KU LEUVEN

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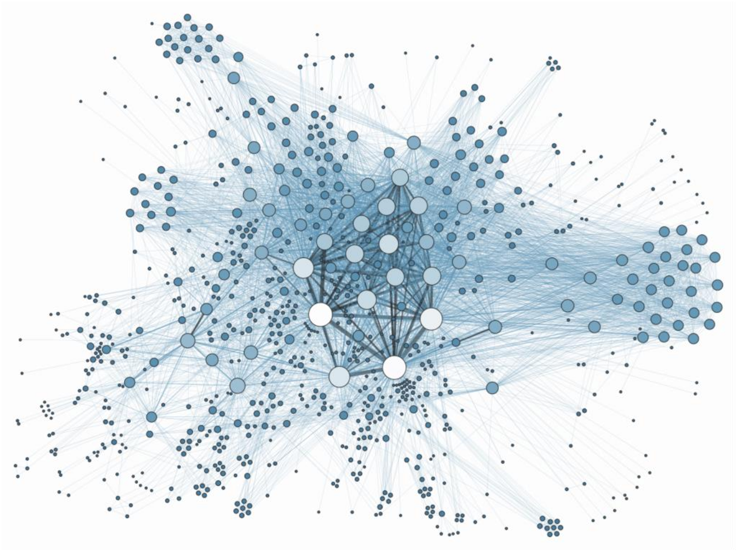
FACULTY OF ENGINEERING SCIENCE

Managing Positive and Negative Complexity

Design and Validation of an IT Project Complexity Management Framework



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Dissertation presented in partial fulfilment of the requirements for the degree of Doctor of Engineering Science (PhD): Mechanical Engineering

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To universality and science.

Preface & acknowledgments

This research project is about designing new models, methods and tools for advancing IT engineering management. It is what managers and IT engineers do: we create continuously and pragmatically new solutions to new problems.

My initial goal was to learn. Then, the mission of this project, the guiding torch was: how will this help. I hope that the results – the new model of Positive, Appropriate, and Negative Complexity, the IT-PCM framework and the associated tools – will support building better IT engineering products.

It was a difficult and personal journey. Research frequently goes differently than planned. It has ups and downs, years of groundwork, periods of over-confidence and of doubt, ages of analysis paralysis, and a few inspirational jumps. Overall, it was a remarkable and fulfilling experience.

There are no words to express my gratitude to my supervisors, Prof. Liliane Pintelon and Prof. Rob J. Kusters, for their guidance, wisdom, patience and persuasiveness to keep this project going; for their commitment to ensuring the highest scientific standards. Thank you from my heart to my supervisory committee members, Prof. Joos Vandewalle and Prof. Traian C. Ionescu, for their continuous support and advice; and to the members of the examination committee for their most useful comments and suggestions.

My utmost respect for the great learning opportunities and environment provided by the Katholieke Universiteit Leuven.

Lots of thanks and appreciation for their professional support to my colleagues, professors, collaborators, partners – most dear friends that I am so lucky to have by my side. They challenged and criticized my theories and concepts; contributed their time, experience, invaluable ideas, input, feedback, insights. Thank you Prof. Radu Jugureanu, Florin Ilia, Doina Binig, Prof. Radu Gramatovici, Alexandra Craciunoiu, Cristian Taslitchi, Rudolf de Schipper, Mihaela Seidl, Theodor Stanescu, Florin Anton, Jimmy Char, Prof. Constanta Bodea, Otto Zelch, Gabriel Nastase, Adrian Nas, Stefan Van Assche, Emil Dragomirescu, Adeline Simota, Marius Hanganu, Ioana Radulescu, Ioan Cocan, Dan Dorneanu, Bogdan Nitulescu, Mihai Olteanu, Monica Vidoni, Ioana Bardan, Andreea Tariuc, Daniel Mihai, Florin Bota, Dan Maxim, Carmen Pana, Marian Chirnoaga, Cristian Fagarasan, Prof. Claudiu Herteliu.

My warmest feelings to my family, and thanks for your support.

Abstract

The world of IT engineering becomes more complex every day. IT products are larger and more complicated, projects are more and more challenging, difficult to manage and control. Complexity correlates with high risk, poor performance and high failure rates; thus the study of project complexity becomes more and more relevant for managing IT projects effectively.

At the same time, IT contributes even more to the society and economy. Complexity is ubiquitous in modern engineering, as well as in project management. It works. It delivers creativity, innovation, and functionality.

This project was about understanding IT project complexity and contributing to its theoretical foundations and practice. It proposes a holistic view, and provides insights into its Positive, Appropriate (requisite), and Negative effects. It proposes a structured framework for IT Project Complexity Management (IT-PCM), composed of formal processes: plan, identify, analyze, plan responses, monitor and control. These are defined and described in terms of inputs and outputs, and with an inventory of available tools and techniques. Anchored in this framework, new practical tools are proposed, for: measuring complexity; analyzing its sources and effects; planning and monitoring complexity mitigation strategies.

The research is grounded in practice, as well as on a literature review on project management, risk and vulnerability management, IT/IS and systems engineering, complexity and systems theory, systems thinking. It was an exploratory qualitative process, based on design science. Several cycles of design-and-validation were performed with semi-structured interviews with experts, based on an analysis of complex IT project cases. A qualitative longitudinal evaluation consisted of the implementation and repeated assessment of the set of proposed tools, in multiple live industry projects.

This thesis aims to provide project managers with methods for increasing project success rates and reducing failure in complex IT project environments. Complexity management contributes to the success of high-risk IT projects, helps better project understanding, allows for better prioritization and planning of resources. Managing negative complexity reduces project risk. Positive and Appropriate complexity are catalysts for opportunities.

Beknopte samenvatting

De wereld van IT-engineering wordt met de dag complexer. IT-producten worden groter en ingewikkelder, projecten worden uitdagender en tevens moeilijker te beheren en te controleren. Deze complexiteit hangt samen met een hoog risico, slechte prestaties en hoge mislukkingspercentages; de studie van projectcomplexiteit wordt dus steeds relevanter voor het effectief beheren van IT-projecten.

Tegelijkertijd levert IT een steeds grotere bijdrage aan de samenleving en de economie. Complexiteit is alomtegenwoordig in moderne engineering, evenals in projectmanagement. Het werkt. Het levert creativiteit, innovatie en functionaliteit op.

Dit project ging over het begrijpen van de complexiteit van IT-projecten en het bijdragen tot de theoretische fundering en de praktijk ervan. Dit onderzoek stelt een holistische kijk voor, en verschaft inzicht in Positieve, Passende (vereiste), en Negatieve effecten van IT-complexiteit. Er wordt een gestructureerd kader met betrekking tot “IT Project Complexity Management (IT-PCM)” voorgesteld. Dit bestaat uit formele processen: plannen, identificeren, analyseren, plannen van (re)acties, monitoren en controleren. Deze processen worden gedefinieerd en beschreven in termen van inputs en outputs, en worden voorzien van een inventaris van beschikbare instrumenten en technieken. Op basis van dit kader worden nieuwe praktische instrumenten voorgesteld voor: het meten van complexiteit; het analyseren van de bronnen en effecten ervan; het plannen en controleren van strategieën om complexiteit te beperken.

Het onderzoek is gebaseerd op de praktijk en op een uitgebreide literatuurstudie inzake projectmanagement, risico- en kwetsbaarheidsmanagement, IT/IS en systems engineering, complexiteit en systeemtheorie, en systeemdenken. De aanpak kan beschreven worden als een verkennend kwalitatief proces, gebaseerd op ontwerpwetenschap. Verschillende cycli van ontwerp-en-validatie werden uitgevoerd aan de hand van semi-gestructureerde interviews met deskundigen en op basis van een analyse van complexe IT-project cases. Een kwalitatieve longitudinale evaluatie bestond uit de implementatie en herhaalde beoordeling van de set van voorgestelde tools, in meerdere live industriële projecten.

Dit doctoraatsonderzoek beoogt projectmanagers te voorzien van methoden om de slaagkansen van projecten te vergroten en falen in complexe IT-

projectomgevingen te verminderen. Complexiteitsmanagement draagt bij tot het succes van IT-projecten met een hoog risico, tot een beter begrip van het project, en maakt een betere prioritering en planning van middelen mogelijk. Het managen van negatieve complexiteit vermindert het projectrisico. Positieve en gepaste complexiteit zijn katalysatoren voor kansen.

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Abbreviations

AI	Artificial Intelligence
APM	Association for Project Management (UK)
CCM	Critical Chain Management
CES	Complexity Effect Scale
CMMI	Capability Maturity Model Integration
COBIT	Control Objectives for Information and Related Technology
COSM	Complexity Source/Effect Matrix
COTS	Commercial off-the-shelf
CoRe	Complexity Register
DSM	Design Structure Matrix
EGIT	Enterprise governance of information and technology
ERP	Enterprise Resource Planning system
EV, EVA, EVM	Earned Value, EV Analysis, EV Management
FP, FPA	Function Points, FP Analysis
FTE	Full-time equivalent
ICT	Information and Communications Technology
IPMA	International Project Management Association
IS	Information System
ISACA	Information Systems Audit and Control Association
ISO/IEC	International Organization for Standardization / International Electrotechnical Commission
ISTQB	International Software Testing Qualifications Board
IT	Information Technology
IT-PCM	IT Project Complexity Management framework
ITIL	IT Infrastructure Library
MDM	Multiple Dependency Matrix
MSM	Mitigation Strategy Matrix
NLP	Natural language processing
OO, OOAD	Object Oriented, OO Analysis and Design

PEST, PERSI, STEEP, STEEPLE	Mnemonics used as checklists, with letters representing factors: • Political, Economic, Social, and Technological. • Religion, and Intellectual. • Environmental. • Legal, and Ethical.
PM	Project Management
PMI	Project Management Institute
PMO	Project Management Office
PMBoK	PM Body of Knowledge
RAD	Rapid Application Development
SDLC	Systems Development Life Cycle
SWOT	Strengths, Weaknesses, Opportunities, and Threats matrix
TOGAF	The Open Group Architecture Framework
UML	Unified Modeling Language
X-BS: WBS, CBS, RBS, ResBS, PBS, OBS	x-Breakdown Structure: Work BS, Cost BS, Risk BS, Resource BS, Product BS, Organization BS

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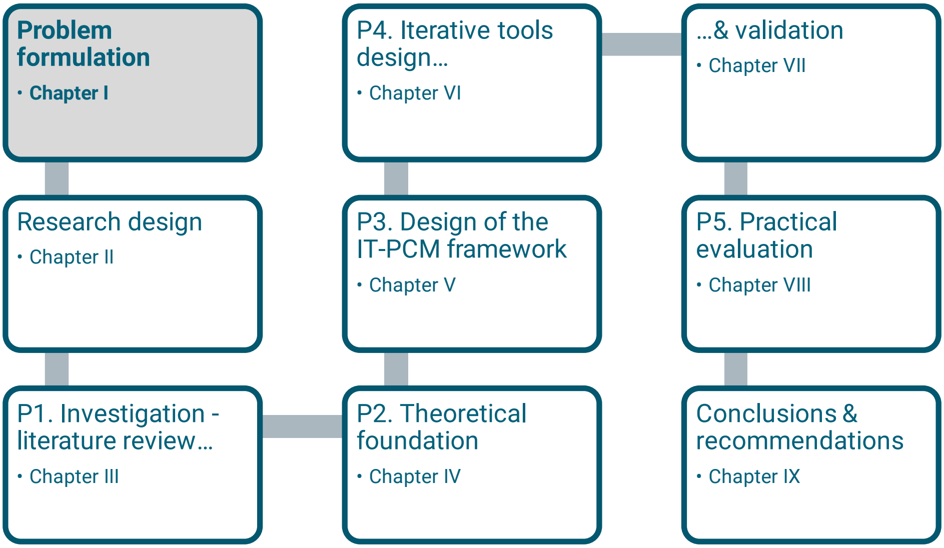
Chapter I.
Introduction



Project management, as well as IT and software engineering, are critical disciplines in today's world, established and recognized, with clear standards, methods, tools, certifications, and professional bodies. While contemporary IT engineering projects, technology, organizations, processes, and markets are becoming more and more complex, complex projects are still poorly understood and face significant challenges and risks.

This chapter starts with an introduction to project management and IT projects, framed in the context of organizational governance (section I.1), and an introduction to the concept of complexity (section I.2). Details are then provided on the specific challenges of managing complex IT projects (section I.3).

The general research goal and objectives are presented in section I.4, followed by the research methods employed (section I.5). The chapter concludes with the structure of the current thesis (section I.6).

This research started from the observation that IT projects become more and more challenging, while more and more rewarding. Projects and products are larger, more complicated, more difficult. At the same time, the benefits of technology to society and the economy are constantly growing.

An astounding contemporary proof of the benefits and importance of technology in today's economy and society was provided by the Covid-2019/Coronavirus pandemic. The global challenges posed during the last 2 years (2020-2021) were tackled successfully with the help of technology. The new remote distributed work model offers in fact significant opportunities to business, economy, to the entire society.

More than this, the current Covid-2019 pandemic offered the opportunity to validate on a huge scale that, indeed, digital collaboration environments are not only simulacra of the physical world, but instead they offer different, enriched experiences. *Skeuomorphism* has always been a driving principle in the design of new artifacts, based on old patterns – i.e. we design new artifacts by mimicking the behavior of ancient artifacts, even if out of context. In our specific example, digital artifacts tend to mimic their physical counterpart. Thus, the calendar applications simulate paper calendars; the memos or notes management apps look like paper-stickers and have paper lips drawn in the corners; e-books look like paperback; the mouse pointer looks like a finger, a pen, or a pencil.

At the same time, digital collaboration enhances the available toolset with *different* tools – not available in the traditional physical environment; thus that cannot respect skeuomorphism principles. A simple example is remote videoconferencing: while it tries to mimic physical meetings, in fact it provides much more than the meeting room; it also replaces the travel, and even offers *new* tools such as (collaborative) whiteboards. Another simple and already common example is the large-scale co-editing of documents: using tools such as Microsoft Office or Google Apps, large groups of tens of people can create a document together – something that is impossible in a physical setting.

Due to the complexity of today's IT product engineering, single projects, single departments or even single organizations can no longer develop a complete product independently. Thus, the industry moves towards specialized lifecycles that involve concurrent, distributed, incremental/iterative, agile development (Moll, Jacobs, Kusters, & Trienekens, 2004) (Moe, Dingsøyr, & Rolland, 2018). IT engineering projects face significant problems related to the complexity of both the products being developed as well as to the ambiguity and uncertainty related to the methods, tools and technologies employed during the development process.

Complexity is a ubiquitous characteristic of contemporary engineering and project management. While it is traditionally associated with risk and high failure rates, the traditional approaches of simplification and reductionism into smaller simpler sub-systems are not always the best option. Specialized tools can reduce it or manage it better; at the same time, complexity offers essential benefits. In fact, we notice all around us that complexity works; it delivers advanced functionality to technical products such as phones, machines, and space aircraft; it supports innovation, creativity, adaptability and viability of organizations (Morcov, Pintelon, & Kusters, 2020b) (Maurer, 2017) (Bar-Yam, 2003) (Stacey, 1995).

I.1. IT projects and organizational governance

I.1.1. Project, portfolio, and program management

A project is a temporary organization to which resources are assigned to create a unique product, service, or result, bringing beneficial change (PMI, 2017) (Turner, 2006a). This definition encompasses several key characteristics of projects:

i) **temporary**, time-boxed, i.e. they have a clearly defined duration.
ii) **unique**, i.e. not repeatable.
iii) clear **objective**, creating specific **value**.
iv) driving **change**.

Project management started as a practical discipline. Its objective is to enable organizations to execute projects effectively and efficiently. As the domain became more and more structured, and as research interest grew, more rigorous theoretical foundations were also established, allowing project management to be recognized as a proper academic discipline (Turner, 2006a) (Turner, 2006c).

Its main professional bodies are the Project Management Institute PMI, and the International Project Management Association IPMA.

The **body of knowledge of project management** consists of management frameworks, standards, methodologies, and manuals. It is described as knowledge areas, processes, tools, and guidelines.

Projects are characterized by the **iron triangle**: they have a clear scope, budget, and schedule. These three dimensions are key knowledge areas in project management. Other important knowledge areas are quality management, resource management, communication, risk, procurement, integration, and stakeholder management.

Portfolios and programs are extensions to project management that support managing groups of projects more effectively.

Portfolios are collections of similar projects. Portfolio management supports efficiencies of scale, increasing success rates, and reducing project risks, by applying similar standardized techniques to all projects in the portfolio, by a group of project management professionals sharing common tools and knowledge. Organizations often create Project Management Offices as an organizational structure to support project portfolio management in a structured way.

Programs are collections of projects that support a common objective and set of goals. While individual projects have clearly defined and specific scope and timeline, a program's objectives and duration are defined with a lower level of granularity.

The literature also lists additional structures that combine different characteristics of the above, such as project networks, mega-projects, or mega-programs. A project network is a temporary project formed of several different distinct evolving phases, crossing organizational lines (Crompvoets & Vanschoenwinkel, 2020) (Artto & Kujala, 2008) (Defillippi & Sydow, 2016). Mega-projects and mega-programs are defined as exceptional in terms of size, cost, public and political attention, and competencies required (Kardes, Ozturk, Cavusgil, & Cavusgil, 2013) (Nyarirangwe & Babatunde, 2019) (Flyvbjerg, 2017) (Sauer & Willcocks, 2007).

The following section positions IT project management in the context of enterprise IT governance and management.

I.1.2. IT project management in the context of organizational governance

Corporate governance is the set of procedures and processes based on which an organization is directed and controlled. It ensures that specific individual initiatives and actions, including temporary projects, are aligned with the global goals and values. Governance includes defining enterprise objectives, ensuring that these are achieved by evaluating stakeholder needs, conditions and options; setting direction through prioritization and decision making; assigning rights and responsibilities; and monitoring performance, compliance, and progress against agreed-on direction and objectives (ISACA, 2019) (ECB, 2009). Governance has thus 3 components: i) structures and processes; ii) managing and controlling; iii) stakeholders (Buntinx, Crompvoets, Ho, Timm, & Wayumba, 2018).

IT governance is the system that ensures that the use of ICT is directed and controlled at the level of an organization, sustaining and extending the organization's strategies and objectives (ISO/IEC, 2015). IT governance aims to clarify the strategic objectives of IT in the organization, to ensure that they are implemented, and to minimize the associated risks.

Developed by the Information Systems Audit and Control Association ISACA, COBIT - Control Objectives for Information and Related Technology is one of the most used enterprise governance of information and technology (EGIT) frameworks (ISACA, 2019). COBIT supports 3 main outcomes: realizing benefits, optimizing risks, and optimizing resources. COBIT aims to be a comprehensive and holistic framework covering enterprises end-to-end, assisting them in achieving their goals and delivering value through effective governance and management of enterprise IT. It defines several components: i) processes; ii) organizational structures; iii) principles and policies, iv) information; v) culture, ethics, and behavior; vi) people and skills; vii) services and infrastructure.

COBIT specifically differentiates between governance and management.

Management is the group of processes that ensures the execution of the organizational activities, in alignment with the direction set as part of the **Governance** processes.

Introducing or modifying an IT-related process or tool is an organizational change, with implications likely to cross boundaries and affect various parts of the organization. Such a change is typically implemented by organizations through specific IT projects.

IT projects are unique, time-boxed endeavors, that use technology to achieve a specific objective, typically a change in the organization, in support of a larger organizational goal. Upon the initiation and execution of individual projects, an organization must ensure its alignment with the overall goals. The mechanisms for ensuring this alignment are part of enterprise governance of information and technology (EGIT) (De Haes, Van Grembergen, Joshi, & Huygh, 2020).

The concept of *governance* is distinct from *management*. Also, governance is relevant at all levels, including at the level of projects. Thus, ***project governance*** consists of defining the objectives, the means of obtaining them, and the means of monitoring the performance of a project (Turner, 2006b).

IT project management is the process of managing, i.e. planning, organizing, and delineating responsibility, for the completion of a set of specific information technology (IT) goals of an organization (Cole, 2015). Since IT is ubiquitous to modern organizations and society, the scope of IT projects in contemporary organizations can be significantly large and complex. These projects impact the whole organization; therefore the boundaries of traditional project management are less strict in IT projects; they overlap with other projects and organizational processes (Elbanna, 2010). IT projects exhibit thus particular complexity traits, and require specific coordination and management tools – as argued in the next section.

IT governance and management are areas of particular interest to contemporary organizations. They cover a wide variety of topics and evolve continuously. From this wide range of relevant topics, the current research concentrates on a specific aspect, which is the management of complex IT projects.

The following section provides an introduction to the concept of complexity, before looking into the particularities of complex IT project management.

I.2. The concept of complexity

The definition of the word complexity alludes to interconnectivity. Its etymology is Latin and relates to complicatedness – the word being formed of *com* meaning together, and *plectere* meaning weave.

The term *complex* is thus often used instead of, and interchangeably with, *complicated*.

The word is also often used to describe *difficult* problems (Ehrlenspiel, 1995) (Maurer, 2007). Also, a large project or system is often described as *"complex"* (a discussion on complexity measurement can be found in section III.5. The relation between size and complexity is discussed in section III.3.2).

Its dictionary definitions are[1]:

- consisting of many different and connected/ interrelated parts;
- not easy/difficult to analyze or understand, to deal with;
- complicated or intricate;
- compound, composite;
- made or done with great care or with much detail.

Noticeably, *"complex"* is a fashionable word; having connotations such as fancy, sophisticated, elaborate, baroque[2].

[1] Oxford's English dictionaries, Merriam-Webster, Random House Unabridged Dictionary etc.: https://www.google.com/search?q=define+complex, https://www.merriam-webster.com/thesaurus/complex, https://www.dictionary.com/browse/complex, https://www.oxfordlearnersdictionaries.com/definition/english/complex_1, https://www.oxfordlearnersdictionaries.com/definition/academic/complex1

[2] Merriam-Webster: https://www.merriam-webster.com/thesaurus/complex, https://www.synonym.com/synonyms/complex

The concept of complexity, as being more than complicatedness, is ancient; its roots can be traced to Greek philosophy. Aristotle probably formulated the first definition of complexity, when arguing that *the whole is something else than the sum of its parts* (Aristotle). This definition was later simplified by Euclid as: the whole is *more* than the sum of its parts (Euclid). These 2 definitions re-emerged in contemporary approaches to complexity, which differentiate between simple, complicated, complex and really complex – as argued in section III.3.3 – “Simple, complicated, complex, and really complex projects”.

Complexity re-entered mainstream science and research with the theories of *holism* and *gestalt psychology* (Smuts, 1927) (Koffka, 1935). It is now recognized as vital in a multitude of domains such as mathematics, chaos theory, information and computing science, engineering, biology, ecology, sociology, psychology, education, economics, and management.

A complex system is formed of so many interwoven components and factors, that it does not allow varying only one factor at a time; any change in any one factor triggering dynamic changes in a great many others (Ashby, 1961).

Mathematics and computer science made attempts at formalizing complexity, e.g. Kolmogorov complexity (Edmonds, 1999) (Maurer, 2017). These are not transferable to other domains that cannot be easily formulated mathematically. In project management, such formal methods were particularly attempted for limited problems, such as measuring the complexity of a project plan (Nassar & Hegab, 2006).

Complexity is a topic of interest in a wide area of domains, including engineering. Out of these, the current thesis concentrates on the specific domain of complexity of IT projects. Accordingly, the level of applicability of the results of the current thesis to other domains cannot be easily formulated; such assessment being a potential topic for further investigation.

The following section discusses the particularities and challenges posed by the management of complex IT projects.

I.3. Complexity of IT engineering projects

Interacting with complexity is crucial almost everywhere in engineering (Vidal, 2009) (Maurer, 2017). While similarities are documented across different engineering fields, the level of maturity of understanding and tackling complexity varies from one discipline to the other, mainly because these disciplines were founded at very different moments, and thus have different states of the art and dispose of different tools – with software engineering being a particularly young domain (Maurer, 2017, p. 5).

IT projects are recognized by both practitioners and researchers to have a significant risk of failure, and high-cost overruns. IT projects systematically derail, with industry reports suggesting that only a handful are successful - between 16% and 31% (Standish Group, 1994) (Nelson, 2007) (Standish Group, 2014). All IT projects exhibit traits of complexity, being difficult to manage and control. A practical observation is that a well-managed project is a project with a well-managed mess, rather than a project without a mess.

Some IT projects are particularly large and complex, and face significantly difficult challenges. Research shows that a surprisingly large number of IT projects incur massive cost and schedule challenges. In fact, one in six IT projects is expected to be "a black swan, with a cost overrun of 200%, on average, and a schedule overrun of almost 70%" (Flyvbjerg & Budzier, Why Your IT Project May Be Riskier Than You Think, 2011). A significant number of IT projects are reporting incredible losses: Levi Strauss' SAP implementation was a $5 million project that led to an almost $200 million loss; the "Toll Collect" project cost Germany $10 billion in lost revenue; the overall losses incurred by underperforming IT projects in the US are estimated at $55 billion annually (Flyvbjerg & Budzier, Why Your IT Project May Be Riskier Than You Think, 2011). When the European Commission finally launched the Schengen Information System (SIS II) in 2013, the project was more than 6 years late and 8 times more expensive than the initial estimate, at a final cost of €500 million (European Court of Auditors, 2014). Berlin Brandenburg Airport in Germany, scheduled to open in 2011 for 2.5 billion Eur, was finally opened in 2020, with a final bill of 7 billion (Baulinks, 2018) (Euronews, 2020).

Complexity strongly correlates with high-cost, high-risk, and poor project performance (Williams T. M., 2005) (Patanakul, 2014) (Floricel, Michel, &

Piperca, 2016) (Bjorvatn & Wald, 2018). This makes IT project complexity research particularly relevant to today's IT and software engineering environments.

I.3.1. Complexity of AI projects and ethical considerations

Ethical considerations impact our research in several aspects. Ethical factors are environmental factors that generate complexity in IT engineering projects both directly, as well as from a regulatory and political point of view. The ethical aspects of engineering projects can form a complexity sub-system in itself. Also, ethics management frameworks will become in the future more and more a part of IT engineering.

The low level of explainability, data biases, data security, data privacy, and ethical problems, as well as the complexity and capability associated with technologies such as AI, make such projects unique and controversial (Siau & Wang, 2018) (Siau & Wang, 2020) (Gabriels, 2021).

Ethics is a key characteristic of intelligence, hence it is incorporated into the contemporary theoretical definitions and models for artificial intelligence (AI). Thus, ethical intelligent agents have been classified into 4 categories, starting with ethical impact agents (AMA level 1), and up to full-ethical agents (AMA 4) (Moor, 2006).

Researchers and engineers acknowledge that true artificial intelligence does not exist yet. "True AI" is defined as full-ethical agents, i.e. machines endowed with conscientiousness, awareness, intentionality, free will. Accordingly, the ethical considerations related to artificial awareness are still a domain of theoretical research, yet to be incorporated into more practical applications. The European Commission has dedicated special research funds and specific actions to this domain (European Innovation Council, 2021).

Ethical aspects are highly relevant in contemporary engineering even at lower levels than true AI. In fact, ethics and morality are embedded in every human product. Accordingly, it makes sense to ask ethical questions about design, right from the outset, in any project (Gabriels, 2021).

Explicit ethical agents (AMA level 3), which represent machines that make ethical decisions based on predefined sets of rules, are specifically relevant to this discussion. Such machines are already ubiquitous in today's society. We are already surrounded by such agents: cars able to make decisions, sometimes even overriding the driver – e.g. breaking in emergency situations; digital social networks that decide what kind of content is appropriate for specific audiences, by using NLP – natural language processing and context analysis tools. Ethical rule engines are difficult to define and measure, which makes their behavior in itself a complex problem, difficult to understand and explain even when given reasonable information regarding its mechanisms.

These engineering projects have political and social implications. While ethics is already strongly regulated in other fields such as medicine (World Medical Association, 2013) (EP-EC, 2014), a stronger regulatory environment is being announced in engineering as well, especially related to artificial intelligence (European Commission, 2021).

Artificial Intelligence machines and ethical considerations of machines constitute an important factor and cause of complexity in today's IT engineering.

I.3.2. The specific challenges of managing complex IT projects

Complexity in IT project management is a young area of research, but it draws from previous theoretical research such as systems, complexity, or chaos theories, as well as technical research areas such as systems engineering and IT/software development.

Lack of understanding and recognition of system complexity is a critical cause of poor performance of large-scale IS/IT projects (Patanakul, 2014). The approach prevalent in the project management research and community of practice is that complexity affects negatively both project performance and project management performance (Floricel, Michel, & Piperca, 2016) (Bjorvatn & Wald, 2018) (Ivory & Alderman, 2005) (Montequín, Joaquín, Sonia María, & Francisco, 2018) (Głodziński, 2019).

Large-scale, complex projects are expensive. Complexity impacts negatively all the components of the iron triangle of project management: the budget, schedule, scope, as well as quality. The *cost of complexity* is therefore expressed not only in financial terms, but also in time, delivered scope, and quality. The cost of this complexity may *compound* to huge values at completion. Complex projects have a higher risk of not accomplishing their objectives and a higher monetary value associated with these risks, hence significant costs are incurred when they fail.

Therefore, the management of complex IT projects is an expensive activity, requiring special tools, expertise, and skills. Complex IT projects cannot be managed with traditional deterministic, monolithic, top-down approaches (Daniel & Daniel, 2018) (He, Luo, Hu, & Chan, 2015) (Zhu & Mostafavi, 2018). They face significant, unpredictable change, similar to Lorenz's "butterfly effect" (Lorenz, 1963). Complexity increases the likelihood of occurrence of Black Swan events and significantly reduces the effectiveness of traditional tools such as forecasting (Taleb, Goldstein, & Spitznagel, The Six Mistakes Executives Make in Risk Management, 2009).

The skills and competencies of the project manager, already key to overall project success, become even more important (Ammeter & Dukerich, 2002). The identification of complex projects is specifically important to multi-project engineering environments (Vidal, Marle, & Bocquet, 2011). The traditional project management frameworks do not differentiate between the tools and methods that should be used for complex non-deterministic projects as opposed to simple and deterministic projects. A systematic approach to complexity management allows for identifying, understanding, and managing projects more efficiently, by choosing the best framework, tools, techniques, and methodologies deployed for such projects.

I.4. Research goal, objectives, and questions

The **goal** of this research project is *to contribute to the understanding and management of complex IT projects*.

The **overall research objective** is *the design, validation, and evaluation of a set of tools for the identification, analysis, and management of IT project complexity*.

To achieve this goal, several intermediate objectives and research questions were set, that build towards the overall research objective (Table 1). Each objective was addressed by a specific research sub-project, as described below.

Table 1. Thesis objectives and research questions

Sub-project	**Research questions**	**Rationale**
P1. Investigation. Systematic literature review 1on the topic of project complexity	RQ1. Which are the existing definitions and approaches to project complexity? RQ2. Which are the characteristics of project complexity? RQ3. How can complexity be identified and measured?	Validate the importance of the topic. Understand previous research. Build a knowledge foundation on which to base the future research.
P2. Establish the theoretical foundation, clarify how we look at project complexity	RQ4. Which is the appropriate theoretical foundation/approach to project complexity, for the scope of this project?	Establish a common language for addressing the topic and ensure a rigorous approach for future tool design. Choose which is the definition and approach to be used in the research project. Clarify how we look at complexity.
P3. Design a practical IT Project Complexity Management (IT-PCM) Framework	RQ5. What framework can support the design of a toolset for IT project complexity analysis and management?	Offer a structured process for the deployment and application of management tools. Identify useful existing tools, and gaps where relevant tools are missing. Ensure a rigorous approach and a framework in which to anchor the design of new tools.
P4. Design and validate IT project complexity management tools	RQ6. What tools can support IT project complexity identification, analysis, and management?	Propose new tool designs to fill the gaps identified in P3, using design science – with 2 design-cycles of design-and-validation activities.
P5. Evaluate the effectiveness of the tools in practice	RQ7. What is the contribution of the designed tools to project success?	Assess the effectiveness in practice of the designed tools. Understand and analyze the application in practice of complexity analysis and management tools.

The intermediate objectives, and the respective sub-projects, build towards the overall thesis objective:

- P1, P2, P3: problem investigation; ensuring the relevance and rigor of the design research project (Hevner, March, Park, & Ram, 2004).
- P3, P4: tool design and validation, in iterative *design-cycles*.
- P5: implementation and evaluation, concluding a full *engineering-cycle* (Wieringa, 2014).

I.5. Methods. Research sub-projects

The research approach was qualitative, based on design science. It started from the literature review and modern perspectives on project management, project complexity, systems theory, and Systems and IT Engineering.

During our design research process, we embraced the fact that qualitative research is a *personal journey* (Gummesson, 2000); where ideas and findings are reconceptualized with each writing and iteration (Bansal & Corley, 2012). As such, the results of each research sub-project modeled the activities and results of the next one; the artifacts were built in successive iterations and increments, and updated according to the successive rounds of review, feedback, validation, and evaluation.

Both project management and engineering take a pragmatic stance; they design and test new tools continuously. Our research methodology followed this pragmatic constructivist approach to solving problems, with an iterative-incremental approach, with trial-and-error cycles, following the *engineering cycle* and the *design cycle* (Wieringa, 2014).

