. Red, orange, green and light. Light is limited risk, project review is done but less intensive. Red projects are viewed very critically. Which criteria are used for the assessment of projects under these 4 colour categories. Guidelines for this will be forwarded later. But this is more an initial screening. Work types are categorized for the customer. What kind of service is offered? This is about Scope, budget is made at the beginning, and forecast is made so that you can see that the scope has changed. This is only based on financial information. Forecast is done once a month. Multiple versions of the forecast. Budget has multiple versions as well. Turnover forecast, cost on project. The forecast multiplier. How often do we collect our costs from sales. Healthy multiplier is above 2.0. This is linked to the scope. Scope management can be linked to this. There is a lot of data connected to calculating this multiplier factor which can give insights.

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
8	Consultant – Business Analytics	Business transformation	United Kingdom	>3 years	Project data analytics	02-06-2020

Business and data management day to day operation

- machine learning
- simulation non statistical techniques
- HSBC advanced analytics
- quantity and quality

- Annual cycle due to banking industry
- Commercial function
- Reporting to commercial
- Mainly programming

- presentation HSBC
- What do you know today that you wished you knew a year ago, we use the past for present context, to use in the future

- Variables Tracked value
- Country
- Type
- Category
- Value
- Date

- Suppliers stakeholders (smart sheets excel)
- pushing powerapps
- 1000 projects 800 covid
- PCA - principle component analysis
- Hardcode
- PM system is labeling or categorizing projects
- process
- extract, tracked, measure, change behavior
- We are going to be on the budget
- Capital planning
- Scope
- Application
- Direction
- Availability
- Transactions money
- Accuracy is really based on models
- Finance
- Programme data
- 6 gateways
- construction phase
- dates
- gate stage
- annual process
- design by certain point in year
- Feature importances
- stage 1 85%
- Stage 3 97%
- main causes
- wrong information input
- exploration
- workstream
- Risk data
- Cost
- Dataset advances
- contracts
- historic cost performance
- Programme data
- forecast is never good
- actual date contractual obliged
- risk
- out of scope benefits

- Lessons learnt from the projects

- Dgitizing rail way
- cost good
- schedule good

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
9	Business Director	Project & Programme Management	Middle Eastern	>25 years	Introduction programme management, lessons learnt reports	16-06-2020

- Yasser Khan

- PgM practice
- Healthcare background
- EC harris
- Arcadis london
- Programme director
- Quatar
- 2012-2018 big projects HMC
- 100 mil reals
- HMC facility department

- Overal arcadis
- industry best practice
- Lessons learnt
- 22 SOPs
- Arcadis way

- Assess on local market
- Client
- Complexity
- NTCP
- Strategy in place
- Prioritization sectors
- Financial pressurre
- HMC asset information model
- CDE common data environment
- Assessment for involvement

- Key consideration
- capability to deliver
- goobal loca
- where to get capability
- focus on asset management
- 3 business
- Joint venture
- 5 year project 100 mil reals
- sensitive decision
- Cost management data is complete
- 1 inform decision making
- 2 helps answers questions
- P6 data --> easy to extract data
- There is no centralized controlled time data base
- Commisioning triangle
- client contracter end user

- DC harris big series templates

#	Function	Division in Arcadis	Region	Experience in AEC business	Interview objectives	Date
10	Programme Director	Retail & Banking	United Kingdom	>30 years	Introduction programme management, barriers and needs for project and portfolio management practices	03-06-20

HSBC (Biggest Account)

1000 projects
700 completely running (corona)
5000 projects

Gate way/stage projects process
Matrix
Initiation phase document requirements
Templates

Other phases--> procurement, handover
Theory of project/programme/ portfolio management is good but the practice is very bad

Simplification os the process is key
Language barrier with setting up substantiated processes
Standard platform is needed
System for information
COO per country is developing processes, arcadis is developing processes, HSBC central ETL is developing processe (alignment)
This triangle of global/local/ client make it difficult and bureaucratic

Categorization

Set criteria

Coutnry strategy versus global strategy

Property strategy

Benefits:
- cost saving
- pre construction stage shorter
- less downtime

Branding
Data management

Benefit realization

ATM replacement is a small project, building entire new building is huge

Appendix IX.

Different maturity models have been compared on scope, levels, domains, and artifacts.