Figure 1 and Table 2 present the research sub-projects and thesis structure.

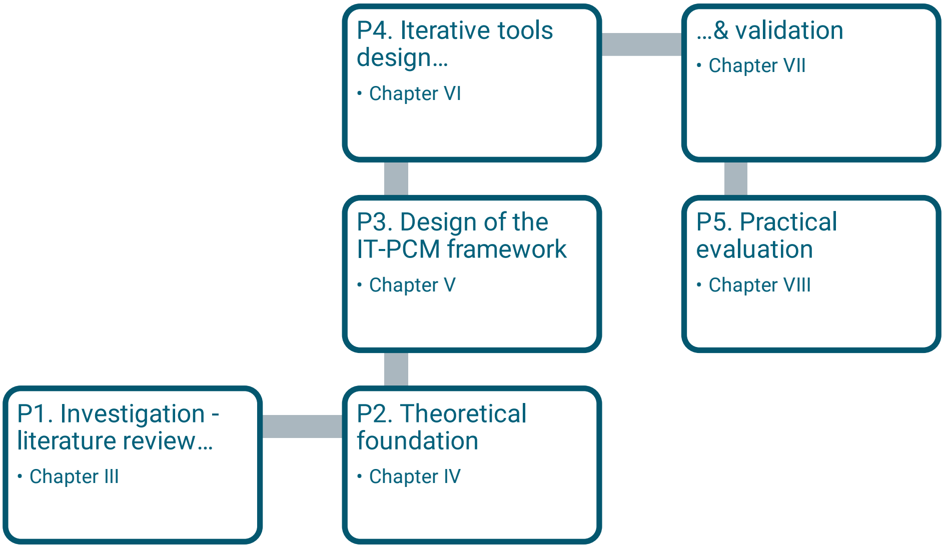


Figure 1. Research sub-projects

Table 2. Research sub-projects & thesis structure

#	Research sub-project	Chapter	Published results
	Problem formulation	I	
	Research design	II	
P1	**Investigation. Literature review**	III	(Morcov, Pintelon, & Kusters, 2020a)
P2	**Theoretical foundation –** perspective on project complexity	IV	Published as part of P4
P3	**Management framework design**	V	(Morcov, Pintelon, & Kusters, 2021a)
P4	**Tools design-and-validation**		(Morcov, Pintelon, & Kusters, 2020b)
a)	*Initial design of the tools*	VI	
b)	*Preliminary validation*	VII	
c)	*Detailed design*	VI	
d)	*Final validation of the tools*	VII	
P5	**Tools evaluation in practice – in live project cases**	VIII	(Morcov, Pintelon, & Kusters, 2021b)
	Conclusions & recommendations	IX	

The research consisted of the following sub-projects and activities:

P1. **Investigation: a literature review** on project complexity literature, systems theory, systems and IT engineering, to establish the theoretical and practical foundation for the design, to uncover valuable recent contributions. Its research questions are to identify the theoretical definitions, models and approaches to project complexity; complexity characteristics; and complexity measurement tools *(*Chapter III*)*.

P2. The literature review supported establishing **the theoretical foundation of this project**. These are the basis for the research; the chosen approach and the perspective taken to project complexity. This step ensures rigor for the future tool design *(*Chapter IV*).*

P3. **Management framework design**: development of the IT project complexity management framework, with detailed processes and tools inventory. It also supports a rigorous approach to the design of new tools, offering the framework in which to anchor the concepts and individual tool designs. It provides structure for the deployment and application of complexity analysis and management tools *(*Chapter V*)*.

P4. **Tools design-and-validation**. The objective was to design a set of tools to support the identification, analysis, and management of IT project complexity. This sub-project consisted of several *iterative-incremental* activities, depicted in Figure 2:

a) **Initial design of complexity management tools**: development of the initial design concepts, based on the literature review, and refined through interviews with experts and analysis of actual complex IT project cases (Chapter VI).
b) **Preliminary validation** of the designed tools, done with empirical methods – semi-structured interviews with experts, based on actual project cases. This phase aimed to validate the practical use of the tools, their relevance and applicability (Chapter VII). It was a qualitative validation that supported the iterative refinement of the design artifacts, in the subsequent step.
c) **Detailed design of the tools** – during which the tools were refined based on the results of the Preliminary validation, with special attention to the negative, and to the original feedback received (Chapter VI).

d) **Final validation** of the tools, in a second round of interviews with the same experts (Chapter VII).

P5. **Evaluation in practice** of the proposed tools, in a longitudinal assessment in actual live IT project cases (Chapter VIII).

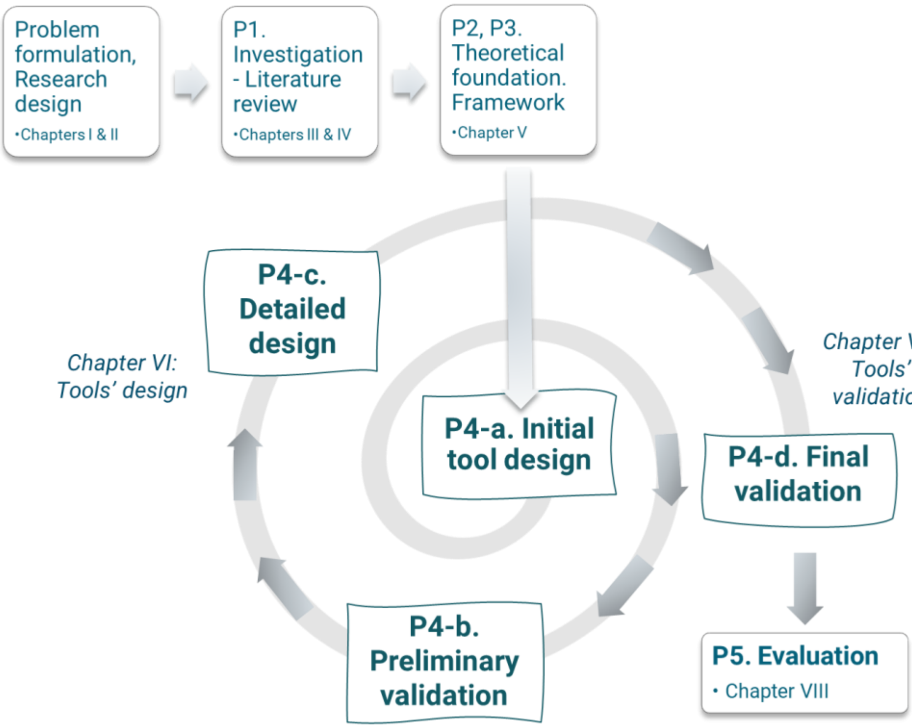


Figure 2. The iterative design-and-validation approach

I.6. Structure of the thesis

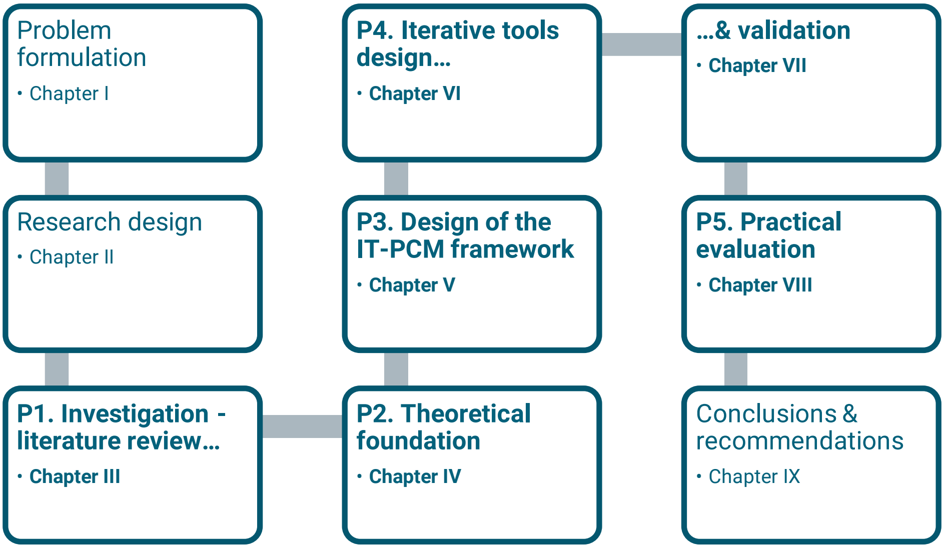


Figure 3. Thesis structure

Chapter I is an overview and introduction to the research topic.

Chapter II presents the overall research methodology. It describes our qualitative approach, based on design science, grounded on a literature review, consisting of 2 cycles of design and validation, and a final evaluation project. The detailed methodologies and results of each research sub-project are described in detail in the subsequent chapters.

Chapter III is a systematic literature review that attempts to identify and classify proposed definitions and measures of IT project complexity. Its results are a map of identified approaches and definitions, a list of classifications of project complexity, a set of proposed measurement tools available to practitioners. It attempts to establish a common language when discussing complexity, to better understand project complexity and its implications to practical IT engineering projects.

Chapter III was published in a shorter form as "Definitions, characteristics and measures of IT Project Complexity - a Systematic Literature Review", in the International Journal of Information Systems and Project Management (Morcov, Pintelon, & Kusters, 2020a).

A set of theoretical constructs are presented in Chapter IV: *Theoretical foundation*. The chapter identifies the chosen definition and model for approaching project complexity. It defines IT Project Complexity Management as a new project management knowledge area. It also explores a holistic paradigm of *complexity of complexities*; and proposes a new approach to complexity analysis, based on its effects: *negative, appropriate, or positive*. These form the theoretical foundation for the future tool designs.

Chapter IV is an expanded form of concepts published, as a preamble to Chapters VI and VII, in (Morcov, Pintelon, & Kusters, 2020b).

Chapter V proposes a practical **IT-PCM framework** to support IT Project Complexity Management in a structured, systematic way. It consists of the following processes: plan, identify, analyze, plan response strategies, monitor and control. The processes and steps interact with each other and with other project management processes; they overlap, are incremental and iterative. These are described in terms of inputs and outputs. A detailed inventory of available tools and techniques is proposed for each process and step.

Chapter V was presented and published, in a shorter form, at the IADIS Information Systems Conference (IS 2021), as: "A Framework for IT Project Complexity Management" (Morcov, Pintelon, & Kusters, 2021a).

A set of specialized tools were designed based on the theoretical research and literature review. These were validated and refined iteratively, through semi-structured interviews with experienced professionals. The tools are described in Chapter VI.

The results of the validation of these tools are presented in Chapter VII.

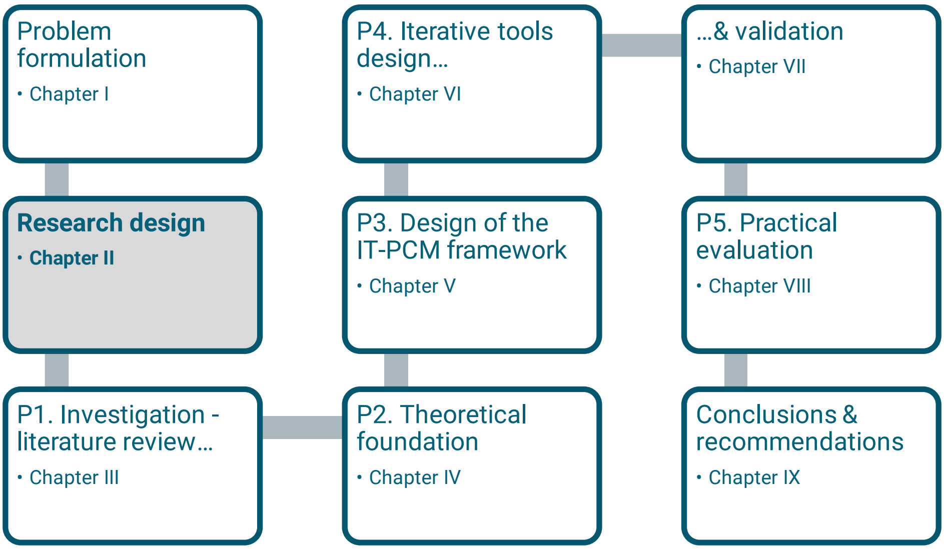
Chapters VI and VII were published, in a shorter form, in the Proceedings of the Romanian Academy - Series A, as "IT Project Complexity Management Based on Sources and Effects: Positive, Appropriate and Negative" (Morcov, Pintelon, & Kusters, 2020b).

Chapter VIII presents the evaluation in practice of the designed tools, in actual project cases.

Chapter VIII was accepted for publication in the International Journal of Information Technology Project Management (IJITPM), as: "A Practical Assessment of Modern IT Project Complexity Management Tools: Taming Positive, Appropriate and Negative Complexity" (Morcov, Pintelon, & Kusters, 2021b).

Chapter IX, the last, presents the conclusions, implications, limitations, and a summary of the contributions of our research to the field of IT Project Complexity Management.

Chapter II. Methodology



This chapter presents the overall methodology of the research, and a summary of the methodologies of the individual research sub-projects.

The research approach is dialectical, qualitative, and inductive. It is based on constructivism. The overall methodology is Design science.

II.1. Research methodology

Qualitative research helps develop initial understanding in a less explored area, such as the topic of this project – as further shown in the investigation, Chapter III (Levitt, et al., 2018) (Gummesson, 2000).

Qualitative research is interpretive, the researcher being part of the context, actively discussing interpretations with research participants (Saunders, Lewis, & Thornhill, 2009). The perspective and interpretation of the participants is a valid starting point to understanding the research context.

The research approach is inductive. The main data collection methods were interviews and case studies, using observation, and detailed analysis of the available documentation (Yin R. K., 2011). The data collection is both cross-sectional and longitudinal, and uses in-depth investigations of small samples (Saunders, Lewis, & Thornhill, 2009). Based on qualitative analysis of the initial data, we build theories and models, that we further test, validate, and evaluate. Inductive research is sensitive to its context; the observations and testing are valid in a specific environment, therefore it is not easy to generalize their conclusions beyond the stated conditions (Saunders, Lewis, & Thornhill, 2009).

In qualitative research, the role of academic researcher often overlaps with the role of consultant. This mix is recognized in management research literature as the action research paradigm (Gummesson, 2000).

Design science is a valid research methodology to develop solutions for practical engineering problems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). We consider complexity management to be a *wicked problem*, for which design science is particularly suitable (Hevner, March, Park, & Ram, 2004).

The research project is formed of sub-projects that together constitute a full ***engineering cycle*** (Wieringa, 2014). The typical engineering cycle is presented in Figure 4 and Figure 5, and consists of:

- Problem investigation.
- Treatment design.
- Treatment validation.
- Treatment implementation.
- Implementation evaluation.

The engineering and design cycles do not prescribe a mandatory, rigid sequence of activities. Moreover, they are often applied recursively for sub-problems of the main research objective.

The engineering cycle and the design cycle are often applied in several iterations (hence “cycle”). In such a case, the evaluation may become the investigation part of the next engineering cycle.

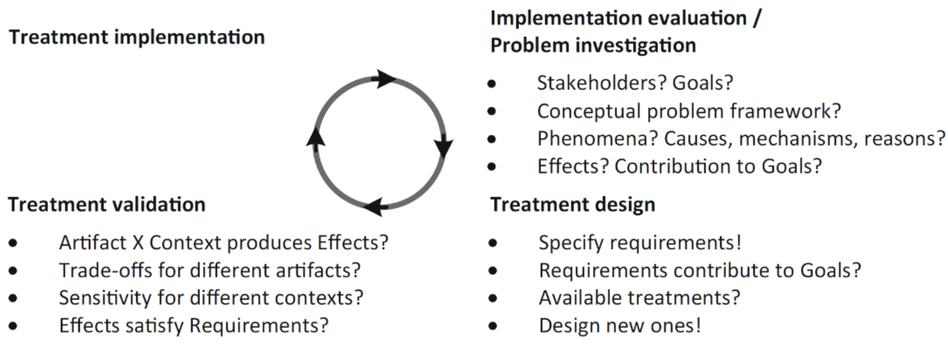


Figure 4. The engineering cycle (Wieringa, 2014)

The *design cycle* consists of the first 3 tasks of the engineering cycle: investigation, design, and validation (Figure 5) (Wieringa, 2014).

In the current research project, the design cycle was applied in 2 iterations.

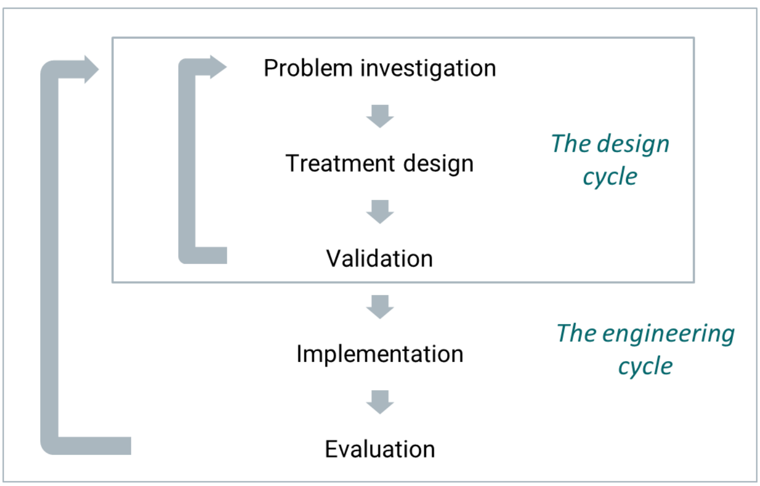


Figure 5. The engineering cycle and the design cycle. Author design, based on (Wieringa, 2014)

According to the Design science methodology of (Wieringa, 2014), ***validation*** is part of the design cycle. It involves checking if the designed artifacts support the initial assumptions. It is executed in a theoretical, "laboratory" environment; such as through discussions and interviews with practitioners and experts. Validation is executed before the implementation in practice.

On the other hand, ***evaluation*** is executed *after* the implementation in practice of the designs. It involves analyzing the behavior, effects, and impact of the designed artifacts in practice, in the field. In our case, this meant implementation and analysis of the designs in actual, industry IT projects.

To make a parallel with a similar framework, the Technology Readiness Level (TRL) model, which was proposed by NASA and is currently also widely applied in European research programs such as Horizon: *validation* leads to TRL level 4 - "Technology validated in a laboratory environment"; while *evaluation* leads to a TRL level 6 - "Technology demonstrated in a relevant environment" (Héder, 2017) (European Commission, 2021b).

This research project consisted of a set of 5 sub-projects, listed above in section I.4. Each of these answers to an intermediate objective, together contributing to the overall research objective. These research sub-projects form a full *engineering cycle* (Figure 5):

- P1 is the investigation phase of the *engineering/design cycle*.
- P4 is the main design-cycle. It was applied in 2 iterations.
- P5 consists of an implementation-evaluation task. It completes the engineering-cycle.

The key ingredients to successful Design science are relevance and rigor (Figure 6) (Hevner, March, Park, & Ram, 2004). Also, for a rigorous approach to artifact design and investigation, a framework is needed to define structures in the artifact and its context, so as:

- to define the concepts with which we operate;
- in which to frame observations, questions, problems, and interpretations; and
- to allow sharing information, i.e. to provide a common language (Wieringa, 2014).

Due to the lack of maturity of the research field, P1 could not uncover such an existing framework. Accordingly, 2 additional sub-projects were required for ensuring an adequate level of rigor:

- P2 defined our perspective, our view on project complexity. It consisted of choices and decisions regarding theoretical constructs.
- P3 created the **IT Project Complexity Management (IT-PCM) Framework** in which to anchor the tool designs; a structured approach for their application. P3 is a design activity. Its validation was indirect: a set of its components were validated in P4 and P5.

The sub-projects P2 and P3 contribute to establishing a framework for IT Project Complexity Management: a set of constructs that define and describe the domain. This framework is built as a systemic architectural structure; being described in terms of components (sub-systems, characteristics), events (sources, effects, risks, opportunities), and processes (mechanisms).

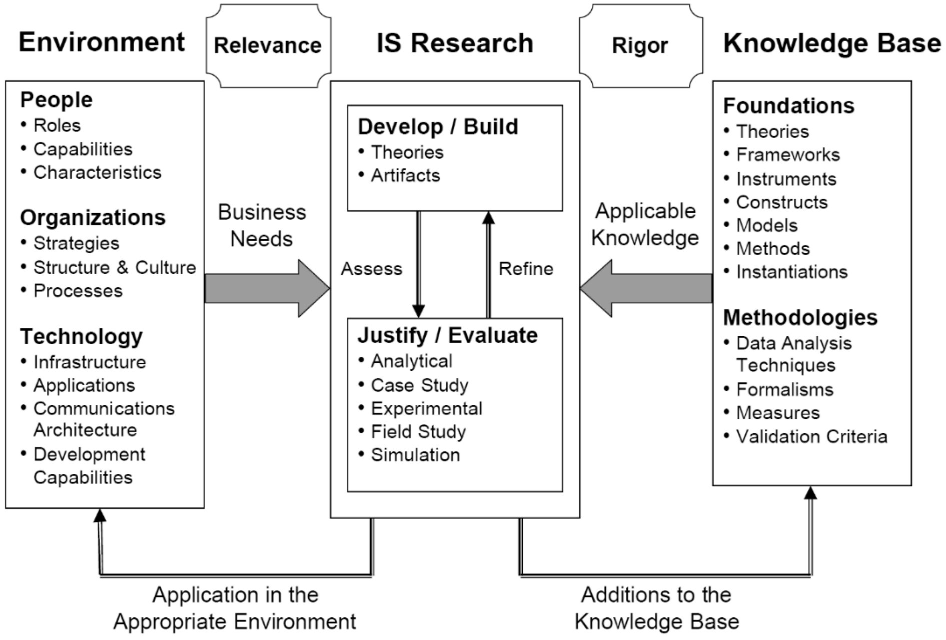


Figure 6. Information Systems Research Framework (Hevner, March, Park, & Ram, 2004)

II.2. Systematic literature review – methods

The literature review on project complexity literature (sub-project P1, presented in Chapter III) aimed to establish the theoretical and practical foundation for the research project, to uncover valuable recent contributions. **Systematic reviews** are relevant methods for defining a framework of existing research, for uncovering gaps in existing research, positioning and suggesting future research; for supporting the creation of new hypotheses (Kitchenham, 2004).

The main research questions were:

- *RQ1. Which are the existing definitions and approaches to project complexity?*
- *RQ2. Which are the characteristics of project complexity?*
- *RQ3. How can complexity be identified and measured?*

The literature review also confirmed the validity and importance of the research topic and identified future directions of research.

The main activities performed were:

- **Identify relevant literature**.
    - The literature review project started from the search phrase: '(complex OR complexity) AND ("project management")', applied to the title and abstract on a large database of blind refereed research papers, extended by snowballing and additional areas such as Systems and IT Engineering.
- **Analyze and structure the information** in categorized inventories (lists and maps):
    - Chronological approaches and definitions – a long and a summarized version.
    - Classifications (or sources) of project complexity.
    - Characteristics of project complexity.
    - Existing complexity measurement tools.
    - Complexity measurement criteria.
- **Extract summaries and conclusions**.

II.3. Theoretical foundation

The research sub-project P2 (Chapter IV) aimed to establish the theoretical foundation, to clarify how we look at project complexity. The research question was *RQ4: Which is the appropriate theoretical foundation/approach to project complexity, for the scope of this project?*

The literature review started from the domain of project complexity. The theory of complex systems, systems theory, and engineering complexity were also investigated. This supported understanding of how complexity works in general, not only in the specific area of IT project management; but also to investigate potential solutions from other areas.

Based on this literature review, a set of theoretical constructs are proposed. The literature review and these theoretical constructs formed the theoretical basis in the quest to answer the research question: *how can project complexity be understood, analyzed, and managed*; i.e. they are the basis for the design of specialized tools.

A holistic paradigm of ***complexity of complexities*** is proposed, based on systems theory.

Starting from a positive, empiricist perspective prevalent in engineering, a new approach to complexity analysis is proposed, based on its effects: **negative, appropriate, or positive**.

The choices and constructs were refined, validated, and evaluated, as part of the research sub-projects P4 and P5.

II.4. Design of the IT Project Complexity Management (IT-PCM) framework

The research sub-project P3 (Chapter V) had the intermediate objective to design a practical IT Project Complexity Management (IT-PCM) Framework. The research question was *RQ5: What framework can support the design of a toolset for IT project complexity analysis and management?*

The framework aims to ensure a rigorous approach to the design of new analysis and management tools, and a structured process for their deployment and application. It will provide a structure in which to anchor the tools that will be further designed, validated, and evaluated in the research sub-projects P4 and P5.

In fact, specialized tools function in a specific context, and need structure for their application. A framework identified when and how tools should be deployed, and their specific purpose.

The IT-PCM framework is based on an analysis of various similar management frameworks. It is aligned with the recognized project management body of knowledge. Its core structure is similar to the risk management knowledge area of PMBoK (PMI, 2017). Other frameworks and tools analyzed were: project management, risk and vulnerability management, problem-solving, decision-making, software engineering, systems engineering, and instructional design.

The framework was not validated or evaluated as an independent artifact. Instead, components of the framework were validated and evaluated as part of the research sub-projects P4 and P5.

II.5. Tools design and validation methodology

The research sub-project P4 attempted the design and validation of specialized tools for the identification, analysis, and management of IT project complexity. The research question was *RQ6. What tools can support IT project complexity identification, analysis, and management?*

Design science is a valid research methodology to develop solutions for practical engineering problems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007).

The design-and-validation methodology was an iterative incremental process, based on the design cycle of the engineering cycle (Wieringa, 2014). It consisted of 2 rounds of design and 2 rounds of validation with experts, using actual IT project cases. A set of new tools were thus iteratively designed (the results are in Chapter VI) and validated (Chapter VII).

The tools were designed:

- based on the literature review (sub-project P1).
- based on the proposed theoretical foundations (formulated in sub-project P2).
- anchored in the structured IT-PCM framework (sub-project P3).

The data collection methods employed were:

- interviewing.
- collecting project case data (Yin R. K., 2011).

Considering the novelty of the research topic and hence the unclear terminology, the preferred method of investigation was face-to-face open interviews, which also supported the qualitative exploratory research.

The design-and-validation methodology is presented in detail in Chapter VI, together with the final versions of the designed tools, namely:

- A specialized IT project complexity measurement tool;
- The Complexity Effect Scale – CES tool, to support the identification, visualization and analysis of IT project complexity based on its effects: Positive, Appropriate, and Negative.
- The Complexity Source/Effect Segmentation Matrix – COSM tool, to support analysis of complexity based on its sources and effects.
- The complexity Mitigation Strategies Matrix – MSM, to support the decision process for mitigating complexity, by proposing various approaches, based on the effects and sources of complexity.
- The Complexity Register – CoRe, for data collection, complexity analysis and monitoring.

The results and conclusions of the validation with experts are presented in detail below, in Chapter VII.

II.6. Tools evaluation methodology

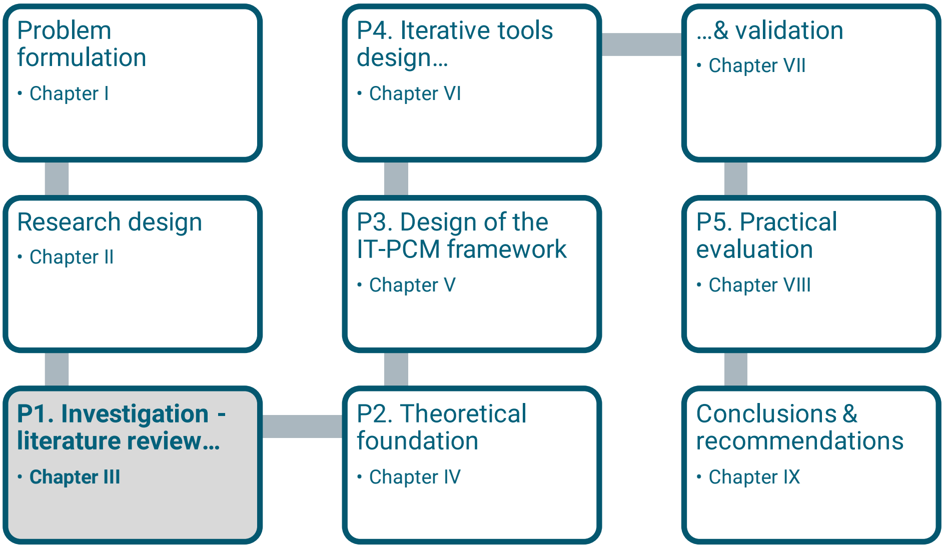
In order to evaluate the designed tools in actual live IT project cases, following the design-and-validation research sub-project, an additional research sub-project P5 was implemented. Besides assessing the effectiveness in practice of the designed tools, it aimed to understand and analyze their application in practice. The research question was *RQ7: What is the contribution of the designed tools to project success?*

The research approach employed for the evaluation was also qualitative. It is a longitudinal study, based on multiple project cases, consisting of the deployment, application, and repeated evaluation of the set of tools, with a live assessment of their impact on the respective projects.

For collecting feedback and assessment of the tools, live interviews with case-study participants were conducted.

The evaluation methodology and the results are presented in detail below, in Chapter VIII.

Chapter III.
Background: literature review



The systematic literature review research sub-project P1 aimed to validate the importance of the topic, to understand previous research, and build a knowledge foundation on which to base the future research.

The research questions are:

- *RQ1. Which are the existing definitions and approaches to project complexity?*
- *RQ2. Which are the characteristics of project complexity?*
- *RQ3. How can complexity be identified and measured?*

This chapter aims to contribute to establishing a common language when discussing complexity, as well as to a better understanding of project complexity and its implications to practical IT engineering projects.

A shorter form of this chapter, i.e. the results of the research sub-project P1, was published in the International Journal of Information Systems and Project Management, as "Definitions, characteristics and measures of IT Project Complexity - a Systematic Literature Review", (Morcov, Pintelon, & Kusters, 2020a).

III.1. Introduction

Project complexity is not clearly understood nor sufficiently defined. The identification and analysis of complexity suffer from vague definitions, ambiguity in the terminology employed; confusion between definition, sources, causes, characteristics, manifestations, and metrics. The terms are overloaded and over-used (Edmonds, 1999). These issues affect theoretical research as well as practice.

While significant contributions have been made to understanding project complexity, there is still a strong need for practical tools that enable identification and analysis of project complexity and associated strategies, and for validation of such proposed tools.

Project complexity management has become during the past 25 years a topic of major interest (Atkinson, Crawford, & Ward, 2006) (Baccarini, 1996) (Castejón-Limas, Ordieres-Meré, González-Marcos, & González-Castro, 2010) (Cicmil, Williams, Thomas, & Hodgson, 2006) (Crawford, Morris, Thomas, & Winter, 2006) (Williams T. M., 2005) (Geraldi, Maylor, & Williams, 2011) (Botchkarev & Finnigan, 2015). It is extensively described and defined, in various models, in terms of characteristics, causes, and effects. Attempts were made at measuring it.

The main historical approaches for defining project complexity are subjective/objective, structural, and dynamic. The subjective (perceived) complexity paradigm assumes that the complexity of a project system is always improperly understood through the perception of an observer. The objective (or descriptive) complexity paradigm considers complexity as an intrinsic property of a project system. Structural complexity is expressed in terms of quantity, variety, and interdependence of project components (Baccarini, 1996). Dynamic complexity is related to such characteristics as uncertainty, ambiguity, chaos, emergence, or propagation (Schlindwein & Ison, 2004) (Marle & Vidal, 2016).

At the same time, the terminology and concepts used by literature are ambiguous, often imported from incompletely developed sciences; they overlap, are synonyms, or express different aspects of the same concept. There is no widely accepted definition of complexity itself; it can be understood differently not only in different fields, but also within the same field; it is not yet defined why it should be measured or how (Calinescu, Efstathiou, Schirn, & Bermejo, 1998) (Morel & Ramanujam, 1999) (Padalkar & Gopinath, 2016).

This chapter builds knowledge in understanding complex IT projects and in unifying the language of the domain. It maps and compares the various approaches proposed by research. The main method employed is a systematic review of the existing literature, followed by a classification of results. The research also consolidates the results of other literature reviews (Geraldi, Maylor, & Williams, 2011) (Hertogh & Westerveld, 2010) (Jaafari, 2003) (Kiridena & Sense, 2016) (Bakhshi, Ireland, & Gorod, 2016).

The results of the literature review are presented below. They include:

- In answering to research question RQ1:
    - A chronological summary of historical definitions and approaches to project complexity: presented in summary in section III.3, Table 4; the extended version in Appendix A.
    - A list of classifications of project complexity: section III.3.6, Table 6.
- Research question RQ2:
    - A structured map of the characteristics of complexity: section III.4, Table 7.
- Research question RQ3:
    - A list of identified complexity measurement tools: section III.5, Table 8.
    - A set of measurement factors and criteria: presented in Appendix B. These were the basis for a proposed IT project complexity measurement tool, presented in section VI.2, Table 11.

This chapter presents the research method employed, sources, results, conclusions, and potential directions for future research.

III.2. Literature review - research method

The literature review employed a rigorous method of identifying, evaluating, and interpreting previous research related to complex IT projects. Systematic reviews are relevant methods to validate theoretical hypotheses, to support the creation of a new hypothesis, to define a framework of existing research, to identify gaps in existing research, to position and suggest future research (Kitchenham, 2004).

The systematic review consisted of two distinct phases: a structured search and a classification of the results.

The **search** was done on a large database of blind refereed research papers, which includes ScienceDirect, Scopus, Web of Science. No time filter was used. The topic appears in 1993 and is formalized in 1996 (Turner & Cochrane, 1993) (Baccarini, 1996). The initial search strategy aimed at narrowing the searched literature to the niche topic of "complex project management". Each of the two domains "project management" and "complexity" is too broad for the scope of the current research, while their strict intersection is extremely narrow and risks excluding relevant results. Therefore, the main search phrase used was '(complex OR complexity) AND ("project management")', which returns 68,784 peer-reviewed articles for a full-text search. In order to limit the results to a manageable number, while not losing relevant articles by excessive filtering, the search phrase was only applied to the title and abstract of peer-reviewed articles, thus reducing the list to 691 articles. These results were thereafter extensively extended by snowballing – analyzing the reference lists of existing papers and backward-searching on papers that reference existing papers. All papers that matched the topic were retained, including primary and secondary studies: meta-analyses of the topic, descriptions of the industry situation, specific case studies, and structured reviews. Articles that do not match the topic were not retained. The most common cause of topic-mismatch is due to the word "complex" itself being overloaded and over-used, often to mean "large" or "difficult". The research retained only articles related to project management, while acknowledging the significant results from related domains, including the complexity area itself, which provided the classic definition of a complex system: "made up of a large number of parts that interact in a non-simple way" (Simon, 1962). A number of 116 papers were found to match exactly the topic of this review, proposing definitions, approaches, and/or measures of project complexity.

The articles were reviewed and summarized in free text form. The amount of information is very large, highly redundant, has heavy cross-referencing, and the approaches are at times contradictory. The second major phase of the research consisted, therefore, in structuring the information.

The first information structuring targeted **definitions of project complexity**. A map was created with all definitions, characteristics, sources, causes, and manifestations of project complexity, as these appear in the literature. The method used was a formal method of classification. First, double entries were removed; the characteristics were grouped by lexical synonymy, each item being analyzed and either added to an existing category, or a distinct category would be created. Second, these characteristics were grouped by logical synonymy – using abstraction to logically group definitions that describe the same concept or characteristic. Depending on the specific author and approach, aspects of complexity are sometimes considered as definition, sometimes description, cause, or effect. Duplicate items were maintained when the authors express different concepts with the same word. The result is a structured list of 27 characteristics, that maps the definitions and approaches, which allows for comparison between various authors.

The second information structuring concerned **measurement criteria** and tools.

III.3. Definitions and approaches to project complexity (research question RQ1)

The main historical approaches for defining IT project complexity are subjective/objective, size-related, structural, and dynamic.

- Size-related: the simplest definition of a complex project is often a large, or sometimes a difficult project. Size can be measured by the number of project components such as budget, effort, duration, team members, stakeholders, product components, work packages, activities.
- The subjective (perceived) complexity paradigm assumes that the complexity of a project system is always improperly understood through the perception of an observer.

- The objective (or descriptive) complexity paradigm considers complexity as an intrinsic property of a project system (Marle & Vidal, 2016) (Schlindwein & Ison, 2004) (Genelot, 2001).
- Structural complexity: based on measuring the variety and interdependency of such project components.
- Dynamic complexity: related to such characteristics as uncertainty, ambiguity, chaos, emergence, or propagation.

These approaches are mostly complementary, combinations giving more comprehensive views of complex projects.

They are summarized in Table 3 and Figure 7.

Table 3. Project complexity paradigms

Subjective (perceived) complexity	The complexity of a project system is always improperly understood through the perception of an observer (Marle & Vidal, 2016) (Schlindwein & Ison, 2004) (Karsky, 1997) (Genelot, 2001).
Objective (descriptive) complexity	Complexity is seen as an intrinsic property of a project system (Marle & Vidal, 2016) (Schlindwein & Ison, 2004).
Structural complexity (also known as detail complexity, or complicatedness)	Consisting of many varied interrelated parts (Baccarini, 1996). It is typically expressed in terms of size, variety, and interdependence of project components, and described by technological and organizational factors.
Dynamic complexity, sometimes called “real complexity” to differentiate from complicatedness	It refers to phenomena, characteristics, and manifestations such as ambiguity, uncertainty, propagation, emergence, and chaos (Marle & Vidal, 2016).

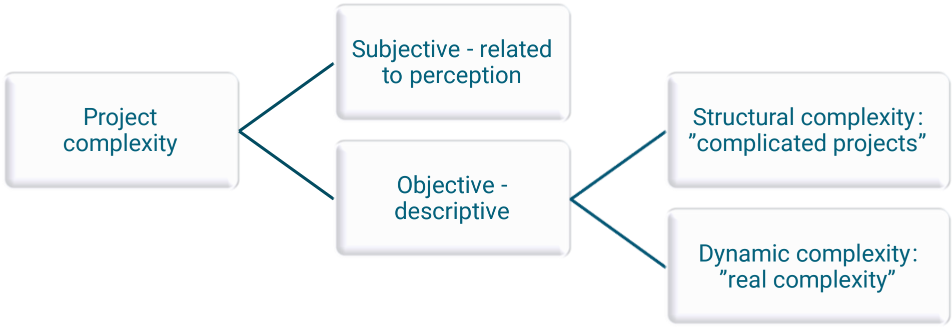


Figure 7. Project complexity paradigms

III.3.1. Historical approaches to project complexity

Theoretical, formal models have been proposed for analyzing complex projects, that group and consolidate the different approaches described above. Typically, these models propose a description of:

- The characteristics (or aspects, or dimensions) of complex projects.
- The causes (or sources, or factors) of complexity.
- The effects (or manifestations, or phenomena) of complexity.
- The measures of complexity.
- A combination of the above.

The described approaches are complementary. Combinations give a more comprehensive perspective (Edmonds, 1999) (Vidal, 2009) (Geraldi J. G., 2009) (Geraldi, Maylor, & Williams, 2011).

Table 4 presents a summary of definitions and historical approaches to project complexity.

Table 4. Summary of definitions and historical approaches to project complexity

Author	**Approach**	**Definition/model**
(Baccarini, 1996)	The first systematic approach, introducing structural complexity	Consisting of many varied interrelated parts. Operationalized in terms of differentiation and interdependency. Categorized (mainly) as organizational and technological.
(McKeen, Guimaraes, & Wetherbe, 1994) (Williams T. M., 1999) (Pich, Loch, & De Meyer, 2002) (Vaaland & Hakansson, 2003) (McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011) (Whitty & Maylor, 2009) (Hertogh & Westerveld, 2010)	Complexity of system development. Structural complexity. Uncertainty of goals and methods. Multiplicity and ambiguity.	Dynamic complexity, in addition to detailed (structural) complexity. Ambiguity or uncertainty as sources. Categorized as "task-related" (business, external, organizational) or "system-related" (technological). Multiplicity, i.e. many approaches and end-states. Ambiguity, i.e. conflict and uncertainty in decisions.
(Jaafari, 2003) (Bertelsen, 2004) (Cooke-Davies, Cicmil, Crawford, & Richardson, 2007)	Complexity in social sciences or biology. Complex systems theory.	Complex society is characterized by open systems, chaos, self-organization, and interdependence. Emergence, unpredictability.
(Edmonds, 1999) (Vidal, 2009) (Vidal, Marle, & Bocquet, 2011)	Holistic models, delineating definition, sources, manifestations, characteristics of project complexity.	"Difficult to understand, foresee and keep under control". Ambiguity, uncertainty, propagation, and chaos are considered not sources, but consequences of complexity.

(Geraldi, Maylor, & Williams, 2011)		Five dimensions of complexity: structural, uncertainty, dynamics, pace, and socio-political
(Zhu & Mostafavi, 2017)		Two dimensions of project complexity (detail and dynamic complexity), three dimensions of project emergent properties: absorptive, adaptive, restorative capacities

A detailed analysis of the historical approaches and models of project complexity is presented in Appendix A.

III.3.2. Size vs. complexity

Firstly, a special discussion is worthwhile regarding the relation between size and complexity.

The term "complex" is commonly used by practitioners and sometimes research for describing large or difficult problems. Even if size and difficulty are associated with complexity from a practical point of view, they are not part of the definition of complexity from a purely theoretical perspective.

Purist theoretical approaches to project complexity consider that size is not a correct factor or measure, because a large project without interdependencies could theoretically be split into several small, simple projects (Baccarini, 1996).

In practice, size factors have proven to be good measures of complexity. In this context, size factors refer to capital, budget, effort, duration, team size, the number of stakeholders, number of users, number of business areas, number of technical components, number of deliverables, the involvement of a multitude of management and technical factors (Kailash, 2008a) (Kailash, 2008b) (Whitty & Maylor, 2009) (Vaaland & Hakansson, 2003).

Project size is thus a strong predictor of complexity. Large projects tend to be more complex. Size is strongly related to uncertainty (Zmud, 1980) and risk exposure (Wallace, Keilb, & Rai, 2004) (Huang & Han, 2008). Mega-projects and complex projects have common characteristics (Nyarirangwe &

Babatunde, 2019). Also, due to budget constraints, only large projects should be treated as complex in practice (Vidal, 2009) (Kardes, Ozturk, Cavusgil, & Cavusgil, 2013) (Qureshi & Kang, 2015) (Marle & Vidal, 2016).

Accordingly, size cannot be separated from complexity.

III.3.3. Simple, complicated, complex, and really complex projects

Approaches based on cybernetics differentiate between simple, complicated, and complex projects; and consider structural complexity as mere complicatedness (Wiener, 1948) (Marle & Vidal, 2016) (Hertogh & Westerveld, 2010) (Bakhshi, Ireland, & Gorod, 2016).

Going one step forward, and based on the Cynefin framework for decision making, we can differentiate between 4 levels of complexity, depicted in Table 5 and Figure 8 (Snowden & Boone, 2007) (Ulrich & Probst, 1988) (Marle & Vidal, 2016):

- **Simple** (or clear, obvious, known) projects, systems, or contexts. These are characterized by known knowns, stability, clear cause-and-effect relationships. They can be solved with standard operating procedures and best practices.
- **Complicated**: characterized by known unknowns.
  A complicated system is the sum of its parts. In principle, it can be deconstructed into smaller simpler components.
  A typical example of a complicated problem is finding a needle in a haystack.
  While difficult, complicated problems are solvable with additional resources and hard work; with specialized expertise; with analytical, reductionist, simplification, decomposition techniques; with scenario planning; and following good practices (Maurer, 2017) (Kurtz & Snowden, 2003).
- **Complex**: characterized by unknown unknowns, and emergence.
  Patterns could be uncovered, but they are not obvious.
  A complex system can be described by Euclid's statement that **the whole is *more* than the sum of its parts.**
  These types of problems are irreducible. Also, they are not solvable by simply adding additional resources.
- **Really complex** projects, *a.k.a. very complex*, or *chaotic*: characterized by unknowables.

> No patterns are discernible in really complex projects. Causes and effects are unclear, even in retrospect.
> Paraphrasing Aristotle, **a really complex system is *different* from the sum of its parts.**

Complex and really complex problems are not solvable with clear algorithms. Instead, authors encourage innovation, open discussion, monitoring for change and emergence; taking actions and monitoring their results; focusing on what works, and probing for solutions, rather than searching for answers (Snowden & Boone, 2007).

Complex problems do not have definite outcomes. Instead, they face unknown events – both threats and opportunities (Kurtz & Snowden, 2003).

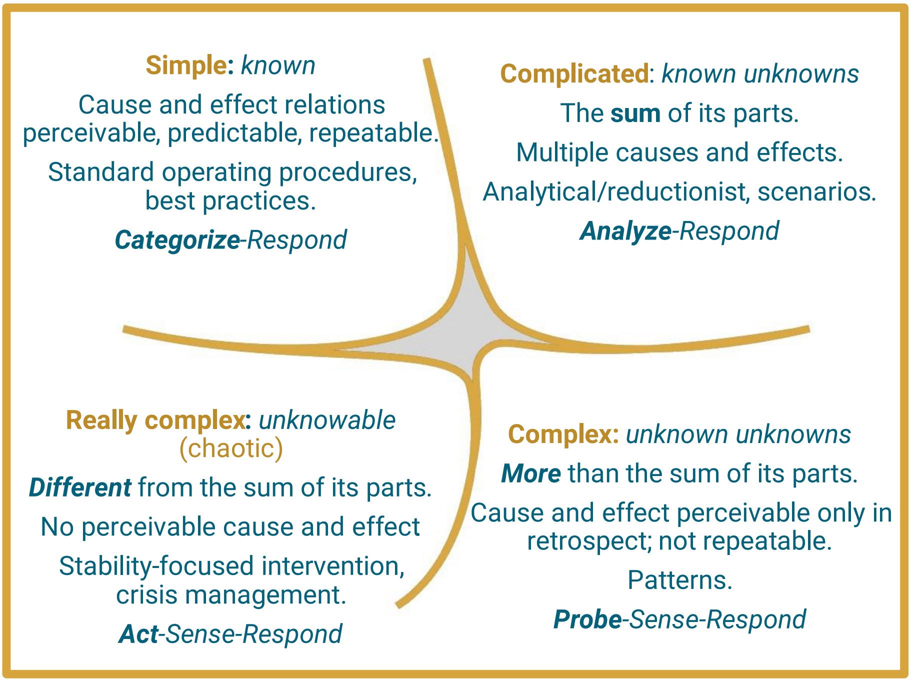


Figure 8. Simple, complicated, complex, and really complex projects – partially based on the Cynefin framework (Snowden & Boone, 2007) (Kurtz & Snowden, 2003)

Table 5. Simple, complicated, complex, and really complex projects – categorized as per the Cynefin framework (Snowden & Boone, 2007)

Level	Description	Cause and effect relationships
Simple (*clear, obvious*)	Characterized by known knowns, stability	Clear, repeatable, predictable cause-and-effect relationships.
Complicated	Characterized by known unknowns – knowables. *The **sum** of its parts.*	The relationship between cause and effect requires analysis or expertise, and there are multiple correct answers.
Complex	Characterized by unknown unknowns, and emergence. ***More** than the sum of its parts.*	The relationship between cause and effect can only be deduced in retrospect, and is not repeatable.
Really complex (*very complex*, or *chaotic*)	Characterized by unknowables. ***Different** than the sum of its parts.*	Causes and effects are unclear, the relationship is impossible to determine even in retrospect.

III.3.4. Structural complexity

***Structural*, or *descriptive, spatial, detailed complexity*,** is defined as consisting of many varied interrelated or interacting parts – with a strong accent on differentiation (varied) and interdependence (Baccarini, 1996) (Karsky, 1997). It may refer to technical (product) or organizational complexity (Williams T. M., 1999). Descriptive complexity considers complexity as an intrinsic property of a project system (Schlindwein & Ison, 2004) (Marle & Vidal, 2016). Structural complexity allows objective measures, and reducing the level of abstraction of the language. Accordingly, it is the most common approach when dealing with project complexity.

III.3.5. Dynamic complexity

Dynamic complexity (also known as ***true*, or *real complexity*)**, includes uncertainty, ambiguity, variability aspects (Xia & Lee, 2005) (McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011).

***Ambiguity** refers to lack of clarity: inexactness, having more than one possible meaning or interpretation, which may cause confusion[3].*

***Uncertainty** refers to unknown; to lack of information: not defined, not definite or decided, likely to change[4].*

***Variability** refers to lack of consistency; being subject to change.*

Uncertainty in both goals and methods is typical for complex projects (Turner & Cochrane, 1993) (Castejón-Limas, Ordieres-Meré, González-Marcos, & González-Castro, 2010) (College of Complex Project Managers And Defence Materiel Organisation, 2006) (Williams T. M., 1999) (McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011) (Gilchrist, Burton-Jones, & Green, 2018). Complexity arises from ambiguity or uncertainty related to the tasks or the system (McKeen, Guimaraes, & Wetherbe, 1994).

Complex projects have multiple approaches that may be employed and end-states that must be satisfied to complete the project, i.e. they are characterized by **ambiguity** (McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011).

Dynamic complexity is related to *open systems, chaos, self-organization and interdependence, self-modification, upward and downward causation and unpredictability, adaptiveness* (Jaafari, 2003) (Bertelsen, 2004) (Remington & Pollack, 2007). Complex systems are defined by *non-linearity*, continuous interactions with their environment, and *complex feedback loops* (Cooke-Davies, Cicmil, Crawford, & Richardson, 2007). They are *emergent*; therefore,

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[3] Oxford's English dictionaries, Cambridge Dictionary, Merriam-Webster: https://www.oxfordlearnersdictionaries.com/definition/english/ambiguity?q=ambiguity, https://dictionary.cambridge.org/dictionary/english/ambiguity, https://www.merriam-webster.com/dictionary/ambiguity.

[4] Oxford's English dictionaries, Cambridge Dictionary, Merriam-Webster: https://www.oxfordlearnersdictionaries.com/definition/english/uncertain?q=uncertain, https://www.merriam-webster.com/dictionary/uncertain, https://dictionary.cambridge.org/dictionary/english/uncertainty.

control on individual components does not guarantee the control, nor the overall behavior, of the whole project (Whitty & Maylor, 2009).

Complex projects display significant changes triggered by small factors with compounded exponential effect – similar to Lorenz's famed ***butterfly effect*** or Taleb's ***Black Swan*** events, and are difficult or impossible to forecast (Lorenz, 1963) (Taleb, 2007) (Taleb, Goldstein, & Spitznagel, The Six Mistakes Executives Make in Risk Management, 2009).

Structural complexity (complicatedness) is sometimes considered a cause or an effect of "real complexity" (Whitty & Maylor, 2009) (Kiridena & Sense, 2016) (Bakhshi, Ireland, & Gorod, 2016).

III.3.6. Classifications of project complexity

The literature review resulted in an inventory of definitions, models, and approaches to project complexity. An important part of these definitions and approaches involves classifications or categorization of project complexity. Table 6 below presents an inventory of the classifications and models of project complexity, proposed by the literature.

Table 6. Inventory of classifications and models of project complexity

1.	Technical vs. organizational complexity (Baccarini, 1996) (Williams T. M., 1999) Also: task-related complexity (business, external, organizational complexity) vs. system-related complexity (technological complexity) (McKeen, Guimaraes, & Wetherbe, 1994). Also: the TOE model - technological, organizational, environmental complexity (Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011).
2.	Structural vs. dynamic complexity (Xia & Lee, 2005) (Whitty & Maylor, 2009) Or: detail vs. dynamic complexity (Hertogh & Westerveld, 2010) Variation: structural complexity vs. uncertainty (Williams T. M., 1999)
3.	Simple, complicated, complex, really complex projects (Snowden & Boone, 2007) (Hertogh & Westerveld, 2010) (Bakhshi, Ireland, & Gorod, 2016)
4.	Objective (descriptive) vs. subjective (perceived) complexity (Marle & Vidal, 2016) (Schlindwein & Ison, 2004) (Karsky, 1997) (Genelot, 2001)
5.	Uncertainty in goals vs. uncertainty in methods (Turner & Cochrane, 1993)

6.	Multiplicity (many approaches and end-states) vs. ambiguity (conflict and uncertainty in decisions) (McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011)
7.	Ambiguity (unknown) vs. complexity (unpredictable) (Pich, Loch, & De Meyer, 2002)
8.	Size, variety, interdependencies, context-dependencies (Vidal, 2009) (Qureshi & Kang, 2015)
9.	Ambiguity, uncertainty, propagation, and chaos (Vidal, 2009)
10.	Size, innovation, interdependencies, variety (Vaaland & Hakansson, 2003)
11.	Variety vs. variability vs. integration (Ribbers & Schoo, 2002)
12.	Uncertainty of faith (uncertainty, uniqueness, unknown), of fact (strong interdependencies), of interaction (politics, ambiguity, multiculturalism) (Geraldi J. G., 2009) (Geraldi & Adlbrecht, 2007)
13.	Structural; Technical; Directional; Temporal (Remington & Pollack, 2007)
14.	Structural, uncertainty, dynamics, pace, and socio-political (Geraldi, Maylor, & Williams, 2011)
15.	Two dimensions of project complexity (detail, dynamic) and three dimensions of project emergent properties: absorptive, adaptive, and restorative capacities (Zhu & Mostafavi, 2017)

Other classifications were also proposed by (Floricel, Michel, & Piperca, 2016) (He, Luo, Hu, & Chan, 2015) (Lu, Luo, Wang, Le, & Shi, 2015) (Maylor, Turner, & Murray-Webster, 2013) (Lessard, Sakhrani, & Miller, 2013) (Dao, Kermanshachia, Shaneb, & Anderson, 2016) (Poveda-Bautista, Diego-Mas, & Leon-Medina, 2018). These are variations or combinations between the models already listed in Table 6.

III.4. Characteristics of project complexity (research question RQ2)

Table 7 presents a summary of the structured map of the characteristics of complex projects obtained from the literature review.

These characteristics have different importance and are treated differently by various models. They are grouped by authors under specific categories. E.g., in the model of (Xia & Lee, 2005):

- Ambiguity, Uncertainty, Dynamics (variability, change) are grouped under dynamic complexity.

- Variety, Multiplicity, interaction between parts, and Interdependence are grouped under structural complexity.

Also, characteristics are categorized by various models as either effects, sources, measures, or both. As an example, an elaborate complexity model is proposed by (Vidal, 2009), who defines 3 distinct types of aspects:

- **Definitory**: Difficult to understand, to foresee, and to control are part of the *definition* of complexity.
- **Sources**: Size, Variety, Interdependence, and Context are *drivers*, or *factors*.
- **Effects**: Ambiguity, Uncertainty, Propagation, and Chaos are *phenomena*, or *manifestations*.

Table 7. Structured map of the characteristics of complex projects

Characteristics: / Author:	(Baccarini, 1996)	(Williams T. M., 1999)	(Vaaland & Hakansson, 2003)	(Bertelsen, 2004)	(Xia & Lee, 2005)	(College of Complex Project Managers And Defence Materiel Organisation, 2006)	(Cooke-Davies, Cicmil, Crawford, & Richardson, 2007)	(Mulenburg, 2008)	(Whitty & Maylor, 2009)	(Vidal, 2009)	(Hertogh & Westerveld, 2010)
1. Multiplicity					x						
2. Ambiguity					x			x		x	
3. Uncertainty		x			x	x		x		x	
4. Details (structural)	x	x						x	x		x
5. Dynamics					x			x			x
6. Disorder						x					
7. Instability						x				x	
8. Emergence				x		x	x		x		
9. Non-linearity				x		x	x				
10. Recursiveness						x					

11. Irregularity						x					
12. Randomness						x	x				
13. Dynamic complexity = parts interact					x	x		x			x
14. Uncertainty of objectives and methods		x				x					x
15. Varied stakeholders, competing views			x		x	x					x
16. Changing objectives				x		x					
17. Adaptive, evolving				x		x	x			x	x
18. Involves double-loop learning						x					
19. Explanation of states of stability-instability				x			x				x
20. Size			x							x	
21. Variety			x		x					x	
22. Interdependence			x		x					x	
23. Context										x	
24. Innovation			x								
25. Difficult to understand										x	
26. Difficult to foresee				x						x	
27. Difficult to control										x	

The inventory of classifications (Table 6) and map of characteristics (Table 7) provide the basis for the future design of tools for analyzing and managing project complexity, in the following chapters.

III.5. Identification and measurement of IT project complexity. Inventory of measurement tools (research question RQ3)

This section presents an inventory of complexity identification and measurement tools, identified as part of the literature review.

The identification and analysis of project complexity are relevant throughout all project phases, but are particularly important at two specific moments: during project approval (or Project Initiation), and during Project Planning.

Various models and tools were proposed for measuring the degree of project complexity, defining approaches scales, measures and criteria (Xia & Lee, 2005) (Calinescu, Efstathiou, Schirn, & Bermejo, 1998) (Nassar & Hegab, 2006) (Ameen & Jacob, 2009) (Hass, 2008a) (Hass, 2008b) (Vidal, Marle, & Bocquet, 2011) (Janssens, Hoeijenbos, & Kusters, 2011) (Marle & Vidal, 2016) (Shafiei-Monfared & Jenab, 2012) (Bakhshi, Ireland, & Gorod, 2016) (Qureshi & Kang, 2015) (Chapman, 2016) (Wood & Ashton, 2010) (Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011).

While most authors underline the importance of comparability and repeatability, the metrics tend to remain subjective and strongly dependent on industry, technology, organization, or project type.

The inventory of complexity measurement tools is presented in Table 8 below.

Table 8. Project complexity measurement tools

	Tool	Description
1.	The Complexity Assessment Questionnaire introduced by the Project Management Institute (PMI, 2014)	Long, verbose. Set of 48 yes/no questions, covering all areas of a project. Subjective. Not weighted. General-purpose.
2.	The Crawford-Ishikura Factor Table for Evaluating Roles – CIFTER supported by the International Project Management Association (GAPPS, 2007)	Short, qualitative scale, with 7 subjective criteria. Likert-type ordinal scale from 1 to 4 (low, moderate, high, very high) without midpoint. Not weighted. General-purpose.
3.	The Project Complexity Assessment and Management tool – PCAM (Dao B. P., 2016)	Long, very detailed. 37 complexity indicators, scoring from 1 to 9, combining numerically quantifiable as well as subjective aspects.
4.	Hass' Project Complexity Model Formula (Hass, 2008b)	Simple and short: 5 complexity dimensions (11 in the extended version), quantifiable as well as subjective. Ordinal scale from 1 to 3, with a midpoint (low, moderate, high). Not weighted. General-purpose.
5.	Vidal's AHP (Analytic Hierarchy Process) measurement tool (Vidal, Marle, & Bocquet, 2011)	Structured, abstract. 4 criteria, 17 sub-criteria. Subjective. Saaty scale (1 to 9). Weighted. General-purpose.

6.	Acquisition Categorisation – ACAT (Australian Government, Department of Defence, 2012)	Simple. Projects are classified into 4 categories based on 6 criteria. It assesses levels of complexity against the attributes: cost (size), project management complexity, schedule complexity, technical difficulty, operation, and support, commercial Focused on size.
7.	Project Complexity and Risk Assessment tool – PCRA of the Treasury Board of the Canadian Government (Treasury Board of Canada Secretariat, 2015)	Very complex and detailed: 7 sections, 64 questions. General-purpose.
8.	Measurement model of ISDP complexity proposed by (Xia & Lee, 2005)	Focused on IT product complexity. Formed of 4 components of ISDP complexity: structural organizational complexity, structural IT complexity, dynamic organizational complexity, and dynamic IT complexity; and 15 measurement items.
9.	Complexity Index Tool proposed by (Poveda-Bautista, Diego-Mas, & Leon-Medina, 2018)	Practical tool, focused on IT product complexity, based on the IPMA approach – CIFTER (GAPPS, 2007).

Figure 9 presents Vidal's "refined project complexity framework".

Family	Organisational Complexity (Org)	Technological Complexity (Tech)
Project system size	Number of stakeholders	
Project system variety	Variety of information systems to be combined	
	Geographic location of the stakeholders (and their mutual disaffection)	
	Variety of the interests of the stakeholders	
Project system interdependencies	Dependencies with the environment	Specifications interdependence
	Availability of people, material and of any resources due to sharing	
	Interdependence between sites, departments and companies	
	Interconnectivity and feedback loop in the task and project networks	
	Team cooperation and communication	
	Dependencies between schedules	
	Interdependence of information systems	
	Interdependence of objectives	
	Level of interrelation between phases	
	Processes interdependence	
Project system context-dependence	Cultural configuration and variety	Environment complexity (networked environment)
	Environment complexity (networked envrionment)	

Figure 9. Vidal's "refined project complexity framework" (Vidal, Marle, & Bocquet, 2011)

Table 9 presents the Crawford-Ishikura Factor Table for Evaluating Roles CIFTER – Global Alliance for Project Performance Standards (GAPPS, 2007).

Table 9. The Crawford-Ishikura Factor Table for Evaluating Roles - CIFTER

#	Project Management Complexity Factor	Description and Points			
		1	2	3	4
1	Stability of the overall project context	Very High	High	Moderate	Low
2	Number of distinct disciplines, methods, or approaches involved in performing the project	Low	Moderate	High	Very high
3	Magnitude of legal, social, or environmental implications from performing the project	Low	Moderate	High	Very high
4	Overall expected financial impact (positive or negative) on the project's stakeholders	Low	Moderate	High	Very high
5	Strategic importance of the project to the organization or the organizations involved	Very Low	Low	Moderate	High
6	Stakeholder cohesion regarding the characteristics of the product of the project	High	Moderate	Low	Very low
7	Number and variety of interfaces between the project and other organizational entities	Very Low	Low	Moderate	High

Hass' Project Complexity Model Formula is presented in Figure 10.

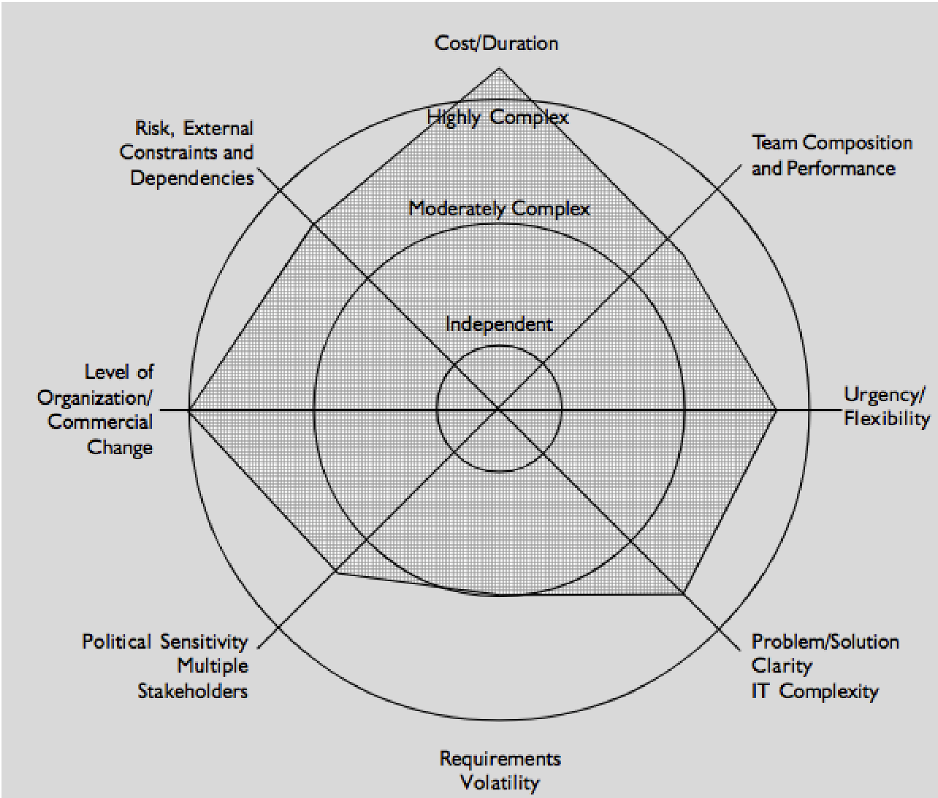


Figure 10. Hass' Project Complexity Model Formula (Hass, 2008b)

The list of measurement tools presented in this section constitutes a starting point for choosing the appropriate tool for assessing complexity in a particular environment, for a particular project or portfolio. Also, these can be enhanced or adapted to create specific tools for specific industries, such as for IT.

III.6. Limitations and contributions of the literature review

While a series of measures were taken for ensuring validity and reliability, several limitations apply to the literature review.

The researched literature was narrowed so that the research remains feasible, while ensuring that relevant articles are not excluded. The Science Direct database was used in the search, as it covers the largest number of journals relevant to the topic. The search phrase was applied only to the titles and the abstract of peer-reviewed articles, so as to limit the number of articles while retaining relevant research. The search was limited to articles in English. The summation of the reviewed articles was done manually, but was documented for each article, which ensured traceability and repeatability of the process. Also, each reviewed article was categorized and archived individually.

While the literature review was not limited strictly to an industry, it is focused on IT. In order to increase specialization hence usability, the domain of applicability of the complexity measures is especially limited to IT projects.