Table 25: Comparison data management maturity models and frameworks (Source: Author's own analysis)

Model/ Key components	DAMA-DMBOK	DCAM	CMMI-CERT-RMM	IBM Maturity model	Stanford Maturity Model	Gartner's Maturity Model	COBIT 4.1	ISO8000-61 ISO8000-62
Scope	Data Management	Data Management	Data Governance	Data Governance	Data Governance	Information Management	IT Governance	Data Quality
Numberst of maturity levels	6	6	Unknown	5	5	Unknown	6	DQ-6 Process-5
Number of domains	11	8	6	4	2	7	NA	4
Domain type	Knowledge area	Capability	Process	Competency	Process	Unknown	Control object	Process
Number of domain dimensions	>4	112	25	10	6	NA	NA	Subprocess-14
Artifacts	Not available	Available	Unknown	Examples	Available	Unknown	Avaiilable	Unknown
Key domain dimensions	1. Activiities 2. Tools 3. Standards 4. People and resources				1. People 2. Policies 3. Capabilities			
Model/ Key components	DAMA-DMBOK	DCAM	CMMI-CERT-RMM	IBM Maturity model	Stanford Maturity Model	Gartner's Maturity Model	COBIT 4.1	ISO8000-61 ISO8000-62
Domain type	Knowledge area	Capability	Process	Competency	Process	Unknown	Control object	Process
Level 0	No capability						No-existent	Basic
Level 1	Initiial/ ad-hoc	Non initiated		Initial	Initial		Initial/ ad-hoc	Basic
Level 2	Repeatable	Conceptual		Managed	Managed		Repeatable	Managed
Level 3	Defined	Developmental		Defined	Defined		Defined	Established
Level 4	Managed	Defined		Quantitively managed	Quantitively managed		Managed and measurable	Predictable
Level 5	Optimized	Achieved		Optimizing	Optimizing		Optimized	Innovating
Level 6		Enhanced						
Number of domain dimensions	1. Data governance 2. Data architecture 3. Data modeling & design 4. Data storage and operations 5. Data security 6. Data integration and interoperabiity 7. Document and content management	1. Data management strategy 2. Data management business case 3. Data management program 4. Data governance 5. Data architecture 6. Technology architecture 7. Data quality 8. Data control environment	1. Data management strategy 2. Data governance 3. Data quality 4. Data operations 5. Platform and architecture 6. Measurement and analysis 7. Process management	1. Data architecture 2. Classification and metadata 3. Audit information logging and reporting core disciplines 4. Data quality management 5. Information lifecycle management 6. Information secutrity and privacy 7. Organizatioal structure and awarenss 8. Policy 9. Stewardship 10. Data risk management and compliance 11. Value creation	1. Awareness 2. Fomalization 3. Metadata project 4. Stewardship 5. Data quality 6. Master data	1. Vision 2. Strategy 3. Metrics 4. Information governance 5. Organiization and roles 6. Information life cycle 7. Enabling infrastructure	1. Business requirements for data management 2. Storage and retention arrangements 3. Media library management systems 4. Disposal 5. Backup and resoration 6. Security requirements for data management	1. Data quality 2. Data related support 3. Data architecture management 4. Data transfer management 5. Data operations management 6. Data security management

	8. Reference and master data 9. DHW&BI 10. Metadata 11. Data quality		8. Process quality assurance 9. Risk management 10. Configuration management					7. Resource provision 8. Data quality organisation management 9. Human resource mangement

Thereafter, through an iterative process the matrix for Data & Analytics maturity has been created to fit within the organisational needs and focus.