III.7. Conclusion

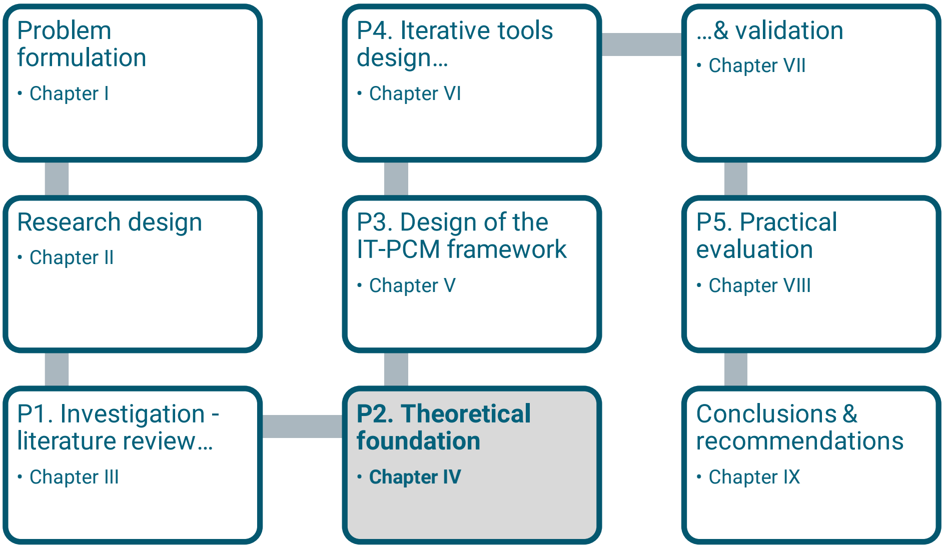
This chapter presented the results of the literature review, sub-project P1. It constitutes the investigation phase of this research project.

The literature review revealed that industry and research recognize the importance of project complexity. Significant contributions have been made to understanding it, with various theoretical definitions and models proposed. These are presented above in sections III.3 and III.4, as answers to our research questions RQ1 and RQ2. Also, a set of tools for measuring IT project complexity have been proposed – as presented in section III.5, in answer to our research question RQ3.

This investigation revealed a series of needs and directions for further research. It confirmed the need for practical tools for identifying, measuring, and managing IT project complexity (Floricel, Michel, & Piperca, 2016) (Daniel & Daniel, 2018) (Zhu & Mostafavi, 2017) (Locatelli, Mancini, & Romano, 2014) (Poveda-Bautista, Diego-Mas, & Leon-Medina, 2018). The industry is still mostly guided by expert judgment (Hass, 2008a). Various mitigation methods were proposed, in the form of best practices or guidelines, also known as “simple rules” (Davies, Dodgson, Gann, & Macaulay, 2017). There is no structured framework or methodology for IT project complexity management.

Based on this investigation, several treatments are further proposed and tested, as described in the following chapters.

Chapter IV.
Theoretical foundation. Perspective on project complexity



This research sub-project P2 aimed to establish the theoretical foundation of the research. It ensures a rigorous approach for the future tool design, by:

- Choosing which is the most appropriate definition and overall approach to be used in the research project.
- Clarifying the way in which we look at complexity.
- Establishing a common language for addressing the topic.

The relevant research question is *RQ4: Which is the appropriate theoretical foundation/approach to project complexity, for the scope of this project?*

This chapter is an expanded form of concepts published in the Proceedings of the Romanian Academy - Series A, in the paper "IT Project Complexity Management Based on Sources and Effects: Positive, Appropriate and Negative", (Morcov, Pintelon, & Kusters, 2020b).

Section IV.1 presents the definition and model of project complexity which were chosen for the scope of this research project. It is a direct consequence of the Literature review – Chapter III.

Sections IV.2 and IV.3 propose new ways in which one can look at IT project complexity:

- Analyzing how systems theory and a holistic approach can be applied to project complexity management – section IV.2.
- Analyzing the effects of complexity, and how complexity can contribute to project success – section IV.3.

Both are also consequences of the Literature review, being derived from previous approaches proposed by project management, engineering, and systems theory.

IV.1.Definition and model of project complexity

The underlying theoretical definition and model of project complexity, adopted and used in this research, is integrative. It is based on previous work of (Edmonds, 1999) and (Vidal, 2009) – described in the literature review, in Chapter III.

Project complexity is the property of a project which makes it difficult to understand, foresee and manage its behavior, even when given reasonably complete information about the project system.

This model includes ambiguity, uncertainty, propagation, and chaos, as the most important associated phenomena, or manifestations, of project complexity.

It covers both structural and dynamic complexity aspects.

Structural complexity is defined as consisting of many varied interrelated parts (Baccarini, 1996). Other names used in literature are *detail complexity* or *complicatedness*. It can be classified according to various criteria and sources, e.g.: {technological, organizational}; {size, variety, interdependence, context}.

Dynamic complexity deals with uncertainty; multiplicity, ambiguity, open systems, chaos, self-organization, interdependence, emergence, and unpredictability (Schlindwein & Ison, 2004) (Marle & Vidal, 2016).

This definition, model, and terminology are used throughout the research, in the subsequent chapters. They are also the basis for the new perspectives proposed for looking at project complexity, presented in the following sections of this chapter.

IV.2.A holistic approach: Complexity of Complexities

This section presents a holistic model proposed for looking at project complexity. This perspective arose from the analysis of the literature review.

Systems theory argues for a holistic approach. Complexity in project management may be tamed by Systems Thinking (Sheffield, Sankaran, & Haslett, 2012). Systems engineering is a discipline that evolved specifically for solving complex engineering problems (Locatelli, Mancini, & Romano, 2014). The holistic approach adopted by modern systems engineering, including the concept of System-of-Systems, could benefit and help advance the project management body of knowledge (Keating, et al., 2003) (Keating, Padilla, & Adams, 2008).

Complexity can be analyzed from high-level perspectives, such as organizational or technological complexity, or from more targeted perspectives (Williams T. , 2017). Engineering focuses on product complexity. Marketing research focuses on the external environment. Management research targets the complexity of organizations and processes. The complexity and capability of AI make it unique and controversial (Siau & Wang, Ethical and Moral Issues with AI, 2018) (Siau & Wang, 2020). The ethical aspects of AI-related projects can form a complexity sub-system in itself.

All in all, IT engineering develops complex IT products for complex markets in complex organizations with complex processes through complex projects. Figure 11 presents a summary of such a model.

IT project complexity can be described therefore as a **Complexity of Complexities**. Thus, the IT project is an ecosystem formed of complex sub-systems, interrelated and influencing each other in ways we cannot predict, nor control based on what we know about each complex sub-system individually[i].

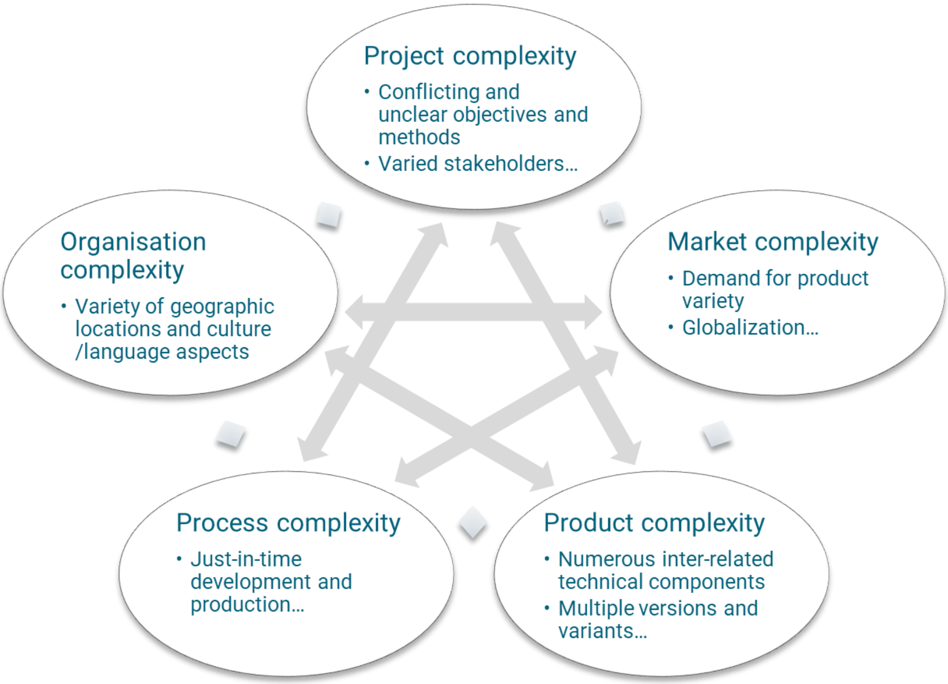


Figure 11. The Complexity of Complexities concept. An extension to the "Complexity fields in engineering" proposed by (Maurer, 2017)

This holistic approach is aligned with systems and complexity theory, which argue that the whole is more, and even different, than the sum of the parts (Aristotle) (Euclid) (Koffka, 1935) (Smuts, 1927), as well as with the observation that a complex IT project can be described as a System of Systems (Botchkarev & Finnigan, 2015).

While phenomena associated with dynamic complexity manifest within each sub-system, systems theory shows that the complexity of each sub-system also propagates to different sub-systems. This is confirmed by empirical evidence, as documented by research such as:

- Product complexity was shown to be derived from the complexity of the organization (Conway's law) and of the process:
    - Conway's law: Organizations design systems that mimic the communication channels of the organization (Conway, 1968);
    - Complex processes require complex functionality of the product; the design, development, and production of a

complex product require a complex organization - see Airbus or US space exploration program (Maurer, 2017).

- The business/IS alignment principle, or the law of *requisite complexity* (or variety), that argues that a system must match or even exceed the complexity of its external environment, in order to adapt, evolve, and survive (Benbya & McKelvey, 2006) (McKelvey & Boisot, 2009) (Boisot & McKelvey, 2011).
- A complex product and/or a complex organization drive project complexity (Eppinger, 2002) (Maurer, 2017).

As argued below, the anticipated benefits of such a paradigm should be – as further detailed below:

1. The correct identification of the real sources of complexity and the correlation between sources and effects.
2. Supporting the selection of the most suitable/efficient mitigation strategies.

1. Identification of the source of complexity.

Perceived complexity is often generated in a distinct sub-system, not in the sub-system where it is observed. Because of propagation phenomena associated with complexity, actions in a sub-system have (un)desired effects in others. Traditional problem-solving or dependency-modeling techniques are effective only in the same sub-systems (Maurer, 2017). Systemic-level solutions are needed for events that cover more than one sub-system, as well as novel dependency-modeling tools.

2. Selection of the most suitable/efficient mitigation strategies and tools.

Each of the sub-complexities is different and requires a specific set of tools and methods – related to project, product, market, organization, process. Therefore, this holistic approach supports the selection of the best tools to manage the overall complexity, as well as the individual complexities.

When the source of the complexity is in the same sub-system, then a systematic approach to problem-solving or to complexity management will be very effective (Maurer, 2017). At the same time, when the source of the complexity is in a different sub-system, a different strategy should be deployed. First, a multi-disciplinary team from all concerned sub-systems should be formed. Also, among the potential strategies to mitigate the problem, specific ones should be considered, such as simplification, reorganization, or increase in the complexity of a sub-system to match the complexity of another. Examples are:

- Simplification:
    - Simplification of one of the sub-systems must consider the impact on the other sub-systems.
    - Decomposition of the project team or WBS will function better if the organization or the product can also be decomposed into a similar OBS; the decomposition could be done on these sub-systems in synergy.
    - Oversimplification of the organization or of the project might have a negative impact if the product cannot be, in fact, simplified. Similarly, oversimplification of a product will make it difficult to support a very complex organization.
- Dependencies:
    - If an organization is forced to downsize by external market pressure: reducing its size also requires simplification; which also means that its processes, tools, and projects must be simplified and downsized as well.
    - Dependencies between components of sub-systems will be mirrored across other complex sub-systems. A DSM or dependency diagram on the organization structure is likely to match the corresponding DSM on the product structure/PBS (Product Breakdown Structure), on the project organization chart/OBS, on the WBS (Work Breakdown Structure), on the Risk-BS and Cost-BS. Consider a large engineering project such as Airbus 380; the dependencies between each engineering component (engines, electronics, air conditioning, passenger bridges) will be mirrored by dependencies between project teams and between processes (Maurer, 2017).
- Correct source identification:
    - Consider an unnecessarily heavy and complex organization, oversized compared to its needs. This is in fact a common situation for all organizations (not only bureaucracies), as proven by empirical evidence such as Parkinson's law, which shows that organizations tend to increase in time both their complexity and size, irrespective of any variation in their responsibilities – because officials create work for each other,

and want to create subordinates, not rivals (Parkinson, 1958). Any complexity-related phenomena, such as the inherent complexity of the products and processes that support such an organization, will be solved much more effectively by reducing the overly complex organization, rather than by oversimplifying the other sub-systems.

- Consider a small organization implementing a very complex and advanced ERP (Enterprise Resource System). The complexity of the product will necessarily require a major redesign of the organization's processes, as part of a complex ERP project implementation. The effects of the product complexity will be reflected in significant complexity and changes in projects, processes, and in the organization; but will not lead to changes in the product itself, which is already a complex COTS tool. The real source of these complexity-related phenomena is the inadequate product choice; hence adapting the organization to the product is not the best solution for this situation. A more efficient solution would be to switch to a different ERP product, simpler and less complex, but more adapted to the organization.

This holistic approach is a model that is used in the next research sub-projects, especially in the design of specialized tools for IT project complexity management. It is also particularly relevant to the analysis of the sources and effects of complexity, and the relation between them. In particular, analyzing the effects of complexity is the topic of the next section.

IV.3. The ubiquitousness of complexity. Positive, Appropriate, and Negative Complexity

All the articles of the literature review on project complexity focus on its negative effects, and on how to reduce or eliminate complexity. Research strongly correlates project complexity with project failure and poor project management performance (Floricel, Michel, & Piperca, 2016) (Bjorvatn & Wald, 2018). References to potential benefits or positive influences of complexity are very rare in project management literature, and always incidental.

At the same time, systems theory and systems engineering provide new insights and different original approaches to project complexity. Thus, in order to be innovative, creative, and adaptable, a system must be taken away from equilibrium, and should make use of disorder, irregularity and difference for driving change (Stacey, 1995). Complexity is often associated with innovation (Floricel, Michel, & Piperca, 2016). In order to remain viable, systems must acquire complexity (Beer, 1972), e.g. to match the complexity of the external environment, and even to create excess complexity, thus becoming "efficaciously adaptive" (McKelvey & Boisot, 2009).

These perspectives are analyzed in the current section.

IV.3.1. The ubiquitousness of complexity

Engineering in general, and in particular IT/software engineering, are highly effective domains, that develop increasingly complex products; they deliver valuable results with increasingly more complex processes. Complexity is a ubiquitous reality, that creates risk as well as opportunity: *"**Complexity works!** Nature, animals and humans are highly complex systems"* (Maurer, 2017).

Technology will necessarily become more and more complex as it evolves. The next-generation computer, space shuttle, phone, watch or car will be *smarter,* and thus more complex. This is needed for providing more functionality, benefits, value; thus remaining competitive and relevant on the market. The organization and processes of the research, marketing, sales and delivery departments' will be more and more complex, so as to offer new products to new users in new markets. Artificial Intelligence, Data Science, and Machine Learning are solving more and more industrial and societal challenges, with a level of complexity already far beyond our understanding.

Also, complexity has sometimes positive unexpected or unintended effects: SMS, Facebook, Coca-Cola, and Viagra are famed examples of emergence and innovation in complex R&D projects: they are highly successful products, but they are different, or used differently, than originally intended or designed. None of them appeared by accident; instead, they are the result of extensive, expensive, and lengthy endeavors, and they build on incredible amounts of previous research. They confirm the holistic paradigm described in the previous section: while they build on the complexity of their constituent parts, they are not only *more* than the sum of these individual parts, but they are also *different* than the sum of their components. Thus, the individual components of Facebook are: collaboration and communication software applications; computers, servers, mobile phones, Internet/mobile networks;

staff of engineers, managers, content curators, sales, marketing; users; content, etc. But Facebook is *different* from the sum of all these individual components; it is a social phenomenon.

We conclude that the fundamental mission of the project manager is not to eliminate complexity; rather it is the completion of a *successful* project[ii]. *Complexity sometimes supports project success, and should not be eliminated.*

Complexity can thus be analyzed from the perspective of its effects.

As a note, while IT project complexity may have positive effects, this does not imply that complexity is in itself an objective.

IV.3.2. Positive, Appropriate, and Negative Complexity

Based on the above observations, and taking a constructive, empiricist approach prevalent in engineering, we thus embrace and introduce in our proposed model the concepts of *Positive* and *Appropriate Complexity*, in addition to, and opposed to the traditional view of negative IT project complexity.

This reconsideration of complexity as not necessarily negative is similar to the history of risk management, which is yet to fully incorporate the management of *opportunities* into practice[iii]. It is also aligned with the current evolutions in vulnerability management, where the concept of *antifragility* was introduced recently (Taleb, Antifragile: things that gain from disorder, 2012).

"Positive complexity" is "the complexity that adds value to our project, and whose contribution to project success outweighs the associated negative consequences".

"Appropriate, or **requisite, complexity"** is "the complexity that is needed for the project to reach its objectives, or whose contribution to project success balances the negative effects, or the cost of mitigation outweighs negative manifestations".

"Negative complexity" is "the complexity that hinders project success".

A graphical map of these concepts is presented in Figure 12.

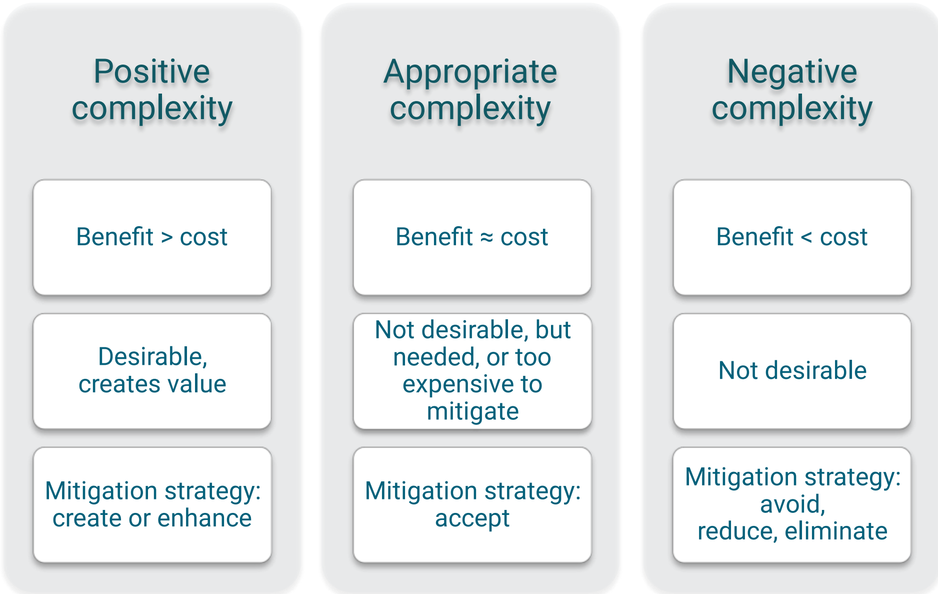


Figure 12. Positive, Appropriate, and Negative Complexity

The model of Positive, Appropriate, and Negative Complexity offers a new perspective on IT complexity. This model was the main foundation for designing specialized tools for complexity identification and analysis – presented in Chapter VI.

IV.4.Conclusion

This chapter presented the results of sub-project P2, which establishes the theoretical foundation of our research, and clarifies how we look at project complexity.

It consisted of decisions regarding theoretical constructs, i.e. choosing which is the most appropriate definition and approach to be used in this research project. Thus, it clarifies the language for addressing the topic. It also proposes definitions for the new theoretical constructs introduced: the Project Complexity Management knowledge area, as well as Positive, Appropriate, and Negative complexity.

It is a consequence of the literature review (sub-project P1, Chapter III). It was needed because of the lack of maturity of the domain of project complexity – which uses ambiguous terminology, and several different definitions and approaches, some contradictory and some complementary. It thus ensures rigor for the future tool design, which is presented in the following chapters.

Notes

[i] *The systems engineering literature has divergent views regarding the definition and synonymy between "system" and "sub-system". It even notices the tautology in the definition of "system of systems", as any system is fundamentally already a system of sub-systems (Hitchins, 2007). In the context of this project, the term "sub-system" is used only when it is considered important to underline the interaction between the components of a master system.*

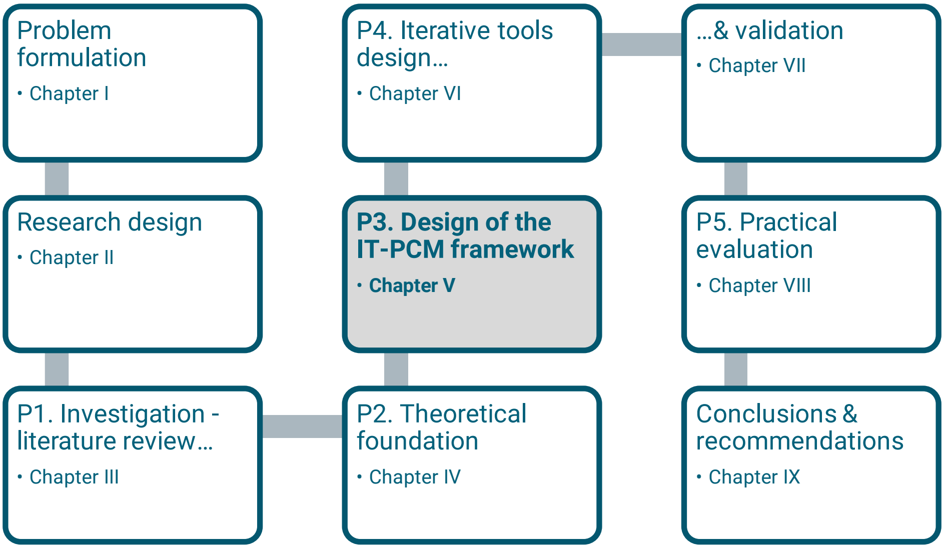
[ii] *In defining success, the recognized project management body of knowledge tends to put the priority on processes, rather than on results. The perspective of the process, i.e. delivering efficient outputs, is typically called "project management performance" or "project efficiency".*

On the other hand, the perspective of the result, i.e. delivering beneficial outcomes, is typically called "project performance" (sometimes just "project success") (Daniel & Daniel, 2018) (Pinto & Winch, 2016). System engineering argues that project success should focus on the resulting system, on the benefits to the organization and to the stakeholders, rather than on measuring methods and processes (PMI, 2017) (Locatelli, Mancini, & Romano, 2014).

[iii] "Risk management" appears in literature since the 1920s, as shown by a search in the KUL library, and becomes a formal science in the 1950s (Dionne, 2013), when articles and books with "risk management" in the title also appear in searches. Opportunities do not appear in the first Project Management Body of Knowledge (PMI, 1987). Opportunities were included in project management literature in the mid-1990s (PMI, 1996) and became a significant part of project risk management in the years 2000s (Goodman, 2005), when articles titled "opportunity management" also begin to appear in a library search.

At the same time, risk-related research as well as practitioners continue to focus significantly more on threats than on opportunities, and risks are still being considered "usually negative" (Ekambaram, Johansen, Jermstad, & Økland, 2010) (Dionne, 2013).

Chapter V. Design of the IT Project Complexity Management (IT-PCM) framework



The research sub-project P3 attempts to answer to the research question *RQ5: What framework can support the design of a toolset for IT project complexity analysis and management?*

The framework should ensure a rigorous approach to the design of new complexity analysis and management tools, and a structured process for the deployment and application of such tools - supporting the management of IT Project Complexity in a structured, systematic way. Anchored in this framework, a set of specific processes and tool designs will be further proposed, validated, and evaluated – in the subsequent chapters VI, VII, and VIII, respectively.

Chapter V was presented and published, in a shorter form, at the IADIS Information Systems Conference (IS 2021), as: "A Framework for IT Project Complexity Management" (Morcov, Pintelon, & Kusters, 2021a).

The proposed IT-PCM framework is composed of:

- A theoretical basis: the proposed definition of Project Complexity Management, as a new project management Knowledge Area (section V.2).
- A set of processes, defined and described in terms of inputs and outputs (section V.4).
- An inventory of tools and techniques that can be used by project managers, per each process and step of the IT-PCM framework (section V.5).

In order to identify a minimum set of steps to be included in the framework, an intermediate analysis of other existent management frameworks was performed. This is presented in section V.3.

V.1. Introduction

The proposed IT-PCM framework is a high-level process design, that aims to add structure to the management of IT project complexity, and to systematize concepts and practical approach.

The framework is aligned with the recognized project management body of knowledge, particularly with (PMI, 2017).

The **design of the processes** of the IT-PCM framework was based on the analysis of a set of recognized management frameworks from different related areas, including: project management, risk management (PMI, 2017), vulnerability management (Marle & Vidal, 2016); problem-solving; communications management; managing complexity in systems engineering (Maurer, 2017), OODA loop (Boyd, 2018), Systems development life cycle (SDLC); Waterfall software development methodology, OOAD (Satzinger, Jackson, & Burd, 2007), Scrum Agile (Schwaber & Sutherland, 2020), ADDIE and SAM models for instructional design (Allen & Sites, 2012), PDCA (or OPDCA) management method - the Deming Cycle (Liker & Franz, 2011).

An **inventory of tools and techniques** is proposed for each process and step in the IT-PCM framework. The inventory of potential tools and methods is not and cannot be exhaustive nor definitive; as all inventories of tools, it is a starting point. There will always be an additional potential tool; new tools are developed every day; some tools are duplicated or similar; there exist different tools with the same name or similar tools with different names.

Various techniques, guidelines, best practices, thumb rules for managing project complexity are already enumerated by literature (GAPPS, 2007) (PMI, 2013) (PMI, 2014) (Davies, Dodgson, Gann, & Macaulay, 2017) (Australian Government, Department of Defence, 2012) (Riis & Pedersen, 2003) (Remington & Pollack, 2007). These are formed of guidelines, best practices, and examples, such as "*simple rules*", easy to formulate and use in a complex environment (Sull & Eisenhardt, 2012). Various traditional tools have also been proposed for managing specific aspects of project complexity. These are already available in the standard arsenal of the IT project manager. Some are generic, some are highly specialized for a specific area such as IT, or even for a very particular situation.

- **Generic tools** have a wide application area. They could be used across multiple industries and domains, as well as across multiple disciplines. Examples are general project management frameworks, risk management, simplification and decomposition techniques; dependency modeling, Design Structure Matrices (DSM); analysis tools such as cause-and-effect analysis; scheduling tools such as Critical chain management (CCM); planning and monitoring tools such as Earned value management (EVM) (PMI, 2017) (Leach, 1999).
- **Very specialized tools** are specific for a specific domain or problem. Examples are Object-Oriented Analysis and Design (OOAD); Scrum agile software development framework; or AgileEVM are very specific tools for managing software-related complexity (Booch, Object-oriented design, 1982) (Pressman, 2001) (Sulaiman & Smits, 2007) (Schwaber & Sutherland, 2020).

These tools are currently applied opportunistically. There is little research regarding frameworks or tools on how to manage IT complex projects (Botchkarev & Finnigan, 2015). Although the interest in the topic is growing continuously and the quantity of papers and research is already significant, there is no framework or structured approach currently available.

The IT-PCM framework attempts to propose a structure in which to anchor both the application of existing tools, as well as future research.

The framework also attempts to provide structure to project managers in managing complexity in practice. As with any tool, each organization and project manager should decide to what degree to apply a specific framework or set of tools, to a particular portfolio or project.

V.2. Definition of Project Complexity Management

We define "**Project Complexity Management**" as the project management Knowledge Area that includes processes to understand, plan strategy and responses, and manage project complexity.

Its objective is to support project success, by enhancing Positive Complexity and reducing Negative Complexity.

Similar to risk analysis, the cost and benefits of complexity refer to the negative and positive impact on the project's budget, but also on the project's schedule, scope, and quality.

This knowledge area is aligned with the standard project management body of knowledge (PMI, 2017). Its theoretical and structured design is aligned with the PMI's approach, and with the wider need for a theoretical basis to the project management domain (Turner, 2006a) (Turner, 2006c).

Project Complexity Management is at the intersection of project management and complexity, and has inputs from practice, systems theory, systems and IT/software engineering.

Project complexity has different components and sources, including the product (typically expressed in terms of structural or technological complexity); as well as the organization, its processes; the surrounding legal, ethical, and regulatory environment; stakeholder complexity and their (often conflicting) objectives; market complexity. Thus, when operating in a complex organization, or when developing a complex product, it is likely that the project itself will encounter phenomena related to dynamic complexity.

The next section discusses what existing management frameworks can be used as a basis for the design of a framework for Project Complexity Management.

V.3. Management frameworks - background

Management frameworks are widely used in various areas, including project, risk, and vulnerability management; problem-solving and ~management; communications management, etc.

A typical management process structure consists of the following main phases, or processes:

a) Planning.
b) Identification.
c) Analysis.
d) Developing response plans (strategies, actions).
e) Implementation, monitoring, control, and lessons learned.

Some widely recognized and accepted frameworks in project management and IT/software engineering are presented below.

V.3.1. Risk management

Risk management consists of the following processes - Figure 13 (PMI, 2017):

1. **Plan Risk Management** - defining how to conduct risk management activities.
2. **Identify Risks** - identifying individual project risks as well as sources.
3. **Perform Qualitative Risk Analysis** - prioritizing individual project risks by assessing probability and impact.
4. **Perform Quantitative Risk Analysis** - numerical analysis of the effects.
5. **Plan Risk Responses** - developing options, selecting strategies and actions.
6. **Implement Risk Responses** - implementing agreed-upon risk response plans. In the 4th Ed. of PMBoK, this process was included as an activity in the Monitor and Control process, but was later separated as a distinct process in PMBoK 6th Ed.
7. **Monitor Risks** - monitoring the implementation. This process was known as Monitor and Control in the previous PMBoK 4th Ed., when it also included the "*Implement Risk Responses*" process.

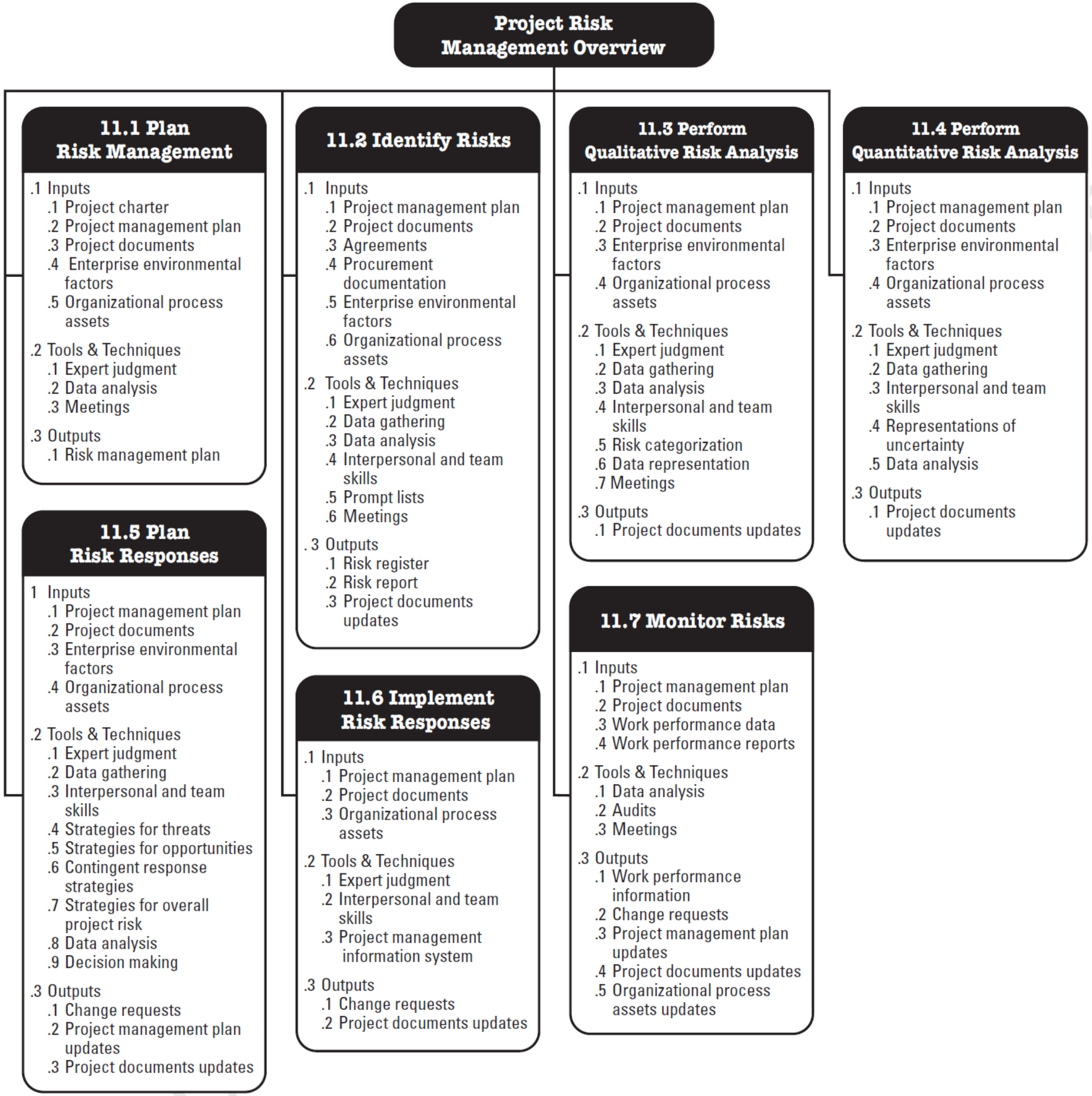


Figure 13. Project Risk Management overview – processes, inputs, outputs, tools and techniques (PMI, 2017)

V.3.2. Vulnerability management

Project vulnerability is the project's susceptibility to being subject to negative events, the analysis of their impact, and the project's capability to cope with negative events (Marle & Vidal, 2016). Based on Systems Thinking, **project systemic vulnerability management** takes a holistic vision, and proposes the following process:

1. Project vulnerability identification.
2. Vulnerability analysis.
3. Vulnerability response planning.
4. Vulnerability controlling – which includes implementation, monitoring, control, and lessons learned.

Coping with negative events is done, in this model, through:

- resistance – the static aspect, referring to the capacity to withstand instantaneous damage, and
- resilience – the dynamic aspect, referring to the capacity to recover in time.

Redundancy is a specific method to increase resistance and resilience (Taleb, Goldstein, & Spitznagel, 2009).

Antifragility is the capacity of systems to not only resist or recover from adverse events, but also to improve because of them (Taleb, 2012).

V.3.3. Complexity management in systems engineering

A proposed model for **managing complexity in systems engineering** - Figure 14 consists of (Maurer, 2017):

1. Define the system.
2. Identify the type of complexity.
3. Determine the strategy.
4. Determine the method.
5. Model the system.
6. Implement the method.

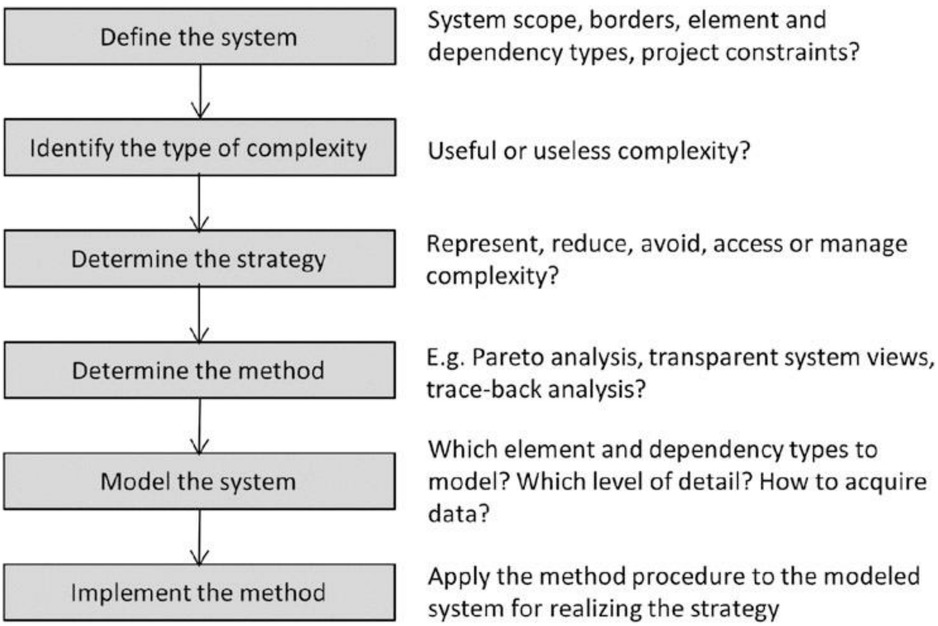


Figure 14. A model proposed for managing complexity in systems engineering (Maurer, 2017)

V.3.4. Software engineering: Systems development life cycle (SDLC), Waterfall, OOAD, Agile

Software engineering proposes models such as the **Systems development life cycle** (SDLC); Waterfall software development methodology / Structured systems analysis and design method SSAD, or OOAD (Satzinger, Jackson, & Burd, 2007).

The six core processes required in the development of a software application - SDLC are (Figure 15):

1. Identify the problem or need and obtain approval to proceed.
2. Plan and monitor the project—what to do, how to do it, and who does it.
3. Discover and understand the details of the problem or the need.
4. Design the system components that solve the problem or satisfy the need.
5. Build, test, and integrate system components.
6. Complete system tests and then deploy the solution.

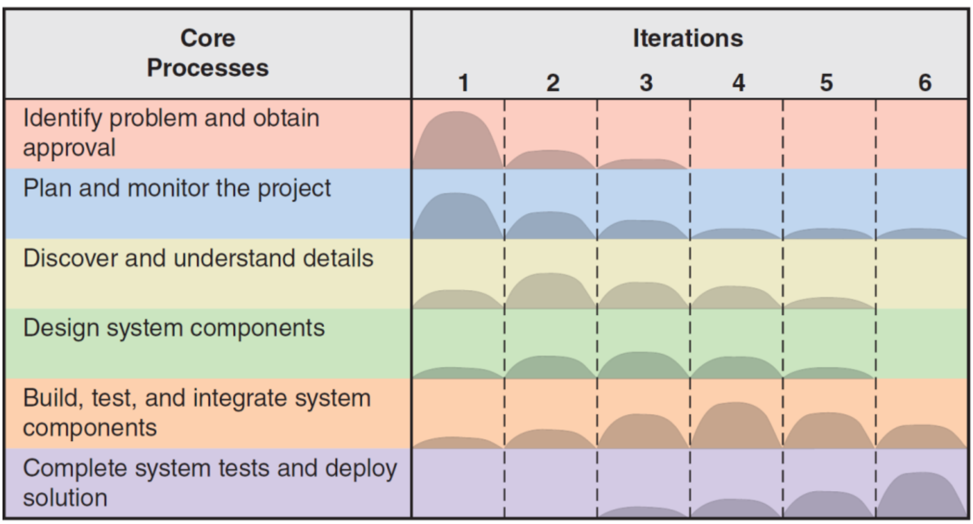


Figure 15. Systems Development Life Cycle (SDLC) – the six core processes in the development of an application, with iterations (Satzinger, Jackson, & Burd, 2007)

The **Waterfall** model is infamous for not providing for iterations, and in general for lack of flexibility. The Waterfall model consists of:

1. Initiation.
2. Planning.
3. Analysis.
4. Design.
5. Implementation.
6. Deployment
7. Maintenance, support.

The **Scrum Agile** software development framework (Schwaber & Sutherland, 2020) proposes short iterative-incremental sprints, where each sprint includes the following events – depicted in Figure 16:

1. Sprint Planning – performed at the beginning of the sprint.
2. Daily Scrum (or stand-up) meetings.
3. Sprint Review, and Sprint Retrospective – at the end of a sprint.

In Scrum, Backlog Refinement is an ongoing activity, not a discrete event.

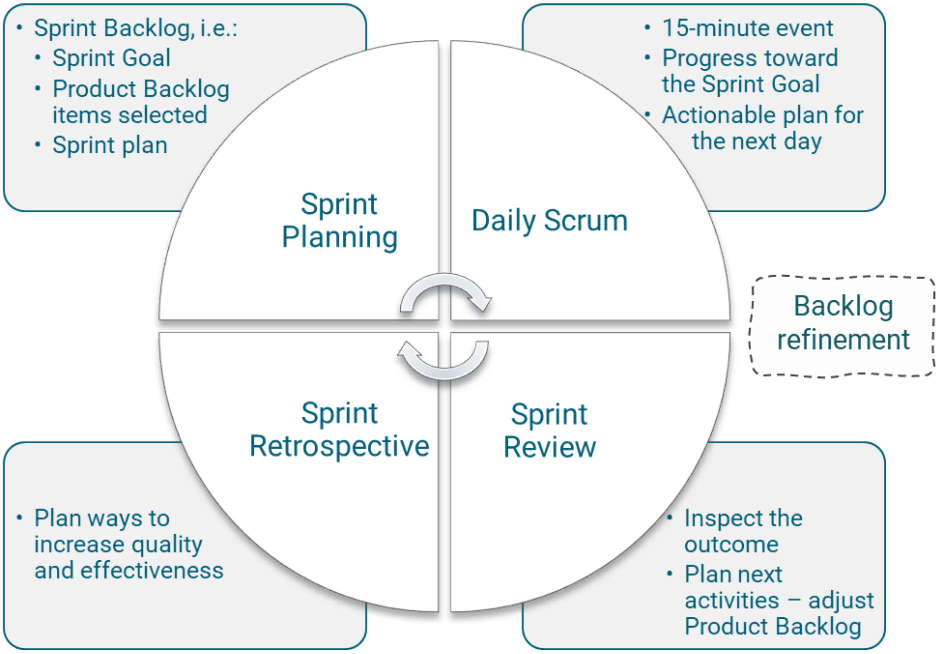


Figure 16. Scrum Agile events. Author design, based on information from (Schwaber & Sutherland, 2020)

V.3.5. ADDIE and SAM models for instructional design

The **ADDIE and SAM models for instructional design** are presented in Figure 17, Figure 18 (Allen & Sites, 2012). The ADDIE model consists of:

1. Analysis.
2. Design.
3. Development.
4. Implementation.
5. Evaluation.

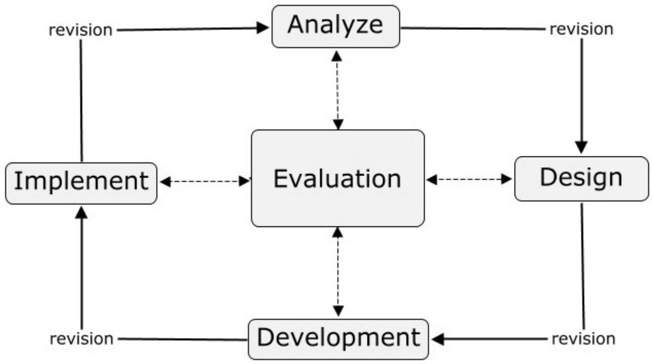


Figure 17. The ADDIE model [5]

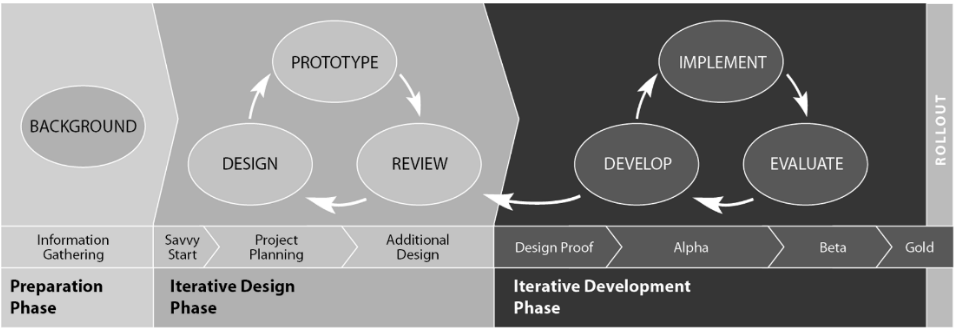


Figure 18. The Successive Approximation Model — SAM (Allen & Sites, 2012)

[5]ADDIE Model of Design, Creative Commons, https://commons.wikimedia.org/wiki/File:ADDIE_Model_of_Design.jpg

V.3.6. OODA loop: observe, orient, decide, act

The **OODA loop** for problem-solving and decision-making is formed of: observe, orient, decide, act. It is presented in Figure 19 (Boyd, 2018).

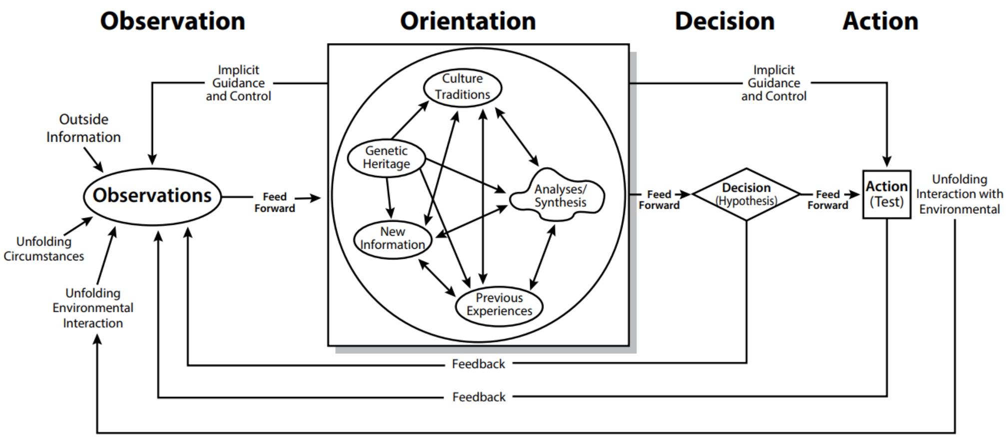


Figure 19. OODA loop (Boyd, 2018)

V.3.7. PDCA: plan, do, check, act

The **PDCA management method** (also known as OPDCA, or the Deming Cycle) is formed of: observe, plan, do, check, act (or adjust). It is presented in Figure 20 (Liker & Franz, 2011).

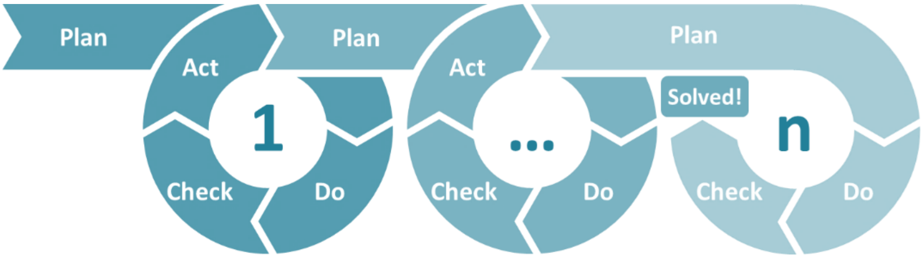


Figure 20. PDCA – Plan-do-check-act model (Roser, 2016)

V.4. Proposed IT Project Complexity Management framework processes

The proposed IT-PCM framework is composed of 5 processes, as presented in Figure 21. For clarity reasons, they are presented as discrete activities, but in practice, the processes and steps interact with each other and with other project management processes, they overlap, and are applied incrementally and iteratively.

Each process itself can be a tool in the arsenal of the project manager. Of course, no set of tools will ensure exhaustiveness.

The IT-PCM framework processes are:

1. **Plan IT project complexity management:** the process of red-flagging complex projects, and deciding on management strategies and tools.
2. **Identify IT project complexity**: the process of determining what elements of complexity characterize the project. It has as objective the detection, inventory, and description of the problem.
3. **Analyze IT project complexity**: the process of analyzing and prioritizing the project complexity elements and characteristics. This step is concerned with understanding the problem.
4. **Plan IT project complexity response strategy**: the process of developing options and actions to enhance and use Positive Complexity, and to reduce or avoid Negative Complexity. This step involves modeling and design of potential solutions.
5. **Monitor and Control IT project complexity**: the process of implementing response strategies, monitoring, controlling, and evaluating the overall effectiveness. It is a continuous activity.

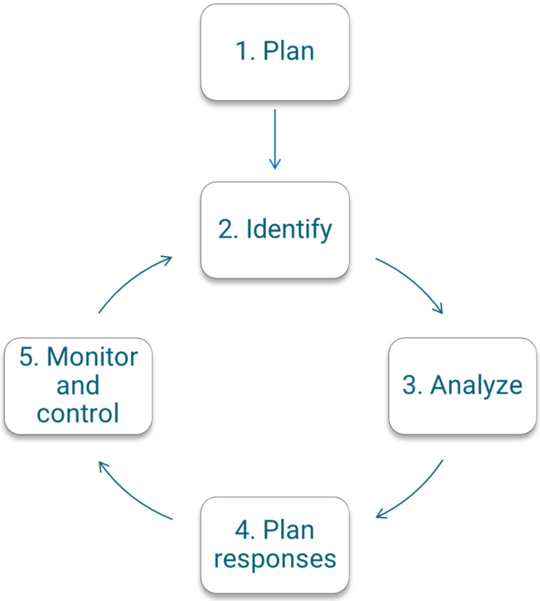
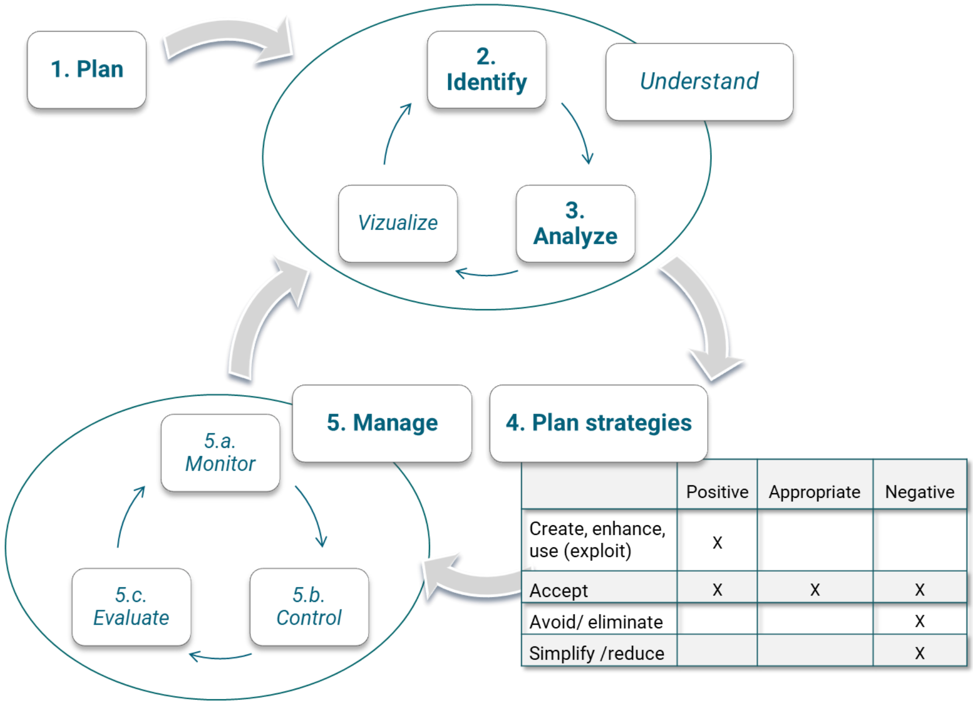


Figure 21. IT Project Complexity Management framework processes

The traditional methodologies for problem management, including the methodologies for risk management and vulnerability management, require a 2-step process for problem understanding: a) identification and b) analysis (PMI, 2017) (Marle & Vidal, 2016). Complexity theory assumes strong structural variety and interdependence of the system's elements, as well as ambiguity and dynamic phenomena; therefore the identification and analysis of complexity cannot be performed in consecutive independent steps; they are intertwined.

Planning and understanding activities are done at the beginning of a project, but all activities are ubiquitous throughout all project phases. Throughout the project, the project manager should continue to understand project complexity better, by identifying additional complexity elements, and by analyzing and re-analyzing project complexity; replan and re-evaluate the process results. Accordingly, we propose an iterative approach, where the results of each step constitute input to both subsequent, as well as to previous steps.

Figure 22 is a more detailed view of the IT Project Complexity Management framework.



	Positive	Appropriate	Negative
Create, enhance, use (exploit)	X		
Accept	X	X	X
Avoid/ eliminate			X
Simplify /reduce			X

Figure 22. Overview of the IT-PCM framework

In the following sections, each process is further defined in terms of objectives, activities, inputs, outputs, and tools. A summary is presented in Figure 23.

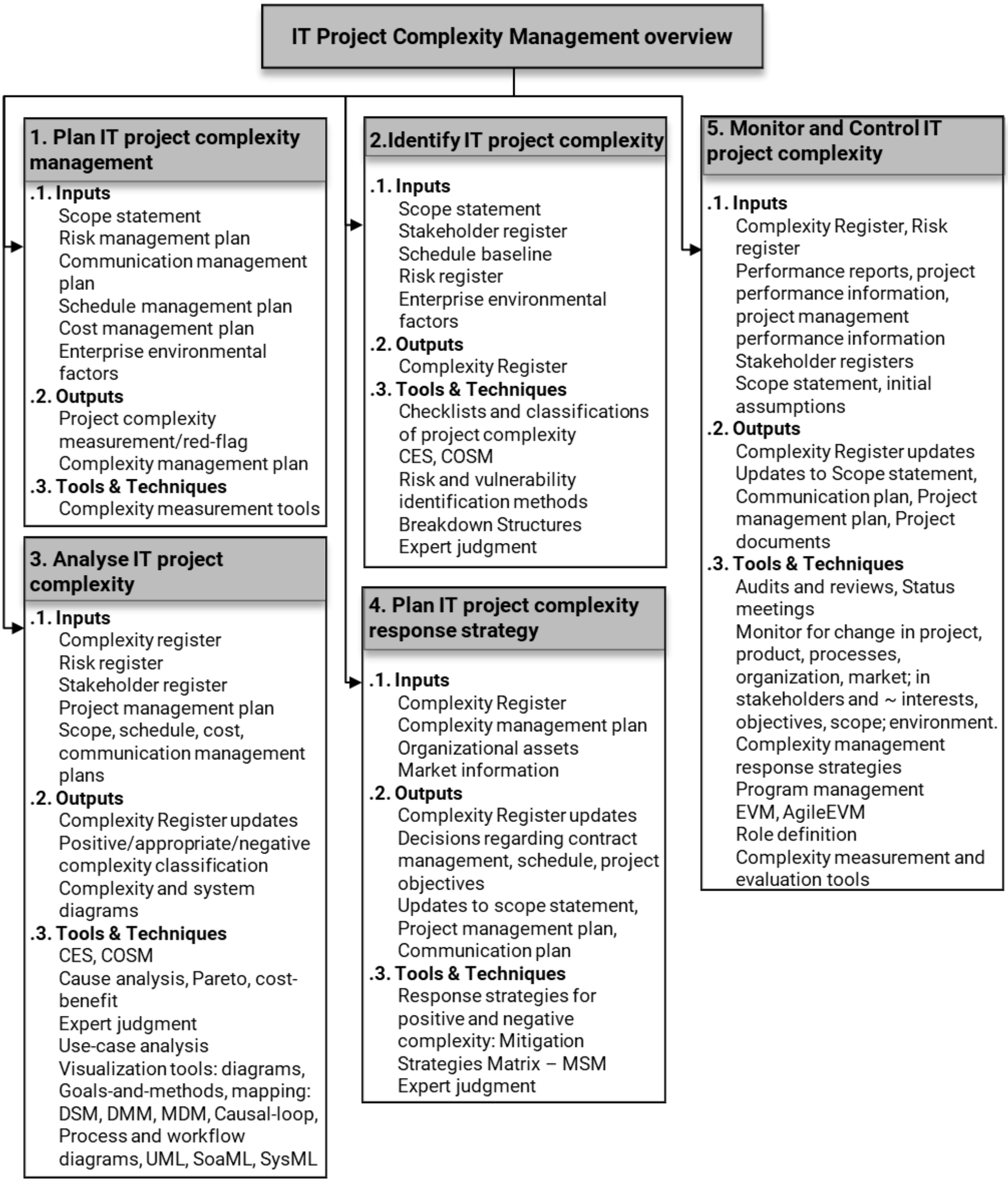


Figure 23. IT Project Complexity Management processes, inputs, outputs, tools and techniques

V.4.1. Planning: deciding when and how to manage complexity

Planning is performed at the beginning of the project, typically at the project approval gates: during a feasibility study, and/or Project Planning phase.

The planning process includes:

1. Preliminary measurement/assessment of the complexity level of the project, i.e. red-flagging if the project is complex – using a simple measurement tool or expert judgment.
2. Decisions if project complexity should be specifically managed, and how; i.e. planning what specific tools will be deployed, if any. This is typically done by choosing from the list of the available tools which are at the disposal of the project manager.
   The deployment of each management tool incurs additional overhead costs; therefore, the decision of the tools and methods to be applied should be based on a cost-benefit analysis (Boadway, 2006).

Complexity can be measured, or red-flagged, with tools such as CIFTER, Vidal, Hass (Morcov, Pintelon, & Kusters, 2020a). A detailed list of potential measurement tools is presented in section III.5.

It should be noted that *red-flagging*, which is part of the Planning phase, partially overlaps with the Identification phase. Indeed, *red-flagging* involves executing a preliminary analysis, thus identification, of complexity. At the same time, this red-flagging does not constitute a detailed analysis of complexity, with its specific tools and associated costs, which might not be appropriate to each specific project.

There are two specific moments when complexity assessment is particularly important: the initial go/no-go decision to start a project, and during the Project Planning phase.

1. The first moment is the initial go/no-go decision to start a project. The terminology is different for various types of projects - it can be a bid/no-bid decision or gate, during a procurement process or sales cycle; for a due diligence process; an approval board; a risk assessment. For a services company, the most important moment is the bid/no-bid decision during proposal preparation. For a product-oriented company, the typical moment is the approval of a new investment.

Currently, the topic of complexity is managed as part of the risk management process. A bid or investment decision is typically taken based on a P&L, accompanied by a risk assessment matrix, and sometimes a cost-benefit analysis or similar decision-making tool.

The go/no-go decision is already a complexity response decision. A new project typically increases the complexity of the organization and its processes. Ending a project or discontinuing a product and simplifying a product portfolio are typical examples of decreasing complexity. Creating a new product, product version or variant increases complexity. Creating a new business unit or merging business units increases organizational complexity.

2. The second moment when it is important to apply a structured approach including assessment of complexity management is during the Project Planning phase, when the strategy, tools, and methods to be used for the particular project are chosen.

V.4.2. Identification

Identification is the process of determining what elements of complexity characterize the project. Its main deliverable is an inventory and detailed description of the problem.

A preliminary analysis was most likely performed during the Planning process, in order to red-flag a project as complex or not. On the other hand, the Identification process involves creating a rigorous register, a detailed complexity map.

When faced with the challenge of understanding and analyzing a new topic or project, practitioners refer to guidelines, templates, examples, precedents, tutorials, methodologies. For identification and initial analysis, checklists are the key tools.

Perceived complexity approaches acknowledge that there is much more to complexity than structural descriptive complexity; than the mere enumeration or description of characteristics of complexity. Complexity is more than structural; it also includes subjective and dynamic aspects.

At the same time, research tends to focus on objective, structural complexity, because structural complexity is less abstract, thus more discussable, analyzable, measurable, and manageable. Accordingly, for practical reasons, this framework, including the identification process, refers significantly to descriptive complexity.

Examples of checklists and tools proposed by the relevant literature are:

- Checklists of groups of elements (Maurer, 2017).
- Identification based on sources and aspects of complexity, such as: technical vs. organizational complexity; related to ambiguity, uncertainty, propagation, or chaos; related to size, variety, interdependence, or context.
- Classification based on the complexity sub-system: market, organization, process, product (Lindemann, Maurer, & Braun, 2009) (Maurer, 2017).
- Other possible classifications of complexity such as based on location: internal vs. external.
- Checklists derived from the complexity measurement tools.
- Marketing analysis, risk identification and management tools and checklists: SWOT, PEST – analysis of Political, Economic, Social, and Technological factors, STEEP - same plus Environmental, STEEPLE – same plus Legal and Ethical, PERSI – Political, Economic, Religion, Social, Intellectual, WWWWHW – who, what, when, where, how, why (PMI, 2017) (Marle & Vidal, 2016).
- Balanced Scorecard.
- External audits.
- Reference-class forecasting (Lovallo & Kahneman, 2003).

V.4.3. Analysis: qualitative and quantitative

The analysis for identifying the type of complexity and selecting the management strategy can be:

- Qualitative analysis
    - Input checklists.
    - Root-cause analysis, fault-tree.
    - Cause-and-effect diagrams, Ishikawa, problem-tree.
    - Toyota 5-Why’s (Liker & Franz, 2011).
    - X-BS: Work Breakdown Structure, Risk Breakdown Structure, Resource BS, Product BS, Organization BS (Levine, 1993).

    - Use-case analysis.
- Quantitative analysis
    - It can help prioritize and thus select the most useful subset of complexity items and tools to be applied in a project.
    - It includes quantifying the elements of complexity in numeric values, such as financial impact; similarly to the quantitative analysis of risks.
    - Based on the quantitative results, numeric tools can be applied, such as:
        - Cost-benefit analysis (Boadway, 2006).
        - Pareto.

Expert judgment, Delphi, focus groups, affinity diagrams, stakeholder analysis, and brainstorming are general tools applicable for both qualitative and quantitative complexity analysis.

Complexity analysis should include categorizing complexity as positive, appropriate, or negative, i.e. useful or damaging – based on its effects. Specific tools with this purpose will be further developed and proposed in Chapter VI. While the analysis of effects should be done primarily against the initial project objectives, these will be adapted if new opportunities are uncovered (PMI, 2017).

V.4.3.1 Complexity visualization

Visualizing IT project complexity is a general tool for analysis, especially suitable for engineering projects.

System views help visualize both structural complexity and dynamic complexity. Visualization tools include:

- Visualizing the effects of complexity – positive, appropriate, or negative (a tool doesn't exist yet, to be developed – see Chapter VI).
- Dependency modeling - which can be used for all aspects of a project, including for:
    - modeling products, objectives, stakeholders, teams, organizations, processes, risks, etc.
    - model the dependencies between elements of the same sub-system, e.g., between product parts; as well as dependencies between different sub-systems.
    - DSM (Browning, 2001).

    - DMM (Eppinger & Browning, 2012) (Maurer, 2017).
    - MDM (Marle & Vidal, 2016).
- Goals-and-methods matrix (Turner & Cochrane, 1993).
- Complexity mapping diagram based on four dimensions of complexities – structural, technical, temporal, directional (Remington & Pollack, 2007).
- Causal-loop diagrams, as defined by Systems Thinking (Kim, 1999).
- Graphs, process and workflow diagrams.
- Breakdown Structures, organization charts.
- Mind-maps.
- UML (Booch, Rumbaugh, & Jacobson, 2005).
- SoaML, SysML (Delligatti, 2013).

V.4.3.2 The required level of detail for decomposition, analysis, and planning

Many tools rely on decomposition, in listing and analyzing individual components of the analyzed system. Decomposition, analysis, and planning can be too granular and details – which would be inefficient; or too general and superficial – which would be not clear nor useful. A key question is therefore: which is the right level of detail when analyzing and decomposing a (complex) system. In individual cases, hard numeric rules can be imposed, such as: "Each task in a project plan or WBS must require less than 4 or 8 man-hours of effort to complete" (these are actual examples from the industry).

A possible answer can be derived from utilitarianist principles. A rule-of-thumb for deciding if an analysis is sufficiently detailed is thus: ***Detail until you know what is to be done*.** When a team member receives a task that they do not know how to implement, then the task is not sufficiently analyzed and detailed, and it requires further decomposition and analysis. This is congruent with Toyota 5-Why's methodology (Liker & Franz, 2011): ask "why" until you understand the problem and its source. In IT Project Complexity Management, we could therefore propose that:

Complexity should be detailed and analyzed until the work to be done is clear.

More than this, the level of detail is different based on the moment and purpose of the analysis. The level of detail will naturally be less granular for go/no-go decisions, more granular when planning the execution of a project, and even more granular during execution. Therefore, also the tools or checklists used for identification of complexity items will not necessarily be the same.

V.4.4. Planning IT project complexity response strategies

Traditionally, both research and practice focus on the negative effects of complexity, on the relationship between complexity, risk, and failure. Still, as argued in section IV.3, the complexity of IT projects and products is sometimes appropriate (or requisite); and even *positive*. Complexity is needed to ensure system viability; it enhances creativity and innovation; it offers functionality (Beer, 1972) (McKelvey & Boisot, 2009) (Floricel, Michel, & Piperca, 2016) (Maurer, 2017).

Accordingly, the potential response strategies should consider that complexity can be negative, but it is sometimes necessary (appropriate, or requisite), and sometimes even positive.

Appropriate Complexity is needed for the project to reach its objectives. Its contribution to project success balances the negative effects, or the cost of mitigation outweighs negative manifestations.

Positive Complexity adds value to a project; its contribution to project success outweighs the associated negative consequences. Since it creates opportunity, this should be exploited rather than eliminated.

Appropriate and Positive Complexity are concepts similar to the opportunities of risk management, to requisite complexity, and antifragility (PMI, 2017) (Boisot & McKelvey, 2011) (Taleb, Antifragile: things that gain from disorder, 2012).

For complexity management planning, an important consideration is that negative complexity-related phenomena in one sub-system could lead to positive effects in another sub-system, or vice-versa, because of propagation phenomena (Marle & Vidal, 2016). As the simplest example, a very complex organization is difficult to manage and might be inefficient, but might be required or even beneficial for the development of highly advanced and innovative products (Maurer, 2017). Alternatively, a highly advanced IT product, i.e. exhibiting positive intrinsic complexity, could have a major negative impact if implemented in a well-functioning organization with well-established and efficient processes already in place.

Another observation for the proposed approach to complexity management planning is that complex IT projects are emergent and dynamic. Planning projects in non-deterministic environments follows a different paradigm than in deterministic environments, since the project plan is known to be subject to change as it unfolds; not all activities can be foreseen; not all methods and objectives are known (Daniel & Daniel, 2018). Therefore, similarly as argued above regarding understanding and analyzing complexity, the plan should be detailed until it is clear what has to be done; but the level of detail required for a project plan is different for the different phases in a project lifecycle. The wave-crest planning model can support such an approach, where the activities of the near future are much more detailed than the activities planned for the distant future. This paradigm is a common practice in software engineering, which has long faced issues of complexity including uncertainty in methods and objectives, and has systematically experimented with and adopted flexible models, e.g. iterative, incremental, and agile development.