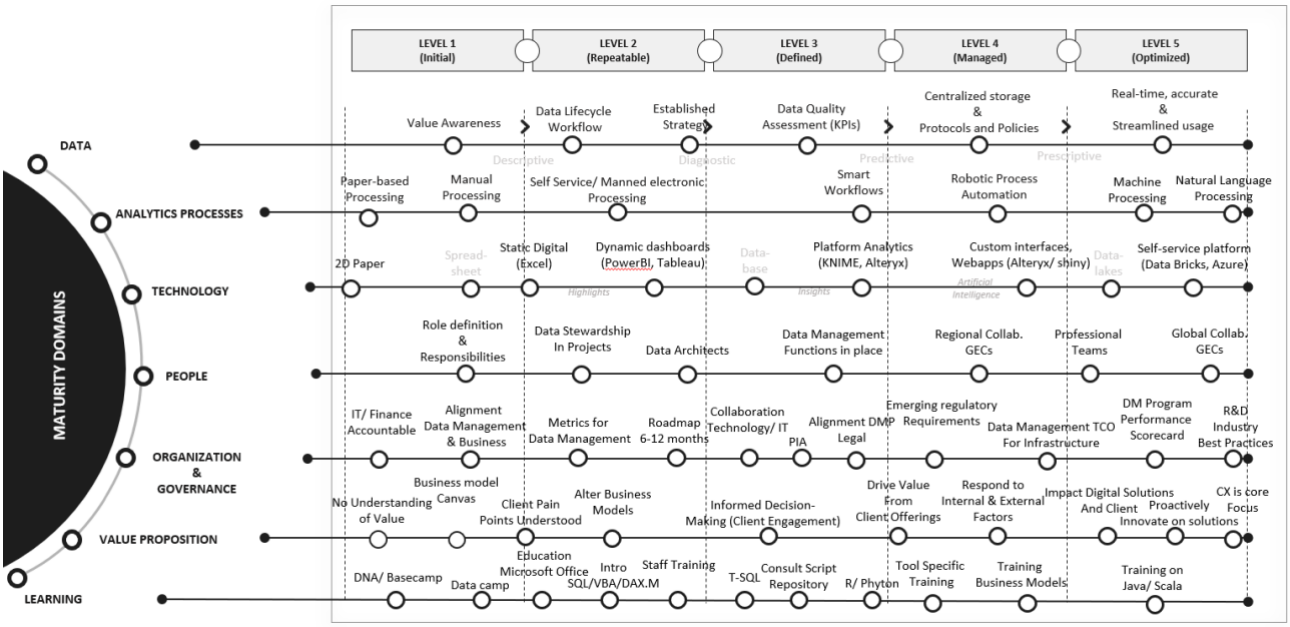

Figure 34: Global Data & Analytics Maturity Matrix AEC Firm (Authors own analysis)

Appendix X.

Expert opinion session with Arcadis subject matter experts – 28.09.2020 12-13h.

A final research presentation was prepared within Arcadis. Here multiple subject matter experts from the AEC industry were invited and asked for feedback and questions regarding the research and the findings.

The presentation lasted for 30 minutes, and an additional 30 minutes were scheduled for question and answer.

Questions from the subject matter experts:

- What level of project management maturity is achieved in Arcadis currently?

As intern it is difficult to estimate this for the entire company, as only internal work has been executed. But as far as I am aware on the maturity of people, processes and technology used in PM practices, I estimated this on a level 3 to for as described in chapter 6.

- Is the framework for PPM more intended for internal use in Arcadis or is it something that we should offer in our services to our Clients?

The framework is generic and is not yet transformed to specific application in a company or in business line. Therefore, strict criteria which are subject to individual preferences must be set up and variable that are important must be investigated. But the structure proposed of the framework give guidance and direction in the way this should be done from a theoretical perspective.

- Only a small percentage (5%) of data available is related to time, of the data that is available of its entirety, how much of the data leaks away do you think/ estimate?

This is difficult to say, as collecting data is the issue here. There is an infinite amount of information available from operations, but the amount we can analyse depends on the way we capture it. This has to do with different methods and systems that are being used. In some cases we are capturing irrelevant data and in some cases we are capturing to little data. With my research I tried to emphasize on different data that is important in project management and portfolio management practices. I think that investigating how we can capture alle the data from the triple constraint of project management (time, cost, scope) is most important. One way to capture all this data is through storing and analysing contracts in a centralized way. Contracts might reveal a lot of information.

- People are very important in digital transformation as your framework is suggesting, what would be your recommendation to drive people to lead digital transformation?

I think it is important to understand that digitalization is something that is initiated through top-down management. But digitalization in the case of project management improvement or portfolio insights needs input from lower level operations and management involvement. Awareness of the value of data is present on higher management levels, but is less present in lower management levels. Especially in the conservative engineers environment in the AEC industry digital innovation must be driven by triggering project executors and project workers to participate in this digitalization.

- Could we combine project management maturity assessments with data & analytics maturity assessments, or should they be treated separately?

This are two different things, that can not be compared. Project management objectives are different than data & analytics objectives. And project management models are different than data management models. Of course there is some overlap, but it is impossible to integrate this.

- Stochastic forecasting is quite complex for most of the people in this call, could you explain what it is and how we should treat this in Arcadis?

This is explained more in detail in my thesis. But to briefly elaborate on this, stochastic forecasting is about making predictions based on trend in macro-economic variables and project characteristics. Here it is advised to define what variables are important for the different sectors we have and what services we are offering to them. If we are for example looking at the oil and gas sector, variances in the oil and gas price and variables regarding supply and demand are interesting. Changes throughout the time can then be linked to client needs and our service offering can than adapt to this.

Feedback from subject matter experts:

"Very nice presentation and really valuable for internal operations, we should strive to implement such a framework in practice, but we are far from that."

"Revenue and margin are maybe better KPIs to focus on instead of NPV and IRR."

"Great work and research executed, interesting but theoretical findings."

"On the barriers and maturity, you are kind with us to say that we are level 3 to 4 on PM. But probably we are more on a level 2 to 3."

"You did a great job on a very complex topic in this organization. Gathering all the data together was a difficult part. And especially integrating all the information and creating an understandable and tangible framework was challenging. But especially the question on leveraging data & analytics in project and portfolio management is very well represented with the thesis."

"Great piece of work, we are using some parts of your thesis in developing some learning modules for the PgM Academy we have in Arcadis, thanks for the simplification of the insights you found to integrate in our current knowledge base"