The literature review did not uncover tools for planning complexity management responses. A specific tool is proposed in Chapter VI below: the Mitigation Strategies Matrix, MSM.

V.4.5. Monitor and control complexity

The process of monitoring, controlling, implementing response strategies, and evaluating the overall effectiveness is a continuous activity performed throughout the project's life, as part of the Monitoring and Controlling Process Group. The overall process is depicted in Figure 24.

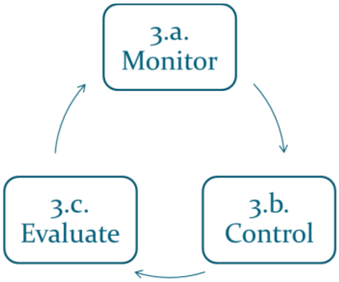


Figure 24. The process Monitor and Control IT project complexity

Possible complexity management methods are:

a. Apply a structured approach to governance, project management, quality management, complexity management.
b. Monitor and control according to quality assurance frameworks – ISO 9001, CMM (ISO/IEC, 2015).
c. Apply security management frameworks such as CIS Controls V8, ISO/IEC 27001, ISO/IEC 27002 (CIS, 2021) (ISO/IEC, 2018) (ISO/IEC, 2013).
d. Change management, configuration management; asset management (Whyte, Stasis, & Lindkvist, 2016).
e. Release management; risk management, communication management.
f. Monitoring the evolution of the analysis and design artifacts – as the system is likely to change.
    i. Artifacts that do not change, such as input checklists
    ii. Elements that should not change
    iii. Elements that are likely to change or that are supposed to change.
g. Implement the project as a program – a system of projects (Remington & Pollack, 2007).
h. Earned Value Performance Measurement (PMI, 2017), including adaptations of EVM for Agile development (Sulaiman & Smits, 2007), as well as integrating uncertainty into EVM (Pajares & López-Paredes, 2011).
i. Role definition (Remington & Pollack, 2007).

Besides structural complicatedness, complexity also refers to subjective and dynamic aspects. At the same time, the inventory of tools and techniques focuses on objective, structural complexity, because structural complexity is less abstract. Dynamic complexity aspects are related to *“unknown unknowns”*; difficult to identify or plan. They behave like Black Swans and follow “Butterfly Effect” patterns (Lorenz, 1963) (Taleb, Goldstein, & Spitznagel, The Six Mistakes Executives Make in Risk Management, 2009). Still, dynamic complexity aspects must be monitored, recognized, and identified as they occur, and the project should be prepared to deal with them.

The main method, in this case, is **monitoring for change**, especially in stakeholders, objectives, and in the environment, as well as in the project context – due to emergence (Snowden & Boone, 2007). “Monitoring” is already listed in the traditional project management body of knowledge.

The literature review did not uncover a specific tool for monitoring the implementation and impact of complexity management plans. Accordingly, such a tool is further proposed in Chapter VI below: the Complexity Register CoRe.

V.5. Structured IT-PCM framework, with inputs, outputs, tools and techniques, per process

Table 10 offers an overview of the proposed IT Project Complexity Management framework, with inputs, outputs, tools and techniques, per each process.

Table 10. IT-PCM framework, with inputs, outputs, tools and techniques, per process

1. Plan IT project complexity management		
Inputs	**Tools and techniques**	**Outputs**
Scope statement Risk management plan Communication management plan Schedule management plan Cost management plan Enterprise environmental factors	Complexity measurement and evaluation tools (section III.5): • CIFTER tool (GAPPS, 2007) • Hass tool (Hass, 2008b) • Vidal AHP tool (Vidal, Marle, & Bocquet, 2011) • Morcov tool (new tool proposed in Chapter VI below) • Cynefin framework (Snowden & Boone, 2007) • PMI's Complexity Assessment Questionnaire (PMI, 2014) • PCAM (Dao B. P., 2016) • ACAT (Australian Government, Department of Defence, 2012) • PCRA (Treasury board of Canada secretariat, 2015) • ISDP complexity measurement model (Xia & Lee, 2005) • Complexity Index (Poveda-Bautista, Diego-Mas, & Leon-Medina, 2018). Inventories, checklists of complexity management tools and techniques.	Red-flag project as complex Complexity measurement Complexity management plan

<table>
<tr><th colspan="3">2. Identify IT project complexity</th></tr>
<tr><th>Inputs</th><th>Tools and techniques</th><th>Outputs</th></tr>
<tr><td>Scope statement, scope baseline
Stakeholder register, communications management plan
Schedule management plan, schedule baseline
Risk management plan, risk register
Project documents
Market analysis
Enterprise environmental factors</td><td>Checklists and classifications of project complexity (section III.3.6):
• Technical vs. organizational complexity (Baccarini, 1996)
• Related to ambiguity, uncertainty, propagation, or chaos; related to size, variety, interdependence, or context (Marle & Vidal, 2016)
• Sub-system: market, organization, process, product (Lindemann, Maurer, & Braun, 2009) (Maurer, 2017)
• Task-related complexity (business, external, organizational complexity) vs. system-related complexity (technological complexity) (McKeen, Guimaraes, & Wetherbe, 1994)
• TOE model - technological, organizational, environmental complexity (Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011)
• Checklists of indicators, dimensions, measures of project complexity - Hass, Vidal, Morcov, CIFTER scales.
Complexity Effect Scale tool – CES, Complexity Source/Effect Segmentation Matrix tool – COSM (new tools proposed in Chapter VI below)
Risk, security, and vulnerability identification methods; SWOT analysis, WWWWHW, analysis of PEST, STEEP, STEEPLE, PERSI factors, Balanced Scorecard (Marle & Vidal, 2016)
Systems engineering analysis (Maurer, 2017)
X-BS: WBS Work Breakdown Structure, Risk BS, Resource BS, Product BS, Organization BS (Levine, 1993)
Audits, documentation reviews, assumptions analysis, Market analysis tools
Reference-class forecasting (Lovallo & Kahneman, 2003)
External audits, Expert judgment</td><td>Complexity Register (new tool proposed in Chapter VI below)</td></tr>
</table>

3. Analyze IT project complexity		
Inputs	**Tools and techniques**	**Outputs**
Complexity register Risk register Stakeholder register Project management plan Scope, schedule, cost, communication management plans	Quantitative & qualitative analysis of complexity effects and sources: CES, COSM Complexity measurement and evaluation tools – as checklists Root-cause analysis, fault-tree; cause-and-effect diagrams, Ishikawa, problem-tree, Toyota 5-Why's (Liker & Franz, 2011), Pareto, use-case analysis Cost-benefit analysis Security management, Project Systemic Vulnerability Analysis Market analysis tools, Delphi, focus groups, affinity diagrams, brainstorming Checklists, Expert judgment **Complexity visualization tools:** Diagramming techniques System views help visualize both structural complexity and dynamic complexity Goals-and-methods matrix (Turner & Cochrane, 1993) Complexity mapping diagram (Remington & Pollack, 2007) Dependency analysis, dependency modeling, DSM (Browning, 2001) DMM (Eppinger & Browning, 2012) (Maurer, 2017), MDM (Marle & Vidal, 2016) Causal-loop diagrams – Systems Thinking (Kim, 1999) Use-case analysis, Process and workflow diagrams Graphs, mind-maps UML (Booch, Rumbaugh, & Jacobson, 2005), SoaML, SysML (Delligatti, 2013)	Complexity Register updates Classification of complexity as Positive, Appropriate, or Negative Complexity and system diagrams

4. Plan IT project complexity response strategy		
Inputs	**Tools and techniques**	**Outputs**
Complexity Register Complexity management plan Organizational assets Market information	Response strategies for positive and negative complexity: Mitigation Strategies Matrix – MSM (new tool proposed in Chapter VI below): • Create, enhance, use (exploit): for Positive Complexity. • Accept: for Positive, Appropriate, or Negative complexity. • Avoid/ eliminate, simplify /reduce: for Negative Complexity. Expert judgment	Decisions and updates to Complexity Register, scope statement (change requests), project management plan, schedule, project documents, communication plan
5. Monitor and control IT project complexity		
5.a. Monitor		
Complexity Register Risk register Performance reports & information Change registers, change requests, configuration Stakeholder registers Scope statement & initial assumptions	Audits and reviews Status meetings Monitor for change (Whyte, Stasis, & Lindkvist, 2016): • in project, product, processes, organization, market. • in stakeholders and stakeholders' interests, project objectives, and scope; environment. COSM Recheck assumptions	Complexity Register updates

5.b. Control		
Inputs	**Tools and techniques**	**Outputs**
Complexity Register	Implement complexity management response strategies Implement the project as a program (Remington & Pollack, 2007) Earned Value Management EVM (PMI, 2017) AgileEVM (Sulaiman & Smits, 2007) Integrating uncertainty into EVM (Pajares & López-Paredes, 2011). Role definition (Remington & Pollack, 2007)	Decisions and updates to Complexity Register, scope statement (change requests), project management plan, schedule, project documents, communication plan
5.c. Evaluate		
Complexity Register Performance reports	Audits and reviews Complexity measurement and evaluation tools	Complexity management plan updates

V.6. Conclusion

This chapter proposes a practical IT-PCM framework to support IT Project Complexity Management in a structured, systematic way. It is formed of processes, described in terms of inputs and outputs.

These interact with each other and with other project management processes. While presented as discrete activities, in practice they overlap, and are applied incrementally and iteratively.

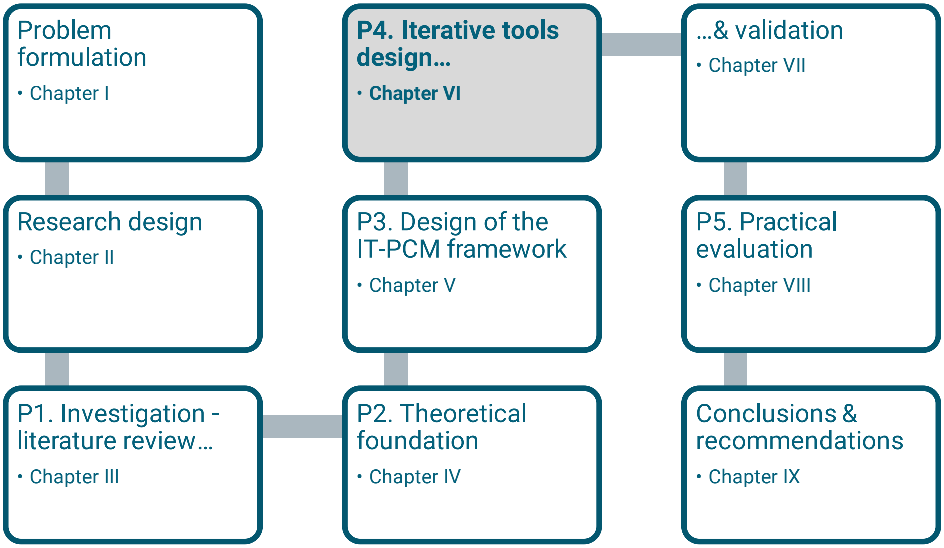
For each process and step in the IT-PCM framework, an inventory of tools and techniques is provided.

Several gaps were uncovered in this inventory of tools. An attempt to fill some of these gaps with proposed new tools is presented in the following Chapter VI – research sub-project P4.

These gaps, and the new tools proposed in the subsequent chapter, relate to:

- Red-flagging and measuring complexity: while several measurement tools were identified as part of the literature review, they are not particularly adapted to an IT environment.
- Identification and analysis of the effects of complexity; particularly to understand if the effects are appropriate or have positive effects (CES and COSM tools).
- Planning complexity response strategies (MSM tool).
- Monitoring the application and impact of complexity response strategies and actions (Complexity Register CoRe tool).

Chapter VI.
Design of specialized tools for IT Project Complexity Management



This chapter presents the design of a set of new proposed tools to support IT project complexity management, in order to fill gaps in the IT-PCM inventory. The research question was *RQ6: What tools can support IT project complexity identification, analysis, and management?*

The sub-project P4 consisted of a design-and-validation process that followed the design-cycle, with several phases: initial design, preliminary validation, refined design, and final validation (Figure 25).

This chapter presents the final version of the tool designs. The next Chapter VII will also present the results of the validation, done with semi-structured expert interviews, using actual complex IT project cases.

The research sub-project P4, which is presented in Chapters VI and VII, was published in the Proceedings of the Romanian Academy - Series A, as: "IT Project Complexity Management Based on Sources and Effects: Positive, Appropriate and Negative" (Morcov, Pintelon, & Kusters, 2020b).

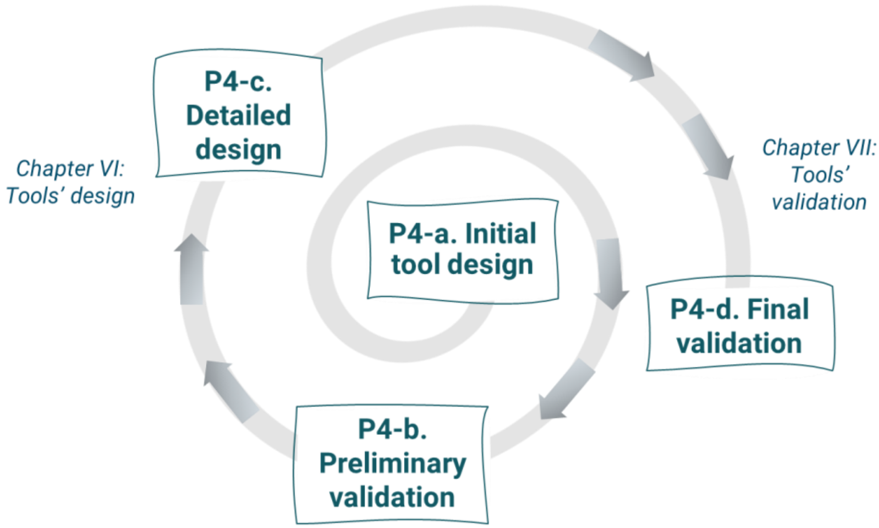


Figure 25. Research sub-project P4 - iterative design-and-validation cycles

Section VI.1 presents the overall methodology of research sub-project P4.

The rest of this chapter presents the final version of the tool designs.

The proposed tools attempt to fill gaps identified in the inventory of tools of the IT-PCM framework – Chapter V:

- IT project complexity measurement tool – section VI.2.
- Identify and analyze the effects of complexity, and understand if it is positive, appropriate, or negative.
    - the Complexity Effect Scale CES – section VI.3.
    - the Complexity Source/Effect Segmentation Matrix COSM – section VI.4.
- Plan response strategies: the Mitigation Strategy Matrix MSM – section VI.5.
- Data collection, complexity analysis, and monitoring the application and impact of specific complexity response strategies and actions: the Complexity Register CoRe – section VI.6.

VI.1.Methods

Based on the literature review (Chapter III), and armed with the new paradigms formulated in the theoretical foundation (Chapter IV), we designed and validated new tools to support IT project complexity management, in a qualitative exploratory approach.

Design science is a valid research methodology to develop solutions for practical engineering problems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Qualitative research helps develop initial understanding in a less explored area (Levitt, et al., 2018) (Gummesson, 2000).

Our research methodology followed a pragmatic constructivist approach to solving problems, with an iterative-incremental 2-rounds design, with trial-and-error cycles, based on the *design cycle* of the *engineering cycle* (Wieringa, 2014). The main activities were:

- Problem formulation: we started with a general research question, on how to manage IT Project Complexity, operationalized as the design of new tools to support identification and analysis.
- Investigation: literature review on project complexity literature (Chapter III, sub-project P1), as well as study of systems theory, systems and IT engineering, to establish the theoretical and practical foundation for the design (Chapter IV, sub-project P2).
- Initial design of the new tools: development of the initial design concepts, based on the literature review, and refined through interviews with experts and analysis of actual complex IT project cases.
- Preliminary validation – with semi-structured interviews, based on actual project cases.
- Detailed design of the new tools, based on the results of the validation.
- Final validation of the tools, in a second round of interviews with the same experts.

The **validation** was done in 2 iterations: preliminary validation (followed by detailed design) and final validation (followed by design adjustments). The results of the validation are presented in Chapter VII.

The validation was done through semi-structured interviews with practitioners, using actual project cases (Yin R. K., 2011). Face-to-face, open interviews support qualitative exploratory research and obtaining new insights and increase innovation and creativity; they are appropriate considering the novelty of the research questions, the niche topic, the overloaded non-standardized terminology. In qualitative research, stronger importance must be placed on negative than on positive feedback, thus uncovering new insights, challenging preconceptions, and avoiding self-confirmation bias (Wieringa, 2014).

Triangulation has been shown to both prove convergence, as well as to explore divergent but possibly new relevant insights. Multiple project cases were therefore used to support the interviews, as they are suitable for building new theories and their external validation (Gibbert & Ruigrok, 2010).

During our research and design process, we embraced the fact that qualitative research is a personal journey (Gummesson, 2000); that ideas and findings get reconceptualized with each writing (Bansal & Corley, 2012). As such, the designs were updated according to each round of feedback received during each validation/re-validation cycle. Noticeably, the Complexity Register CoRe tool emerged during the sub-project P5 – Evaluation, as a data collection and aggregation tool.

VI.2. Proposed IT project complexity measurement and analysis tool ("Morcov tool")

This section presents the design of a complexity measurement tool for IT projects. The tool consists of a list of complexity factors, each with an associated measurement scale and metric.

The list of complexity factors was obtained through the refinement of the inventory of complexity characteristics built as part of the literature review (Chapter III).

The literature review had among its results 2 artifacts to support the identification of project complexity:

- A list of existing tools for measuring project complexity (section III.5, Table 8).
- An inventory enumerating all the measures, criteria, characteristics, factors, and indicators proposed for measuring, identifying, or categorizing complex projects (Appendix B).

Significant empirical proofs show that there are major differences between complexity measures across different industry sectors; therefore, the scope and applicability of this tool was limited to IT (Bosch-Rekveldt, Bakker, & Hertogh, 2018). Based on this consideration, some successful IT/software estimation tools were also analyzed, such as Function Points Analysis and COCOMO. These include IT/software complexity aspects in their model[6]. At the same time, in line with our holistic approach to IT project complexity, described in section IV.2, the complexity factors were not limited to the IT *product*, or to *technology*. Instead, they also cover aspects related to the other project sub-systems, such as *organization, process, market,* and *project*.

The initial large inventory of factors of complexity has 116 items. It does not discriminate against factors specifically excluded from other models, such as size. Many items in this inventory are redundant, and items have variable degrees of relevance. At the same time, the compilation of a large inclusive inventory, containing the maximum possible list of items, ensured reliability and repeatability of the process, as well as construct validity and internal validity, and supported avoiding anecdotic evidence and subjective criteria (Gibbert & Ruigrok, 2010b).

This initial inventory of complexity measures was reduced to 28 items using card-sorting (Paul, 2008) (Spencer & Warfel, 2004). The card-sorting process was executed from the single perspective of the author. During this process, certain choices had to be done which may be considered subjective.

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[6] Function Points Analysis uses a Value Adjustment Factor, computed based on 14 General System Characteristics (Albrecht, 1979) (Longstreet, 2012). COCOMO also uses 15 Cost Driver Attributes in its model (Boehm, 1981) (Pressman, 2001).

This sorting is nevertheless relevant for the scope of our research, it is valid and results from a repeatable process. The resulted list is simple enough to be usable, understood and applied easily. Its items are practical, allow for comparison and measurability and are objective – they do not have multiple interpretations based on context or expert. The result is falsifiable, which ensures its internal validity.

The resulted complexity measurement tool was included in the evaluation sub-project P5 (Chapter VIII), when it was deployed and assessed in actual project cases.

The set of 28 IT project complexity measures is presented in Table 11. The measures are classified by family (Vidal, 2009) and by source (organizational, technological) (Baccarini, 1996). This classification increases the navigability through the items, and the overall usability of the tool.

Table 11. Proposed IT project complexity measurement tool

#	Criterion	Organizational	Technological
Family: Size			
1	Staff quantity (team size)	x	
2	Number of stakeholder organizations (subcontractors, customers, partners, investors, users…)	x	
3	Size of capital investment (budget), including resources	x	
4	Number of deliverables	x	x
5	Effort (man-days)	x	x
6	Duration of the project	x	x
7	Number of business areas involved		x
8	Number of function points		x
Family: Variety			
9	Reusability - application developed to meet one or many user's needs		x

10	Geographic distribution of the project team (collaborating frequently)	x	
11	Variety of the interests of the stakeholders	x	
12	Variety of information systems to be combined (number of application types)	x	x
13	Variety of skills needed	x	x
14	Variety of interdependencies		x
15	Competing objectives		x
16	Uncertainty and stability of the objectives and requirements	x	x
Family: Interdependencies			
17	Availability of people, material and of any resources due to scarcity of supply on the market or in the organization	x	
18	Specifications interdependence		x
19	Interdependence between the components of the product		x
20	Uncertainty of the project plan - level of detail and expected stability		x
21	Uncertainty and stability of the methods (clear project management methodology, clear software development methodology, risk management, communication, etc.)		x
Family: Context			
22	Unknown and/or unstable legal and regulatory environment	x	x
Family: Interdependencies /context			
23	Cultural configuration and variety		x
24	Environment organizational complexity (networked environment)	x	
25	Environment technological complexity (networked environment)		x
26	Knowledge in the organization - organizational (business and industry; e.g. new business or a new type of customer)	x	
27	Knowledge in the organization - technical (technology, infrastructure, external interfaces, development platform, tools...)	x	
28	Level of change imposed by the project on its environment	x	

Practical examples and the results of the application of this measurement tool in practice as part of the evaluation sub-project P5 are presented in Chapter VIII: *Practical evaluation*, and in Appendix F.4.

VI.2.1. Complexity measurement tool - weights

For an assessment tool to be usable, its results must be comparable and repeatable.

The literature review showed that criteria and numeric weights are different across domains, and even between authors, experts, or studies within the same field (Thamhain, 2013). Research suggests that the importance of criteria and thus the values of possible weights vary across different types of projects, across types of organizations, technologies, or industries.

This suggests that the projects which are measured and compared should be reasonably similar, in terms of:

- Products, incl. technology.
- Organization, incl. stakeholders, size, culture.
- Processes, incl. methodologies, standards, tools.
- Market: environment, industry.
- Project, incl. tools, stakeholders, users, size.

Accordingly, this study did not attempt to assign individual weights to each complexity item, or to propose a general complexity formula. No weighting was applied in the practical evaluation sub-project P5 either (Chapter VIII). Of course, for different practical implementations, specific sets of weights could be developed, appropriate to the specific respective organization and project environment.

This conclusion regarding the difficulty to assign weights to individual complexity items is aligned with the analysis of the effectiveness of formal methods for estimating software projects, such as COCOMO, FPA – Function Point Analysis, IFPUG - International Function Point Users Group. Software estimation methods require heavy calibration using historical data related to the exact specific industry, organization, tools and technology employed for the particular projects measured. Because IT projects are particularly varied and complex (Moe, Dingsøyr, & Rolland, 2018), such estimation techniques have systematically proven to be unreliable (Cao, Gu, & Thompson, 2012). Thus, software estimation errors of 10% are considered acceptable, and organizations only worry when error levels exceed 100% (McConnell, 2006).

Therefore, organizations mostly revert to expert judgment for estimation (Jørgensen, 2007). Accordingly, the calculation and assignation of weights to the proposed complexity measures at this time would not meet reasonable reliability and repeatability criteria, and also would not fulfill sufficient external validity conditions for the scope of this research.

VI.2.2. Complexity measurement tool - scales

The scale applied in the practical evaluation is a design choice.

For qualitative criteria, an interval scale with 5 points was used – the most common type of Likert scale. The minimum and maximum values were defined as relative to the organization, i.e. to the project portfolio.

The measurement tool includes quantitative criteria, which are mostly aspects related to size, e.g. effort or duration. For these questions, a Likert scale does not discriminate well between very different projects: there is no universally valid maximum value. *In fact, no matter how large we would set a "reasonable" maximum value for a Likert scale for a quantitative question, a bigger project will eventually appear, for which the scale would not discriminate correctly. At the same time, if an excessively high maximum value is proposed, then the high values of the Likert scale might never be used.*

Therefore, in order to ensure correct discrimination between projects, a ratio scale is proposed for the numeric quantitative questions. The possible answers are in such cases the absolute values, e.g. Team size can be quantified in full-time equivalents, Effort in man-days, and Duration in calendar days.

In the IT-PCM framework, the IT project complexity measurement tool is useful mostly during the identification and analysis processes of the framework.

The tools proposed in the following sections focus on complexity analysis.

VI.3. The Complexity Effect Scale tool – CES: Positive, Appropriate, Negative Complexity

As argued in Chapter IV: *Theoretical foundation*, our approach considers that complexity can sometimes have positive or appropriate effects on overall project success. The analysis of the effects of complexity is important for industry IT projects, in order to better understand it, and to make appropriate decisions and mitigation plans.

The Complexity Effect Scale – CES tool provides a structured method to analyze project complexity based on its effects.

CES attempts to fill a gap in the IT-PCM framework (Chapter V). It is most useful during the complexity analysis process – section V.4.3.

The results of the application of the CES tool are a critical input to the process of Planning response strategies – section V.4.4.

Negative complexity is the complexity that hinders project management performance and project success.

Traditionally, both research and practice focus on the negative effects of complexity, on the relationship between complexity, risk, and failure. Still, as argued in section IV.3, the complexity of IT projects and products is sometimes *Appropriate*; and even *Positive*. Complexity is needed to ensure system viability; it enhances creativity and innovation; offers functionality (Beer, 1972) (McKelvey & Boisot, 2009) (Floricel, Michel, & Piperca, 2016) (Maurer, 2017).

Appropriate, *or* ***requisite, complexity*** is the complexity needed for the project to reach its objectives, or whose contribution to project success balances the negative effects, or the cost of mitigation outweighs negative manifestations.

Positive complexity is the complexity that adds value to a project, and whose contribution to project success outweighs the associated negative consequences. Since it creates opportunity, it should be exploited rather than eliminated.

The concepts of *Appropriate* (requisite) and *Positive Complexity* are similar to *opportunities* in risk management, and to *antifragility* in vulnerability management (PMI, 2017) (Taleb, Antifragile: things that gain from disorder, 2012). Noticeably, both concepts are relatively young. While risk management has been studied since the 2nd World War, *opportunities* still do not appear in PMBoK 1987, being first acknowledged by PMBoK in 1996 (Dionne, 2013) (PMI, 1987) (PMI, 1996).

The Complexity Effect Scale CES tool is presented in Figure 26.

	Positive complexity	**Appropriate (requisite) complexity**	**Negative complexity**
Definition	Adds value to the project. Its contribution to project success outweighs its negative manifestations.	Needed for the project to reach its objectives. Its contribution to project success balances the negative effects, or the cost of mitigation outweighs negative manifestations.	Hinders project success.
Description	**Desirable -** should be embraced and enhanced	**Accepted** Not desirable, but accepted because required, or because too expensive to mitigate	**Undesirable** Should be eliminated or reduced
Identification: cost-benefit analysis (Boadway, 2006)	Benefits > Cost	Benefits ≃ Cost	Benefits < Cost
Examples	*Large budget* *Reusability*	*Political priority* *New technology* *Unclear objectives – scope agility*	*Many varied interdependent technologies and components.* *Unclear objectives.* *Large number and variety of stakeholders.*

Figure 26. Positive, Appropriate, and Negative Complexity. The Complexity Effect Scale tool – CES

The CES tool answers to the need to understand the effects of complexity, in order to further decide the mitigation strategies. The next section proposes a more advanced complexity analysis tool, that attempts to link the effects to their sources.

VI.4. The Complexity Source/Effect Segmentation Matrix tool – COSM

The identification of the effects of complexity and of the real source of complexity is of particular importance for complexity analysis and management, as argued above in Chapter IV. *Theoretical foundation*.

The COSM tool builds on the Complexity Effect Scale CES tool, proposed in the previous section. The CES tool supports the analysis of the effects of complexity. COSM adds to this the identification of the sources of complexity, and the analysis of the relationships between sources and effects.

COSM is most useful during the analysis process of the IT-PCM framework (section V.4.3).

The COSM tool supports identifying the point on which to act, and selecting the most suitable strategy to mitigate the complexity cause or impact. Such decisions are made during the planning response strategies process of the IT-PCM framework (section V.4.4).

The COSM segments complexity on two dimensions: Sources S and Effects E.

The Effects dimension is based on the Complexity Effect Scale:

E = {positive, appropriate, negative}.

The simplified form Es of the Effects dimension has only 2 categories:

Es = {positive & appropriate, negative}.

We propose several segmentations for the Sources dimension, derived from (Maurer, 2017), (Botchkarev & Finnigan, 2015), (Vidal, 2009), as well as from the Complexity of Complexity paradigm (Chapter IV).

S0 = {internal, external};

S1 = {market, organization, process, product, project};

S2 = {external environment, internal environment, product};

S3 = {technological, organizational};

S4 = {size, variety, inter-dependence, context-dependence}.

A comprehensive list of potential classifications of complexity, that can be used for the segmentation of complexity sources, was presented in section III.3.6, Table 6.

Figure 27 below presents the COSM tool, with S0 for source segmentation.

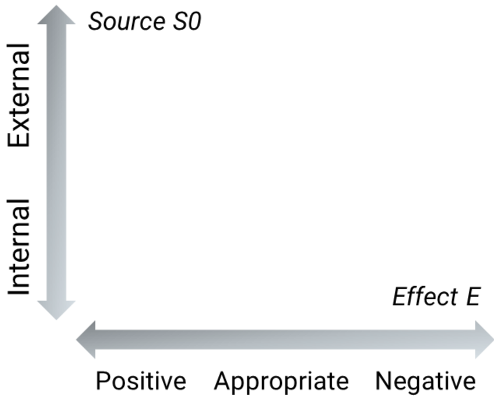


Figure 27. The Complexity Source/Effect Segmentation Matrix COSM tool, with the source segmentation S0

An example of a simplified form of COSM is presented in Figure 28 below. For analyzing the effects, this filled-in example uses the simplified form Es, with only 2 categories (*positive* and *appropriate* are grouped under one category).

In this simplified form, COSM is similar to the SWOT tool (Strengths-Weaknesses-Opportunities-Threats). SWOT is used successfully in risk management for the identification of both risks and opportunities; as well as in other fields such as strategy, management, and marketing (Stonehouse & Pemberton, 2002) (Helms & Nixon, 2010). The COSM tool is nevertheless different than SWOT: it focuses on complexity rather than on risks; on systems and systemic behavior rather than on individual events; and on transforming weaknesses and threats in opportunities.

Effects ***Sources***	**Positive & Appropriate**	**Negative**
Internal	*e.g. Diverse expertise within the project team.* *Many products and tools available, with complementary/different functionality.* *New products for current markets.* *Reusability.*	*e.g. The organization has many different, conflicting processes and standards.* *Large project team, distributed geographically (with potential communication problems)* *Many varied interdependent technologies and components.*
External	*e.g. Product used differently than intended.* *A product goes viral.* *New markets for the current product portfolio.* *Markets need new products or features.* *Large budget.* *Political priority.* *New technologies.* *Unclear objectives – scope agility*	*e.g. Strong numerous competitors on the market.* *Many varied stakeholders with divergent objectives.* *Unclear objectives.*

Figure 28. Example of a simplified Complexity Source/Effect Segmentation Matrix COSM tool, using the Sources segmentation S0 and Effects segmentation Es

VI.5. Mitigation Strategies Matrix – MSM

The Mitigation Strategy Matrix (MSM) is a tool for planning complexity response strategies. It is similar to risk or to vulnerability management.

Using the Complexity Effect Scale defined above, and drawing from risk, vulnerability, and engineering management, we identified five strategies for planning responses to IT project complexity:

- Positive Complexity:
    - Create, enhance.
    - Use, exploit.
- Positive, Appropriate, or Negative Complexity:
    - Accept, ignore.
- Negative Complexity:
    - Simplify, reduce.
    - Avoid, eliminate.

While analyzing potential response strategies for Positive Complexity, a strong similarity was observed between Positive Complexity and the opportunities defined in risk management. Modern risk management recognizes the importance of opportunities, and proposes specific response strategies for optimizing their effects (PMI, 2017). Only made *after* the design of the Complexity Effect Scale, this observation supported the internal validity of the design.

VI.5.1. Background, and similarities with other response plan strategies

Several methodologies were analyzed as a possible foundation for developing the MSM tool.

Risk management theory proposes response strategies for both threats and opportunities:

- Strategies for **threats**: avoid, transfer, reduce, accept.
- Strategies for **opportunities**: exploit, share, enhance, accept.

Systems engineering proposes three main strategy groups for handling complexity: reduction, management, and avoidance – Figure 29.

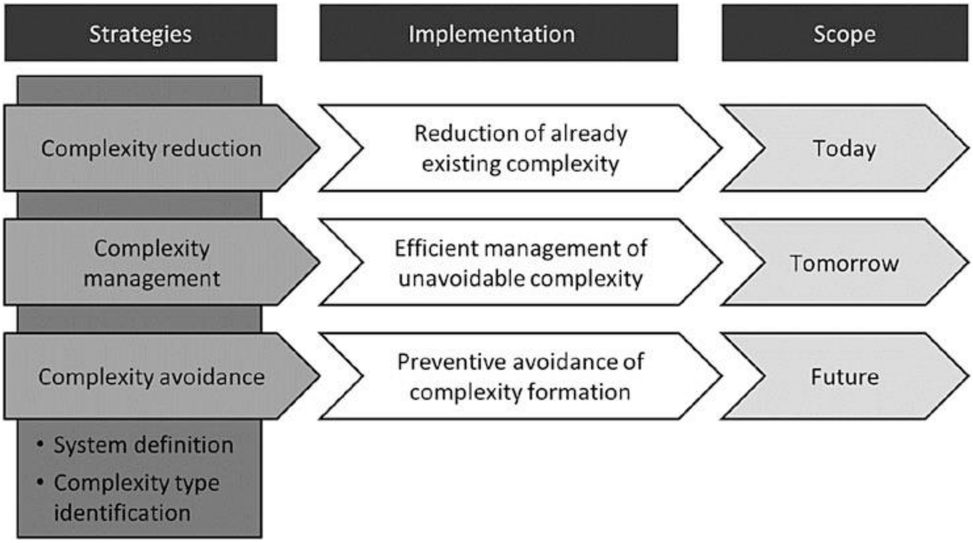


Figure 29 Approaches towards handling complexity (Maurer, 2017)

(Marle & Vidal, 2016) proposed a set of response plans strategies for vulnerability management:

- Mitigation, consisting of improving the resistance of the project elements and/or their resilience.
- Avoidance.
- Transfer.
- Acceptance.
- Contingence.

The mitigation strategies described above were the starting point for the design of the MSM tool described in the following section.

VI.5.2. Project complexity response strategies

The Mitigation Strategies Matrix – MSM tool was based on the similar methodologies for response planning presented above, and was refined according to the feedback received from the validation with experts, according to our overall design-science approach.

The final version is presented in Figure 30. Further on, Appendix C provides more detailed examples of tools and techniques for each proposed response strategy.

	Response strategy	**Complexity Effect**		
		Positive	**Appropriate**	**Negative**
a.	Create, enhance	X		
b.	Use (exploit)	X		
c.	Accept / ignore	X	X	X
d.	Simplify / reduce			X
e.	Avoid / eliminate			X

Figure 30. Project complexity response strategies: the Mitigation Strategies Matrix – MSM

For preventing and mitigating negative complexity, traditional project management proposes rigorous project preparation, risk management, decomposition/divide-et-impera, dependency modeling (Maurer, 2017).

The strategy "**simplify/reduce**" can be applied to complexity, to its characteristics, to causes, or to effects.

Reducing complexity typically involves the simplification of the project system. It can be done through a variety of methods. The following list enumerates the applicable tools and techniques discovered during the literature review. As with any inventory of tools, the list is not definitive, nor exhaustive: additional tools may exist, some tools are similar, and new tools are proposed continuously.

a. Structural decomposition - X-BS: Work Breakdown Structure WBS, Organization Breakdown Structure OBS, Product Breakdown Structure PBS, Cost Breakdown Structure CBS, Risk Breakdown Structure RBS, Resource Breakdown Structure ResBS (Levine, 1993).

b. Modular or OO design, that encourages modularization and reuse.
c. Using COTS - Commercial off-the-shelf components in system design.
d. Transferring parts of the project to third parties, e.g. subcontractors with full delivery responsibility.
e. Standardization (Maurer, 2017).
f. Deploying rapid or simple software development methodologies such as prototyping, or RAD (Rapid Application Development).
g. Split an organization into separate business units.
h. Simplify communication and/or reporting channels, e.g. by creating single points of contact (SPOCs) or eliminating stakeholders from the communication plans.

Complicated projects can theoretically be decomposed in their components (i.e., projects characterized only by structural complexity, or complicatedness, as described in section III.3.3: *Simple, complicated, complex, and really complex projects)*.

(Really) complex projects are difficult, sometimes impossible to decompose into smaller parts, due to the numerous varied interdependencies between their components, and unclear relationships between causes and effects.

Reducing the effects of complexity limits the negative effects. It is suitable especially when the project cannot be simplified. The following list, not definitive nor exhaustive, enumerates the applicable tools and techniques discovered during the literature review:

a. Risk management.
b. Vulnerability management (Vidal, Marle, & Bocquet, 2011) (Marle & Vidal, 2016).
c. Critical Chain Management CCM or other scheduling methods appropriate for complex IT projects.
d. Agile development methodologies, agile and lean management (Sohi, Hertogh, Bosch-Rekveldt, & Blom, 2016).
e. Model-driven design and development (in software engineering).
f. PERT (in project management).
g. Adding complexity or overhead to a project sub-system, thus supporting the management of unavoidable complexity in another sub-system. The typical example is the increase of the

complexity of an organization and its processes, in order to address a more complex market with a more complex product. We need product complexity to offer functionality; we need project complexity and complex organizations to create and support complex products; we need complex products and complex processes to manage complex organizations. While this is an increase in complexity, we can also list it as a method to manage complexity.

h. Planning strategies to deal with uncertainty and project complexity: separate organization, integrate organization, existing knowledge exploitation, new knowledge production (Floricel, Michel, & Piperca, 2016).

The “transfer” strategy is listed in risk management as a distinct mitigation strategy. While parts of complexity can be indeed transferred to third parties, this results in a reduction in the overall complexity, and sometimes in increasing organizational complexity, by adding additional stakeholders. Accordingly, “transfer” is listed in the proposed MSM tool as a method to reduce complexity, and not as a distinct mitigation strategy.

Similarly, “sharing with third parties” is a recommended strategy for dealing with opportunities in risk management. In managing complexity, it is similar to “transfer”, and it also results in the reduction of the complexity of the system. Examples of transferring or sharing complexity are: including COTS components in system design; externalizing certain components or activities, in full or in part; licensing components to and from third parties; externalizing marketing or exploitation rights – which also results in new partnerships.

Avoiding complexity eliminates its cause. It should be performed when the complexity aspect has significant disadvantages while offering little benefit. Examples of tools and techniques for avoiding complexity are:

a. Scope management:
    i. Cut functionality from a product, thus eliminating project and product components.
    ii. Discontinuing products, product lines, product versions, or variants, thus simplifying and reducing the overall product portfolio.

b. Using Commercial off-the-shelf components (COTS) in system design – i.e. taking a buy-vs.-build decision.
c. Risk management techniques.
d. Close the operations completely on specific geographic markets.
e. Close-down organizational or business units.
f. Split an organization into separate independent entities, without links or other interdependencies.
g. Eliminate internal processes.

Accepting complexity maintains both probability and impact. No specific action is taken. It is mostly suitable for Appropriate Complexity, i.e. when its benefits are relatively equal to its cost, or the cost of mitigating complexity would be higher than the benefit.

In this context, cost refers to the negative impact on one or several of the project's components: budget, scope, time, or quality.

Enhancing, creating, using complexity refers to increasing its probability and/or impact. These can be applied when the benefits are significantly higher than the cost, i.e. for Positive Complexity. Examples are:

- Expand the product portfolio to address new customers and new markets (Maurer, 2017). As yet another illustration that there is no single silver bullet in (IT project) management and marketing, both increasing the project and product portfolio, as well as maintaining a focus on a niche portfolio, can both be successful strategies. While some businesses benefit from diversification and a large portfolio of products (such as Samsung, Nokia, Amazon, Nestle, Unilever, General Electric), others do not dilute their product brand and expertise, and as such do not diversify (e.g. Apple, Michelin).
- Add product functionality;
- Encourage creativity in organizations by mixing heterogeneous cross-disciplinary teams;
- Increase the know-how and collaboration, by adding new communication lines in the organization.
- Merge different companies or business units into a larger organization, to obtain economies of scale and create synergies.
- Accept, acknowledge, and formalize new products, functions/features, processes, organizational units, or markets, even if they emerged independently, unplanned. Famous examples of such emerging products are Viagra, SMS, or Coca-Cola.

- Create partnerships, in order to better exploit existing assets, such as know-how, expertise, products, processes, markets.

The MSM tool proposes different response strategies, based on the specific effects of complexity on the project system, and targeted at specific sources of complexity. The tool aims to propose a structured approach for planning responses in complexity management.

The implementation of MSM starts from the identified list of project complexity aspects, and the results of the analysis of complexity, obtained from the application of tools such as CES and COSM. By analyzing their effects, specific actions can be planned, then executed, and monitored.

For managing the complexity identification, analysis, response planning, and monitoring of results, a specific register is further proposed in the next chapter: the Complexity Register.

VI.6.CoRe: the Complexity Register form

The Complexity Register tool aims to support the collection, organization, and analysis of the data resulting from the application of tools such as CES, COSM, and MSM. It is a centralization of the results and data from the application of these tools, for a specific project.

The tool was designed during the sub-project P5 evaluation – Chapter VIII, as a practical method for collecting and organizing project case data.

The CoRe tool is a register that lists all the complexity items identified during the analysis process of the IT-PCM framework.

Each entry has a name and a description. For each entry, there are fields for recording the type of effect, according to the CES tool (section VI.3). The type of source can be classified using one, or several source segmentation methods simultaneously. The possible segmentations are proposed by the COSM tool (section VI.4). CoRe also documents the proposed response strategy, according to MSM.

The entries (columns) of the Complexity Register are presented and described in Figure 31 below.

CoRe field	Description
Complexity element	Typically, it is an item from a checklist, such as a measurement scale or a classification
Description	Details of the complexity element, specific to the analyzed project
Effect (as per CES)	E = {Positive, Negative, Appropriate}
Source (as per COSM)	S0 = {internal, external}
	S1 = {market, organization, process, product, project}
	S2 = {external environment, internal environment, product}
	S3 = {technological, organizational}
	S4 = {size, variety, inter-dependence, context-dependence}
Response strategy (as per MSM)	RS = {Create-enhance, Use-exploit, Accept-ignore, Simplify-reduce, Avoid-eliminate}
Response details	Details of the response strategy, actions, related risks and opportunities.

Figure 31. Complexity Register form – CoRe

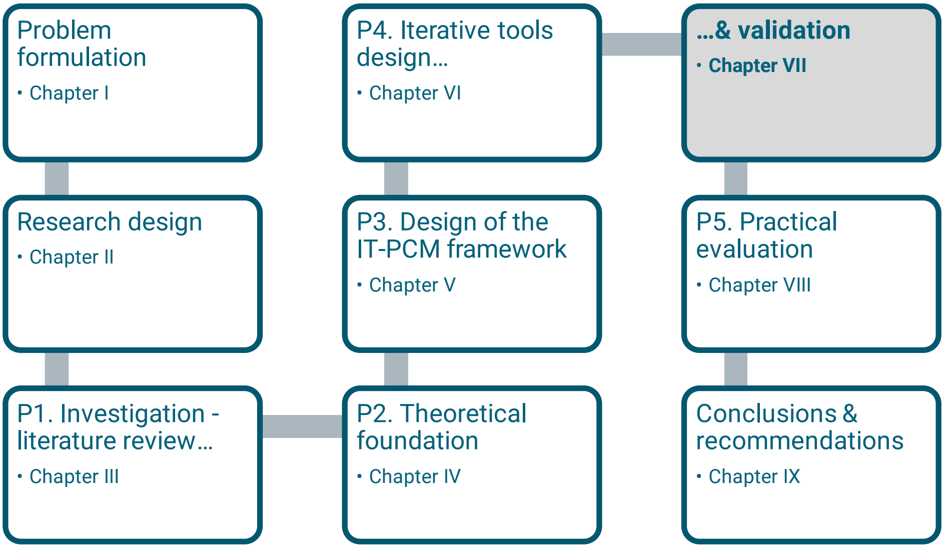
The CoRe tool orchestrates the implementation of all the processes of the IT-PCM framework, from identification and analysis, to response planning and monitoring.

VI.7.Conclusion

This chapter introduces a set of new tool designs, that attempt to fill gaps in the inventory of tools and techniques proposed in Chapter V – the IT-PCM framework.

They are an output of research sub-project P4, which used several design-cycles for an iterative design-and-validation process. The results of the validation part of this sub-project P4 are presented in the next chapter.

Chapter VII.
Validation of the tools with experts



Sub-project P4 was an iterative process that followed the design-cycle, with 2 design-and-validation cycles, consisting of: initial design, preliminary validation, refined design, and final validation (Figure 25).

Chapter VI already presented the overall methodology of this sub-project, as well as the final version of the designed tools for analysis and management of IT project complexity.

The current chapter VII presents the results of the preliminary and final validation, through semi-structured interviews with experts, based on actual project cases.

The research sub-project P4, which is presented in Chapters VI and VII, was published in a shorter form in the Proceedings of the Romanian Academy - Series A, as: "IT Project Complexity Management Based on Sources and Effects: Positive, Appropriate and Negative" (Morcov, Pintelon, & Kusters, 2020b).

The following sections present:

- the specific methods used for the validation – section VII.1.
- a summary of the results – section VII.2.
- the detailed results – section VII.3.
- a discussion of the results of the sub-project P4 – section VII.4.
- specific limitations of the research sub-project P4 – section VII.5.

VII.1. Methods

The overall methodology of the research sub-project P4 is presented in the previous chapter, section VI.1.

The preliminary and final validation of the tools, presented in this chapter, were performed with semi-structured interviews with seven experts selected based on their experience and expertise in the domain, and supported by an analysis of actual project cases.

Expert opinion is a validation technique suitable for our exploratory research. It requires that the experts should have a thorough understanding of the topic. Accordingly, the selection criteria for the experts was the practical experience of more than 20 years in software project management and strategic operational IT management, in personally managing or supervising complex IT projects, defined as: *the size of the managed team – more than 100 people; number and variety of project stakeholders; execution and delivery in international/multicultural environments; significant impact on the project environment*.

The project cases were chosen by the experts themselves. They were projects that they managed or supervised personally. These projects provided a practical reference and anchoring for the interviews. The criteria for choosing the projects were size and complexity.

The **interviews** were structured in a standardized questionnaire, with open questions to drive exploratory qualitative research, but also with fixed-choice Likert and yes/no questions to increase reliability. The questionnaire had the following sections (the full questionnaire is in Appendix E):

- **Introduction**: to establish a common language and understanding. It included a presentation with printed slides of the concepts, theoretical foundations, measurement tools, proposed tools.
- **Project case description**. Due to the limited time available, the case documentation was done before when possible, and finalized after the live interview.
- **Analysis** of how complexity was managed in practice in the actual project case.
- **Hypothetical "what-if"** section regarding the potential value of the proposed tools, *as if* they would have been deployed in the actual project.
- **Validation** of the final versions of the tool designs.

Detailed extensive notes were taken during each interview. The answers and notes were shared with the interviewees for approval. Due to confidentiality reasons, the discussions were not audio recorded. Each interviewee asked for a different degree of confidentiality: some project information and expert names cannot be disclosed, while for some the information is fully available.

Due to their professional background and positions, participants have a personal interest in the topic, but limited time. Each face-to-face interview lasted between 40 and 120 minutes, with an overall average of 82 minutes.

The live interviews were supplemented by a preliminary desk investigation before the interview, when possible, and by a written offline follow-up questionnaire.

The cases analyzed during the interviews were actual complex IT projects, that the interviewees managed personally or supervised directly, which included varied activities: software development, integration and implementation of large heterogeneous solutions; large-scale, geographically distributed; with varied external and internal dependencies, many varied deliverables (up to tens of thousands different types of deliverables), with huge numbers of varied stakeholders (thousands) and users (hundreds of thousands or millions). The duration of each project case was 8-10 years. Most projects have been in production for years, being currently in maintenance and upgrade; one project is being currently rolled out after the completion of a large-scale pilot. The project cases included:

- Three very large trans-European projects, critical to the functioning of the European Union, with hundreds of millions of beneficiaries in all EU member states. Budget: hundreds mil. Eur each.
- A large trans-European project, with tens of thousands of users in all European countries and varied activities and stakeholders. Budget: 10-20 mil. Eur.
- Two projects implemented at the national level, in 2 European countries, in 700 / 15,000 sites respectively, with hundreds of thousands/millions of users, respectively. Budgets: 2.4 mil. and 300 mil. Eur, respectively.

The next sections present the summary and detailed results of the preliminary and final validation.

VII.2. Summary of the results

The summary of the results of the preliminary and final validation is presented below:

R1. The importance of the topic of IT project complexity was confirmed. *"IT has an inherent complexity; any software is complex"*, was one of the comments received. The concept of complexity is not standardized; the terminology is overloaded.

R2. All experts recognize the need to measure and classify project complexity.

R3. Experts partially agree that the ***complexity of complexities*** paradigm would be useful in practice. They recommend offering practitioners several possible segmentations for the COSM tool.

R4. Practitioners already use **tools to manage IT project complexity**, such as project management frameworks or formalizing communication plans. Complexity relates to risk management: *"Complexity is always a risk"*.

R5. Practitioners confirm the usefulness of **Positive Complexity**, and associate it with opportunities. *"Complexity is always a compromise".* ***Appropriate Complexity*** brings clarity to the theoretical model, but in practice it is difficult to distinguish from Positive. *"Appropriate Complexity requires a level of precision in measurement that makes me feel uncomfortable"*, was an observation.

VII.3. Detailed results: answers to questionnaires

The summarized answers to the closed questions are presented in Appendix E. All questions were designed to mostly open qualitative exploratory discussions. The main qualitative findings of the interviews are presented below.

R1. The **importance of the topic of IT project complexity** was confirmed by all experts. The concept is recognized and used in the industry, but not standardized; the terminology is overloaded with different meanings.

Experts consider complexity mostly structural. Dynamic complexity is not specifically managed, but dynamic complexity aspects were recognized during discussions.

R2. All experts recognize the need **to measure and classify project complexity**. Some already deployed tools to red-flag "complex" or "high-risk" projects. Experts doubt that a universal, effective, repeatable and comparable measurement tool can be developed, because each evaluator would have a subjective scale according to his/her personal experience, and also each aspect of complexity has different importance depending on the type of organization, type of project or the particular technology. In this respect, complexity is similar to software estimation and measurement, such as Function Point Analysis (FPA) or COCOMO (the Constructive Cost Model for cost estimation) (Albrecht, 1979) (Longstreet, 2012) (Boehm, 1981) (Pressman, 2001) (Jørgensen, 2007). A suggestion was received to develop standard tables of complexity adjustment factors, similar to the tables used in Function Point Analysis.

The effort needed by an expert to evaluate the complexity of a project will vary significantly depending on the project and the experience of the evaluator. Small projects should not enter a special complexity measurement or management process, due to cost. Complexity should be measured and identified in parallel with risk, at the same gates. It was noted that even risk management is far from being generalized in the IT industry, which might indicate that complexity measurement and management should be very simple or will face even bigger adoption problems than risk management. The design followed therefore the design principles of minimalism and simplicity (Occam's Razor).

R3. The experts gave partial and divergent opinions regarding the usefulness in practice of the ***complexity of complexities*** paradigm. The systemic perspective is useful. The segmentation of complexity offers a structured approach to help identify the real source of complexity. A set of sub-systems derived from systems theory, *S1={market, organization, process, product, project},* was proposed but not confirmed by experts, which expressed reserves regarding the choice and advantages of a particular set or another. As a result of this negative feedback received during the validation phase, the CES tool was redesigned. We introduced additional possible segmentations: S2; a general form Sx; and a simplified more practical segmentation S0, as described above in section VI.4.

R4. Practitioners observed that they already use **tools to manage IT project complexity**, such as: project management methodologies; risk or communication management; problem-solving techniques. The need to deploy specific tools for managing complexity in IT projects is strongly supported by practitioners. In order to facilitate their adaptation, customization, and adoption, these tools should be simple and flexible.

R5. Practitioners fully agree that the concept of **"Positive Complexity"** is useful, that Positive Complexity should be specifically identified and managed. The concept was associated with the opportunities proposed by risk management. On the other hand, an expert underlined that *"Complexity is never an objective; it is a compromise that appears because we want to add value".*

Based on the feedback, we added "***Appropriate Complexity"*** as a distinct category to bring clarity to the theoretical model. In practice, it proved difficult to differentiate it from Positive Complexity. Accordingly, it was grouped with Positive Complexity, in the simplified form of the COSM tool. Interestingly (and coincidentally), similar difficulties were met by the concept of *requisite complexity (*or *variety)*, which generally uses the term "match" in its definition, but accepts that *matching* assumes *exceeding* (McKelvey & Boisot, 2009).

Experts underline the importance of cost-benefit analysis when classifying complexity and deciding mitigation strategies. In this regard, an expert observed that the *cost of complexity* is distinct from the *cost to eliminate complexity*. Also, another expert underlined its compound effect: *"Complexity generates complexity. The complexity that we accept at the beginning of the project is compounded in time; therefore, the benefits should be weighed against future costs".*

VII.4. Discussion

Several particular aspects emerged from the research sub-project P4, and are discussed in the following sections:

- relation between the sources and effects of complexity.
- the cost of managing and of not-managing complexity;
- the practicality of complexity management tools.
- the benefits of program management for managing complex projects.

VII.4.1. Relation between sources and effects of complexity

The sources of complexity are linked to their effects through two types of processes:

a. Processes, tools, and methods under the control of the IT project manager;
b. Complexity-related phenomena, typically difficult to understand, predict, or control.

These two types of processes overlap: some dynamic complexity-related phenomena, external environment variables, or impact can be controlled; and also actions undertaken by the project manager (i.e. from the project sub-system), are likely to propagate to other sub-systems of the Complexity of Complexities model.

The relation between sources and effects is particularly important for choosing the appropriate response plans, including where to act and what mitigation strategy to apply.

VII.4.2. The cost of managing and of not-managing complexity

The discussions with participants revealed that **the tools and strategies to deal with complexity** always relate to cost, i.e. the impact on budget, schedule, scope, and quality.

The effects propagate exponentially with a high compound rate; therefore, decisions should be based on the analysis of *"cost-benefit at completion"*.

The cost taken into consideration in such a cost-benefit analysis includes:

a. **The cost of *not managing* complexity**. This can be calculated as the monetary value of the risks and opportunities caused by complexity *if not managed*. An example is the cost for solving technical errors in an IT product, which had been caused by an exceptional variety of technologies, of stakeholders, or by unknown or conflicting project objectives.
b. **The cost *of mitigating* complexity**. This is overhead. It is the cost needed for the additional processes and tools introduced in the project to manage its complexity: either to reduce the probability and impact of risks; or to increase the probability and impact of opportunities. Examples are the cost of reducing the diversity of technology in an IT system; the cost of introducing and maintaining dependency matrices between technologies, system components, project objectives, and/or stakeholder requirements; the cost of creating and maintaining detailed stakeholder registers and communication plans.

The effects and associated costs of complexity propagate exponentially, and they have a high compound rate. Therefore, the most relevant cost is the cost forecast for the whole duration of the project, i.e. *"**cost-benefit at completion**"*. The practical difficulty in calculating such a variable is that, for complex systems, impact forecasts do not correlate well with results (Taleb, Goldstein, & Spitznagel, The Six Mistakes Executives Make in Risk Management, 2009).

Implementing new tools increases the project complexity, overhead, and cost; therefore, specialized complexity management tools are effective and applicable only for very large projects. Misuse or overuse of project management tools can also be a source of project failure (Browning, 2019).

In this regard, it is relevant that, while early theoretical models of complexity specifically excluded size as a factor (Baccarini, 1996), size has since been linked, and recognized to be a strong predictor of complex projects (Vidal, 2009) (Kardes, Ozturk, Cavusgil, & Cavusgil, 2013) (Qureshi & Kang, 2015).

VII.4.3. Monitoring dynamic complexity

Complexity-related processes refer to structural (complicatedness), but also to subjective and **dynamic aspects.** Research and experts acknowledge that complexity is more than structural complicatedness; that complexity includes subjective and dynamic aspects.

At the same time, research tends to focus on objective, structural complexity, because structural complexity is less abstract, thus more discussable, measurable, thus manageable. Dynamic complexity aspects, on the other hand, are usually *"unknown unknowns"*; difficult to identify or plan; mostly related to changes in stakeholders and environment. They behave like Black Swans and follow "Butterfly Effect" patterns (Lorenz, 1963) (Taleb, Goldstein, & Spitznagel, The Six Mistakes Executives Make in Risk Management, 2009).

Dynamic complexity aspects still must be monitored, recognized and identified as they occur, and projects should be prepared to deal with them.

The main tool for dealing with dynamic complexity is thus monitoring for change, especially in stakeholders, objectives, and the environment. This is part of the monitoring process.

VII.4.4. Program management for complex projects

Implementing complex projects as a program was shown useful both by theory and practice. It brings significant advantages, such as: strategic importance and focus, access to power sponsors, agility (Ribbers & Schoo, 2002) (Remington & Pollack, 2007). Individual projects, which are part of larger programs, are smaller and shorter, hence more agile, with clearer results, easier to measure and control, by offering more transparency. Organizing projects in larger programs supports the coordination across different projects (Moe, Dingsøyr, & Rolland, 2018).

In fact, all project cases analyzed during the validation were implemented as a program. This approach also aligns with the principle of deploying agility in response to complexity.

VII.5. Limitations, validity, and reliability of the design-and-validation project

While a series of measures were taken for ensuring construct, internal and external validity of the design-and-validation sub-project P4, presented in Chapters VI and VII, as well as reliability, several limitations may impact the results, related to the design and validation phases.

In order to increase specialization hence usability, the domain of applicability was restricted to IT. The number of cases was limited due to the qualitative research method; thus, the results may not be generalized easily beyond the stated conditions. All project cases were implemented in Europe, but across many different countries. A sufficient number of interviews were conducted, to ensure sufficient data points, the required level of variation of the results and responses, to allow for analytical generalization and ensure external validity, to minimize subjectivity, and to validate convergence.

The approach for the validation was cross-sectional – the project cases were analyzed at a specific moment, i.e. at completion (with one exception near completion). The cases were analyzed from a single perspective, so the level of objectivity of the interviewee about the projects cannot be established (with one exception analyzed from several perspectives).

Due to their interactive nature, face-to-face interviews limit replication, hence reliability, and are susceptible to self-confirmation bias. Of course, not all invited experts participated in the research. The participants had limited time available - between 40-120 minutes for each live interview, for an overall average of 82 minutes for the validation; one hour for the evaluation.

The iterative approach of the design process helped ensure internal validity and the avoidance of “anecdotalism”. Each iteration was documented to ensure construct validity, using configuration management. After each iteration, a configuration baseline was established. The intermediate versions were documented for traceability and for ensuring construct validity.

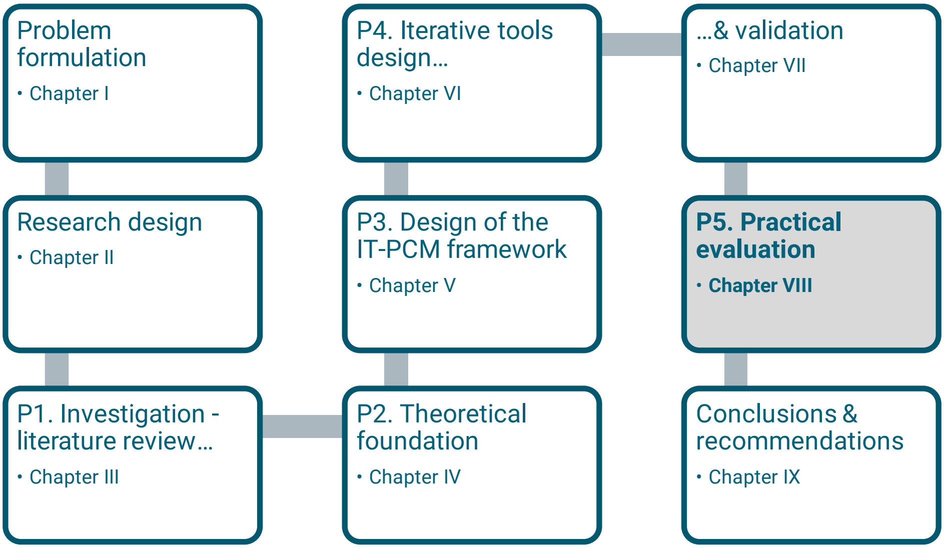
All projects included in the evaluation were IT/software development projects that use similar project management and software development methodologies and have reasonably similar cultural and geographical backgrounds; but they cover a very wide range of technologies and business areas. All customers are Western European, but they are large multinational and multicultural organizations.

Any quantitative analysis must be interpreted with caution, considering the number of data points and the use of ordinal and interval scales. Accordingly, the research focused on the qualitative analysis of the answers received, and of the type of arguments used; with a strong focus on the negative feedback.

VII.6. Conclusion

Chapters VI and VII presented the results of research sub-project P4, an iterative process of design-and-validation of complexity management tools, consisting of 2 design-cycles. The following chapter presents a practical evaluation of the proposed set of tools.

Chapter VIII.
Practical evaluation of the tools in actual project cases



This chapter presents the results of the research sub-project P5 – a practical evaluation of the designed IT project complexity management tools, in live IT project cases.

The sub-project attempted an answer to the research question *RQ7: What is the contribution of the designed tools to project success?* It aims to assess the effectiveness in practice of the designed tools, and to understand and analyze the application in practice of complexity analysis and management tools.

A shorter form of this chapter, i.e. the results of the research sub-project P5, was accepted for publication in the International Journal of Information Technology Project Management (IJITPM), as: "A Practical Assessment of Modern IT Project Complexity Management Tools: Taming Positive, Appropriate and Negative Complexity".

VIII.1. Introduction

The objective of the evaluation was to analyze ***why, when,*** *and* ***how*** a set of specific tools could be applied for the management of IT project complexity – i.e. the assessment of their benefits in practice, as well as best methods and timing of deployment in the projects' lifecycle.

The research method was a longitudinal, qualitative study, consisting of the application and repeated evaluation of the set of tools, in several project cases, with an analysis of their impact in the respective live projects.

The tools were deployed, tested and evaluated repeatedly with multiple participants, over a period of 7 months. They were tested in a real project context, in conjunction with other typical IT project management tools.

The tool deployment in the actual projects followed the **IT-PCM framework**, i.e. a standard framework composed of: planning, identification, analysis, response planning, and monitoring and control. Table 12 presents the set of tools evaluated, per each process and phase in the IT-PCM framework.

Table 12. IT-PCM framework, and the tools applied in the practical evaluation

	Phase	**Objectives**	**Tools selected for evaluation**
1	Plan Complexity Management	Initial complexity assessment Tool selection	CIFTER, Hass, Morcov measurement tool
2	Identify IT project complexity	Problem detection, inventory, and description	Checklists: Hass, CIFTER, Morcov tools, CES, COSM
3	Analyze project complexity	Analysis – understanding	Complexity Effect Scale CES Complexity Source/Effect Segmentation Matrix COSM
4	Plan response strategies	Design of potential solutions	Mitigation Strategy Matrix MSM
5	Manage, monitor and control	Implementation of the strategy	Complexity Register CoRe

VIII.2. Evaluated tools

Identifying (recognizing) IT project complexity is the first and critical step in complexity management – i.e. red-flagging, categorizing, and measuring. The identification of complex projects is important for the selection of the appropriate management tools. It is particularly important for strategic and project portfolio management (Vidal, Marle, & Bocquet, 2011).

Several complexity measurement tools have been proposed by research – as presented in the literature review, section III.5, Table 8. From this inventory of existing measurement tools, the 2 simplest and most practical measurement tools were included in this evaluation, in order to assess how useful they would be considered, and how they would be accepted by the participants. Thus, in addition to the Morcov complexity measurement tool developed during this research and adapted for IT (section VI.2), CIFTER and Hass tools were also evaluated. The evaluated measurement tools are hereafter referred to as *CIFTER, Hass, and Morcov tools*, respectively.

In addition to these complexity measurement tools, the evaluation also included the new tool designs resulted from sub-project P4 (Chapter VI).

The evaluated tools are:

1. **The Crawford-Ishikura Factor Table for Evaluating Roles – CIFTER,** supported by the International Project Management Association (GAPPS, 2007). It has 7 subjective criteria, uses a Likert-type ordinal scale from 1 to 4 (low, moderate, high, very high) without a midpoint. It is not weighted; and has a general purpose.
2. **Hass' Project Complexity Model Formula** (Hass, 2008b). It is simple and short, with 5 complexity dimensions (11 in the extended version). It uses an ordinal scale from 1 to 3, with a midpoint (low, moderate, high). It is not weighted; and has a general purpose.
3. **"Morcov" IT project complexity measurement tool** – introduced in section VI.2. It has a medium level of detail – 28 questions. It uses an interval scale for qualitative questions and a ratio scale for numerically quantifiable questions. It is specialized to IT.
4. The **Complexity Effect Scale CES** tool (section VI.3) provides a structured method to analyze complexity based on its effects.

5. The **Complexity Source/Effect Segmentation Matrix COSM** tool (section VI.4) supports the identification and analysis based on both sources and effects.
6. The **Mitigation Strategy Matrix MSM** tool (section VI.5) supports planning complexity response strategies, based on its specific effects.
7. The **Complexity Register CoRe** form (section VI.6) supports the data collection and management process, including the application of all the above-mentioned tools for the identification, analysis, and management of complexity.

The evaluated complexity analysis and management tools are grounded on the theoretical foundation established in Chapter IV, and particularly on the principle that complexity can have not only negative, but also appropriate or positive effects. This characteristic had a direct impact on the results of this research, being specifically targeted in the deployment and evaluation of the tools.

VIII.3. Methods

VIII.3.1. Approach

Due to the novelty of the topic, a qualitative exploratory approach for the evaluation was chosen, based on the deployment of the tools in actual projects (Levitt, et al., 2018) (Gummesson, 2000).

The main objective was the evaluation of the specific complexity management tools presented in section VIII.2 above. Besides this goal, we also inquired what other tools are used by practitioners for complexity management. This survey of traditional tools provided a common ground in the discussions with the case study participants; it offered a palpable analogy, a basis for comparison between already well-known tools and the newly proposed specialized IT complexity management tools.

The evaluated tools were tested in actual complex IT projects, and the deployment and their effects were monitored over a period of several months. The research was thus more than a simple assessment of the opinion of participants. This constitutes the main difference between this sub-project P5 of evaluation in practice, vs. the validation sub-project P4 presented in the previous Chapter VII: while the validation in P4 was based on experts' opinions and on hypothetical “what-if” questions, this evaluation P5 is based on measuring benefits and results of their deployment in actual projects.

The data collected for evaluation is the informed opinion of the participants to the project cases, based on the concrete, actual situation in their projects, after the deployment of the evaluated tools in the respective projects.

Indeed, the data collected consists of *perceptions* of the interviewed stakeholders, as this was the only practical method for gathering information regarding the impact of the tools in a reasonable time frame. A measurement of the end-results of the projects, i.e. final project success indicators, would have required an unrealistic duration, i.e. many years of monitoring the results of the projects. On the other hand, perceived satisfaction is a valid method for measuring project success, alongside numeric indicators such as meeting project scope, quality, time and budget objectives. Moreover, the opinions of participants are critical in isolating and understanding the impact of these individual tools in the success of a project, considering that the projects analyzed are unique complex projects whose overall success is impacted by a combination of a myriad of different intertwined factors applied together.

To compensate for this potential weakness that we measured the perceived benefits and impact, several data-points were collected for each project, through interviews with several stakeholders, from different levels and different organizations, including the customer side.

VIII.3.2. Methodology

The analysis of the case studies (Yin R. K., 2011) included collecting data and testing the tools in the actual projects, by application mostly during live interviews. Face-to-face, open interviews are suitable because of the novelty of the research problem, and the overloaded non-standardized terminology of the domain. They support qualitative exploratory research. Open questions allowed exploring additional feedback.

All discussions and interviews were video-recorded, for further in-depth text analysis, and to ensure construct validity.

The research sub-project P5 had the following activities:

1. Methodology design.
2. Case study execution.
3. Analysis and interpretation of the research results.

The detailed activities and tasks are described in Table 13.

Table 13. Research activities for the tools' evaluation

1. Methodology design
1.a. Defining the research methods
1.b. Selection of the initial set of projects and participants to the case studies
1.c. Design of the templates and questionnaires
2. Case study execution
2.a. Desk research
2.b. Initial live interview/meetings
2.c. Live follow-up meetings
2.d. Evaluation with top management
3. Analysis and interpretation of the research results
3.a. Extraction of interview transcripts
3.b. Quantitative analysis of the results
3.c. Qualitative analysis

VIII.3.3. Methodology design – details

This activity consisted of:

1.a. Defining the research methods.
1.b. Selection of the project cases and participants.
1.c. Design of the templates and questionnaires.

The projects selected for the research were large IT projects, (presumably) complex; accessible. The projects should be in an early stage in their lifecycle, in order for the tools to have an impact on the respective projects, thus allowing for a meaningful evaluation.

The participants involved in the case studies are project managers and top management. They should be accessible, willing, and senior – with significant IT management experience. The personal involvement of the participants (skin in the game) ensures their involvement, personal feedback, focus on practical results and efficiency. Project managers must have detailed project knowledge, and direct responsibility. Top management also must have reasonable know-how of the actual projects, as well as significant experience.

The participants to each activity, as well as the type of data collected, are presented in Figure 32.

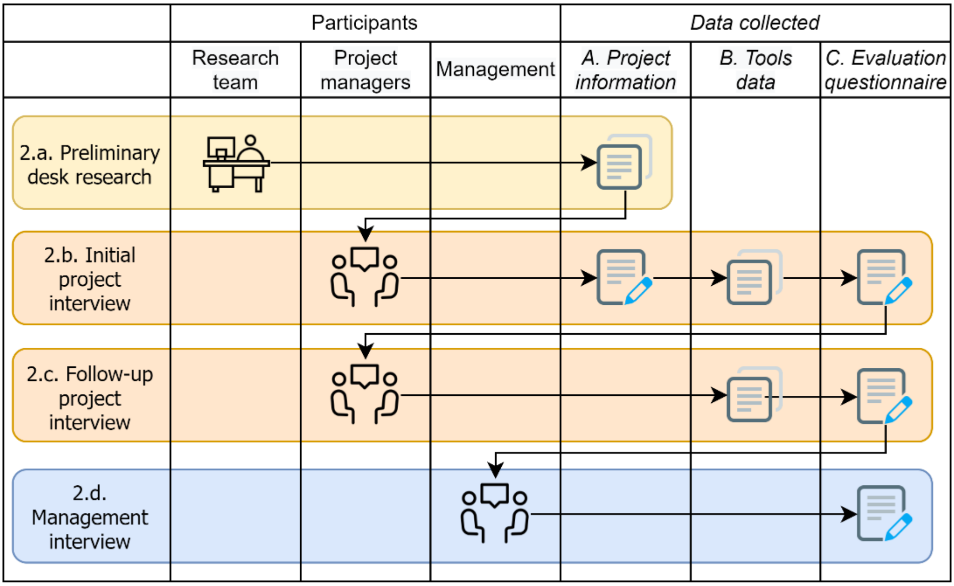


Figure 32. Participants and outputs of the case-study activities

VIII.3.3.1 Design of the templates and questionnaires

Templates and questionnaires were designed in spreadsheet form, to support the deployment of the tools and the collection of case study data. For each project, 3 categories of information were collected:

A. General project information.
B. Forms for deploying the evaluated tools.
C. Evaluation questionnaire.

Figure 32 shows which data was collected from which participant, and when.

The detailed sections of the master questionnaire were:

- General project information.
- Initial subjective assessment of each project's complexity – once per each participant and project, answered independently by each, together with an assessment of management tools, which includes:
    - A question if each of a list of 5 classic tools should be used, with an individual Yes/No answer.
    - Open question: any other tools deployed in the project.
- **Complexity measurement forms**, consisting of the list of criteria defined by each tool, and the scoring mechanism. These are filled in independently by each participant.
- **Forms for applying each tool:** SWOT, CES, COSM, Complexity Register (Figure 26, Figure 27, Figure 30, Figure 31).

  The Complexity Register was created to support the application of the evaluated tools, helping to collect, organize, and analyze the data resulting from the application of CES and COSM; and to supports the application of MSM – by planning and monitoring the mitigation strategy for each identified analyzed complexity item.

  A single form is filled in per each project, aggregating the information from all participants; refined and updated iteratively during each interview.

- **Evaluation questionnaire**, filled in during the live interviews. It consisted of 2 questions for each evaluated tool:
    - **Closed quantitative question**: *How useful is this tool - i.e. benefits outweigh the effort?* Answers are recorded on a Likert-type interval scale, from 1 (not useful, i.e. zero) to 4 (very useful); forced-choice, i.e. without a midpoint so as to avoid neutral/indecision answers; allowing a separate out-of-scale point for non-answer; with no definition for in-between values (i.e. 2, 3) so as to allow limited numeric analysis (Chyung, Roberts, Swanson, & Hankinson, 2017).
    - **Open qualitative exploratory question**: How did this tool help? Why, why not, when?

VIII.3.4. Case study execution – details

This activity consisted of:

2.a. Preliminary desk research.
2.b. Initial live interview/meetings.
2.c. Follow-up interviews.
2.d. Evaluation with top management, in live interviews.

Figure 32 shows the participants to each activity and the type of data collected.

2.a. The **desk research** consisted of gathering project information: objectives, stakeholders, environment, duration, size, technology, team, context, methodologies, and tools.

2.b. The **initial live interview/meeting** with each case study participant consisted of:

- Presentation of the tools, terminology, definitions.
- **Complexity measurement of each project**

  Filling in these forms was, in practice, an operation of collecting detailed, relevant project information.

  In order to avoid external influences and groupthink, and thus to increase objectivity, the measurement was done independently for each project, and for each participant – hiding the answers of the other participants.

  Multiple perspectives (data points) were collected per each case study, with up to 4 participants per project, to ensure triangulation. Thus, the forms were filled in by each participant independently, with minimum external influence. This allowed participants to have a personal first-hand experience with the measurement tools. It also helped avoid external influence, groupthink, or peer-pressure bias.

  The individual results are thereafter aggregated into average project scores.
- **Interactive application of the Complexity Analysis and Management tools - CES, COSM**

  A single Complexity Register form was filled per project, aggregating all project information and all perspectives, from all participants, and visible to all of them. The form is initially filled in during the first interview for a particular project. It is thereafter updated and refined continuously, iteratively, with new information, during each subsequent meeting with another participant relevant to the respective project.

The application of management tools, especially novel, cannot be a neutral data collection activity. In practice, it is a mix of research and consulting, where it is sometimes difficult to establish a clear boundary between the role of academic researcher, and that of management consultant. Known as the action research paradigm, this mix of roles is more and more recognized in management research as valuable for these situations (Gummesson, 2000). In fact, the application of qualitative tools followed a scenario typical for management meetings; where participants analyze a situation interactively, openly, increasing the overall creativity, favoring the exploration of new ideas, generating potential solutions and scenarios; establishing action plans; and in general, making decisions as a group.

- **The tools evaluation questionnaire** was applied individually, 1-to-1, during each live meeting. It was recorded as neutrally as possible from each participant, with answers from other participants hidden, thus minimizing external influences, and increasing objectivity.

2.c. The **live follow-up meetings** with participants, for conclusions and repeated evaluation, had the following objectives:

- to obtain longitudinal feedback.
- to measure any change in perception after the practical application of the tools in the actual projects.

In order to allow time for participants to analyze the tools, to use them independently, and to observe their impact during the actual project's execution, the follow-up meetings were done after at least 3 months from the initial interview.

During the follow-up meeting, the tools and data are reviewed; the forms and Complexity Register were updated. The evaluation questionnaire was applied again, but focusing this time on how useful the tool was in the actual project. Besides quantitative questions, the interview also explored: *when*, *how*, *why*, and *why not* each tool is useful. Qualitative exploration also included discussions if the participant will use, and/or recommend the tool to be applied in other projects.

2.d. **Top management** interviews were performed in order to obtain a higher-level view and feedback on the case study results.

The evaluation questionnaire was applied during these interviews with a focus on the overall results, benefits and costs of the application of the tools; on the usefulness of the tools from the perspective of a portfolio manager.

This assessment is done only once, at the end of the case studies. A longitudinal analysis was not relevant in their case, since they did not use the tools, but only assessed the end results.

VIII.3.5. Analysis and interpretation of the research results

This activity consisted of:

a. extraction of text transcripts from each video recording.
b. quantitative analysis.
c. qualitative analysis of the evaluation questionnaires and interview transcripts.

The **quantitative analysis** included mostly descriptive statistics, as the number of data points does not allow detailed statistical analysis.

The **qualitative analysis** used card-sorting (Paul, 2008) (Spencer & Warfel, 2004):

- A list of arguments was extracted from each transcript, with particular attention to contextual information, e.g. *when and why* a particular tool *was* or *was not* useful.
- These were organized and classified per question and across interviews; each appearance was documented so as to ensure traceability. The classification process followed the criteria for categorization of data of (Merriam, 2009).

VIII.4. Results

VIII.4.1. Data collection

The research consisted of the longitudinal, repeated evaluation of a set of tools, in 5 ongoing live projects. The research spanned over seven months, between May-Dec. 2020. It included 23 interviews. The summary of the cases is presented in Table 14; the detailed results in Appendix F.

Table 14. Project cases summary

No. of participants (data-points)	18
No. of interviews	23
Project size (man-days)	500-15000
Project duration	0.5-4 years

All projects are IT/software, with thousands of man-days of effort, several years duration, many stakeholders. Each includes several technologies and business areas: web development, mobile applications, cloud/DevOps, e-Commerce, e-Learning, policy, e-Government. All are executed and delivered in Europe. All customers are multinational organizations based in western Europe, namely Belgium, Italy, and the UK: a private global corporation, 4 European Union public institutions. All are international projects, with cross-national, multinational teams. Each project has many varied stakeholders, located in 2-38 countries per project, including administrative and business units, users, consortium partners, engineering teams, suppliers, and subcontractors – each based in different countries and locations. The language of all projects is English.

Between 1-4 participants were involved in each case study: the project manager, account manager, technical project manager (in one case), the former project manager (one case), customer project manager (one case). Each interview was 1-to-1. All meetings were organized over videoconference, due to the Covid pandemic crisis of 2020. All meetings were video-recorded.

The initial, subjective perception of the participants regarding the respective project complexity, before the application of the measurement tools, is presented in Appendix F.1, Table 24.

The tested tools were used directly by the participants, during the live interviews. In 2 cases, participants also used the tools independently, offline, between the live interviews – which allowed deeper insights and a more relevant evaluation.

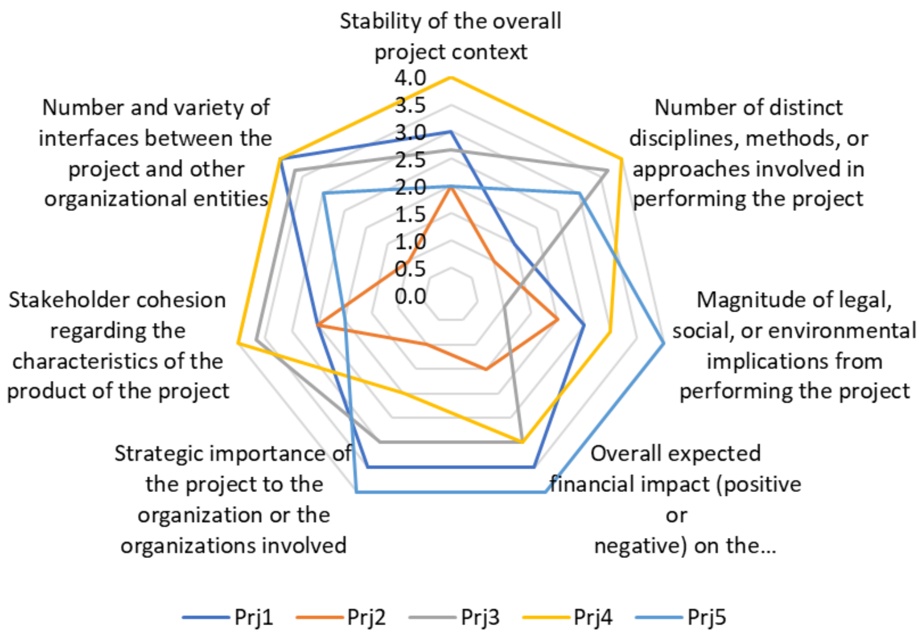
VIII.4.2. Complexity measurement tools

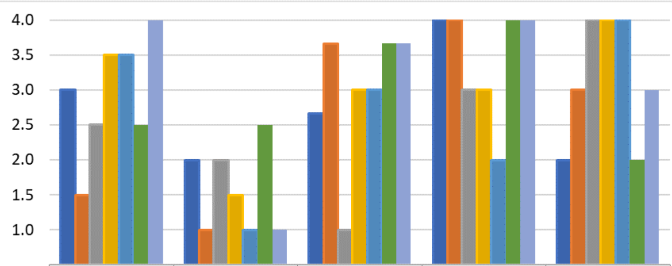
The complexity measurement tools were applied independently, during the first interview with each participant; they were not repeated in the second interview with the same person, since measurement is an initial assessment, part of the Project Planning phase. Each measurement was done independently, with participants not being influenced by the results of their colleagues. For each project, between 1 and 3 distinct measurements were made with each tool. The number of measurements is presented in Appendix F.1, Table 25. Filling in the measurement forms resulted, in practice, in collecting detailed, relevant project information.

Figure 33 and Figure 34 present the results of CIFTER and Hass per project and per criterion.

The measurement results support a good degree of agreement across tools, as well as across participants. Project Prj2 is not confirmed to be complex, with its normalized results of 19%, 32%, 27% per each measurement tool, respectively. This makes it an outlier for several other evaluation criteria as well. Project Prj1 was confirmed as complex, with results of 18, 58, and 65% respectively. Projects Prj3, Prj4, and Prj5 were confirmed to be very complex, with results between 58% and 81% per each tool.

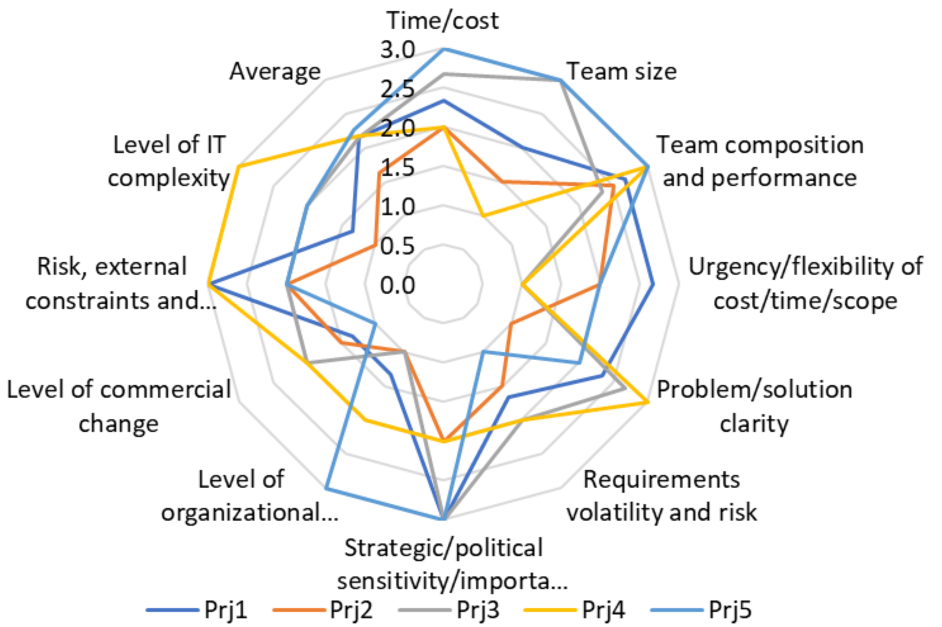
A discussion on these correlations and on the comparative advantages and disadvantages of each tool is presented in section VIII.5.3 - Discussion on the measurement tools, below. Also, section VIII.5.4 includes a discussion on the differences observed in the measurement results of the 3 tools.

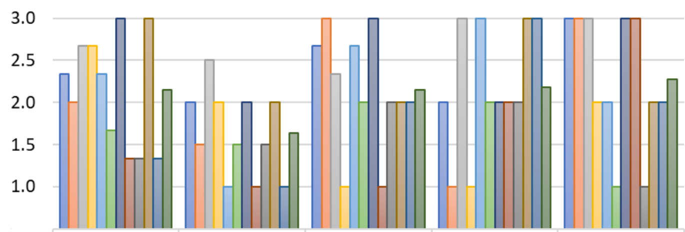




	Prj1	Prj2	Prj3	Prj4	Prj5
Stability of the overall project context	3.0	2.0	2.7	4.0	2.0
Number of distinct disciplines, methods, or approaches involved in performing the project	1.5	1.0	3.7	4.0	3.0
Magnitude of legal, social, or environmental implications from performing the project	2.5	2.0	1.0	3.0	4.0
Overall expected financial impact (positive or negative) on the project's stakeholders	3.5	1.5	3.0	3.0	4.0
Strategic importance of the project to the organization or the organizations involved	3.5	1.0	3.0	2.0	4.0
Stakeholder cohesion regarding the characteristics of the product of the project	2.5	2.5	3.7	4.0	2.0
Number and variety of interfaces between the project and other organizational entities	4.0	1.0	3.7	4.0	3.0

Figure 33. Results of the CIFTER complexity measurement tool – averages per project and criterion (scale of 1-4)

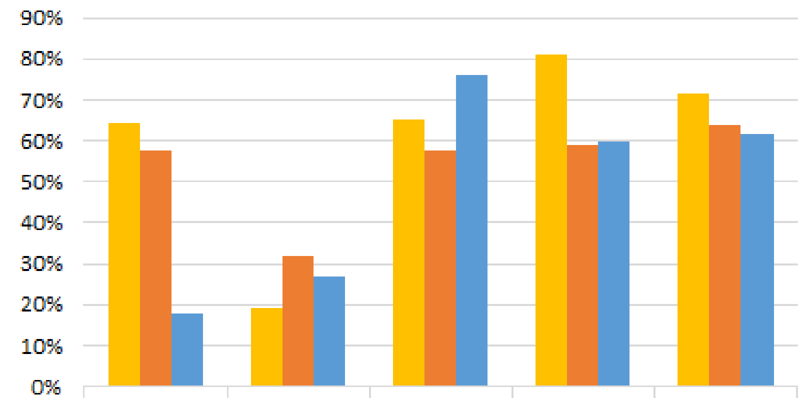




	Prj1	Prj2	Prj3	Prj4	Prj5
Time/cost	2.3	2.0	2.7	2.0	3.0
Team size	2.0	1.5	3.0	1.0	3.0
Team composition and performance	2.7	2.5	2.3	3.0	3.0
Urgency/flexibility of cost/time/scope	2.7	2.0	1.0	1.0	2.0
Problem/solution clarity	2.3	1.0	2.7	3.0	2.0
Requirements volatility and risk	1.7	1.5	2.0	2.0	1.0
Strategic/political sensitivity/importance, multiple stakeholders	3.0	2.0	3.0	2.0	3.0
Level of organizational change	1.3	1.0	1.0	2.0	3.0
Level of commercial change	1.3	1.5	2.0	2.0	1.0
Risk, external constraints and dependencies	3.0	2.0	2.0	3.0	2.0
Level of IT complexity	1.3	1.0	2.0	3.0	2.0
Average	2.2	1.6	2.2	2.2	2.3

Figure 34. Results of the Hass complexity measurement tool – averages per project and criterion (scale of 1-3)

Figure 35 presents the average results of the measurement per project and per tool. The scale of each measurement tool is different, but for graphical illustration purposes, the results were normalized to a 0-100% scale. Further aggregation of the data is difficult, considering that 2 tools use arguably ordinal scales; that each tool uses a different scale; and that the number of data points is limited.



	Prj1	Prj2	Prj3	Prj4	Prj5
CIFTER scale	64%	19%	65%	81%	71%
Hass scale	58%	32%	58%	59%	64%
Morcov scale	18%	27%	76%	60%	62%

Figure 35. Average complexity per project and per measurement tool

VIII.4.3. Identification and analysis of complexity

The identification and analysis of complexity were done during the live interviews, by filling in a Complexity Register form, per each project.

The analysis of the elements of complexity and their effects, i.e. positive, appropriate and negative, was done in-depth, according to the Complexity Effects Scale (CES). This was the key factor in planning mitigation strategies. On the other hand, the detailed analysis of the sources of complexity (as proposed by CoSM) was discontinued after the first 3 interviews. In fact, during these interviews, it was observed that the level of detail and thus the effort required for a rigorous source analysis would be too high, compared to not obvious benefits.

VIII.4.4. Tools evaluation

During each interview, an independent assessment questionnaire was applied, to evaluate the perceived usefulness of each tool, as well as the context and modality in which they were /should be used. The answers to closed assessment questions were analyzed using descriptive statistics. The averages should be interpreted with caution, because of the limited number of data points.

The quantitative assessments of the tools are presented in Figure 36, by project, by group of participants, as well as aggregated. The scale used was Likert 1-4.

The quantitative assessment was supplemented by a qualitative analysis: each assessment being detailed with in-depth research, looking for arguments such as: How did this tool help, why, why not, when. The list of qualitative arguments was extracted from the interview transcripts and organized using card-sorting (Paul, 2008) (Spencer & Warfel, 2004).

During the case-study execution, project Prj2 was not confirmed to be complex. It has therefore divergent results and behaves like an outlier.

The evaluation questionnaire was not applied for Prj4 because of insufficient participants. The lack of sufficient data-points would not ensure an acceptable level of objectivity of the results. Thus, Prj4 is only relevant for the complexity measurement tools, but not for the evaluation of the complexity analysis and management tools.

A) Measuring project complexity is considered useful by all participants, with an average score of 3.1 (on the scale of 1 to 4), and with positive results for each group: 2.8 for project managers, 3.5 for top- and portfolio-management, 3.7 for top-management. The measurement tools considered most useful are Morcov and Hass. The evaluation results show a good degree of agreement across participants and types of participants, with low variation coefficients. The variation coefficients are low for each group, which shows a good convergence of the individual assessments of participants of each group. A true statistical analysis cannot be performed, because of the limited number of data points and because the assessment scale is interval, arguably ratio (Chyung, Roberts, Swanson, & Hankinson, 2017).

B) Regarding the use of **traditional tools:** the risk register, agile approach, and stakeholder map are the most valued tools for managing complexity, with approval rates of 78-89% (yes answers, out of total answers). Communication plan is also valued (56% "yes").

The SWOT tool received inconclusive assessments, mostly negative, at 33% "yes" answers, and high variation coefficients for all stakeholder groups. An example of the SWOT tool is presented in Table 15.

Other traditional tools and approaches, voluntarily suggested by participants, were: decomposition/WBS, knowledge management/ collaboration, planning tools (with 3 independent mentions for each of these), dependency modeling/traceability, delegation (2 mentions each).

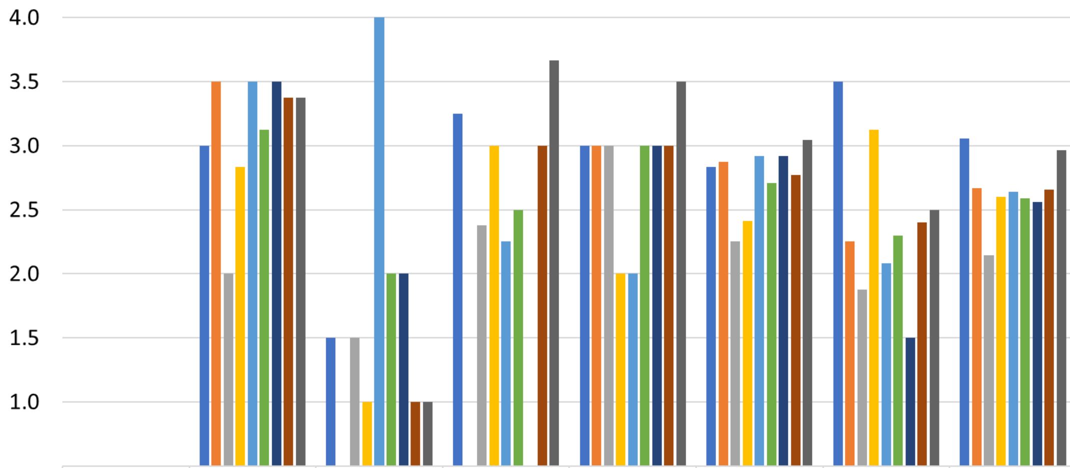
Table 15. SWOT example

	Positive	**Negative**
Internal	*Technology expertise – DevOps.* *Knowledge of the customer.* (Strengths)	*New development technology [...]* (Weaknesses)
External	(Opportunities) *Very high political priority, driving large budget, investment, extensions, high visibility.* *Excellent project reference to use as an entry to extend with other projects.* *Future partnerships.*	(Threats) *Over-dependency on subcontractors.* *Many different stakeholders (subcontractors, many units in the customer organization)*

C) The specialized tools for complexity analysis and management received positive average assessments, but with important differences between participant groups. Project managers have positive convergent assessments regarding the benefits of dedicated complexity analysis and management, and analysis of effects such as Positive Complexity; with low variation coefficients i.e. good alignment of opinions. The variation coefficients for the assessments of the project managers are low, which shows that the opinions of the project managers are reasonably aligned; thus, the average of their assessments is meaningful.

The variation coefficients are increasing when including other participants, showing divergence between groups: top management gave lower scores than project managers. An explanation could be lower social desirability and acquiescence biases for top management. Top management motivated the low scores with the overhead incurred by deploying additional tools. They acknowledge the value of the tools, so they suggested instead upgrading **risk management** by including complexity, rather than adding new tools.

The assessments of the tools per group of participants are presented in Figure 36 (the scale is 1-4).



	Answers	Prj1 avg.	Prj2	Prj3	Prj5	PM avg.	Top mgmt.	Overall avg.
Measuring/red-flag.	18	3.0	1.5	3.3	3.0	2.8	3.5	3.1
Morcov tool	6	3.5			3.0	2.9	2.3	2.7
CIFTER tool	14	2.0	1.5	2.4	3.0	2.3	1.9	2.1
Haas tool	15	2.8	1.0	3.0	2.0	2.4	3.1	2.6
SWOT	18	3.5	4.0	2.3	2.0	2.9	2.1	2.6
Positive / neg. - CES	17	3.1	2.0	2.5	3.0	2.7	2.3	2.6
COSM	8	3.5	2.0		3.0	2.9	1.5	2.6
Complexity Register	16	3.4	1.0	3.0	3.0	2.8	2.4	2.7
Mitigation Strategies MSM	13	3.4	1.0	3.7	3.5	3.0	2.5	3.0

Figure 36. Assessments of the tools per group of participants (scale of 1-4)

D) The arguments proposed spontaneously by participants, as answers to the open questions and discussions, are detailed in Table 16. These arguments were identified from the interview transcripts, through text analysis; then classified and organized using card sorting. The numbers represent how many participants proposed each argument spontaneously, unsolicited. The count is therefore significant, but it doesn't represent a ranking. Noticeably, some arguments contradict each other.

Table 16. Qualitative analysis of the arguments of research participants

	Argument	Project mgrs.	Top mgmt.	Total mentions
1	**Why is complexity management useful**			
1.a	It generates risk	4	3	7
1.b	Supports to prioritize and plan projects in a portfolio	1	0	1
1.c	Better allocation of resources	2	1	3
1.d	Helps to understand the project	0	2	2
2	**When is complexity management (not) useful?**			
2.a	Useful (only) for large/complex projects	5	2	7
2.b	For risky projects, because risk also generates complexity	0	2	2
2.c	Mostly at project inception. Usefulness is low in advanced stages	4	4	8
2.d	Not useful immediately at project start - because the information is not available yet	2	0	2
2.e	Should be continuously updated throughout the project lifecycle	2	1	3
2.f	A tool is important only when it generates actions	5	2	7
2.g	Only for reducing complexity - never to increase it (complexity can be appropriate, or requisite; but never positive)	1	0	1

3	**Why is complexity management NOT useful**			
3.a	Overlaps too much with risk management	3	2	5
4	**Differences between complexity and risk management**			
4.a	Complexity management focuses on positive complexity, on opportunities	3	2	5
4.b	Complexity management supports 1) systemic thinking; and 2) awareness regarding opportunities - even if a specific complexity management tool is not applied systematically	2	0	2
5	**How to apply complexity management tools**			
5.a	Should be applied in 2 steps: red-flagging first, then detailed analysis and management - only for very complex projects.	3	4	7
5.b	Project managers should receive detailed guidelines on how to apply the tools (e.g. templates, checklists, tutorial, methodology)	2	1	3
5.c	A detailed tool (such as Morcov measurement tool) is essential as a checklist, identification and analysis tool for large complex projects	2	2	4
5.d	In order to be effective, tools should be adapted to the project environment	2	0	2
5.e	Project managers should share the results with the team and stakeholders; including business analysts, management, customer	1	0	1
5.f	The risk register should be upgraded to include complexity analysis and management	2	1	3
5.g	A tool must be deployed uniformly (standardized) across an organization	1	1	2
5.h	Project manager’s experience is essential	1	0	1
5.i	Deploying too many tools is overhead, so tools should be prioritized	1	2	3

VIII.5. Discussion

VIII.5.1. Tool selection and timing

Most participants support that analysis and management tools should be deployed as early as possible in a project lifecycle; 8 participants gave this argument, but there were also 2 contrary positions. Participants concur that tools should be continuously updated throughout the project. The majority underlined that a tool is useful only if it generates actions. A participant suggested that the effectiveness depends on the dissemination and sharing of results and actions with the project team and stakeholders.

Participants support the standardization of a clear set of tools and templates at the level of the organization, adapted to the organizational and project context, and easily reusable across projects.

The arguments given especially by top management participants suggest that deploying too many tools is counter-efficient; thus, the implementation of various tools should be prioritized depending on the project.

VIII.5.2. Red-flagging vs. detailed analysis

When deciding on the deployment of additional management tools, an important discussion concerned their cost compared to their benefits. Seven participants gave spontaneous arguments that the cost overhead is not acceptable for simple or small projects. Only projects "red-flagged" as potentially complex high-risk should enter in a detailed complexity assessment or measurement, and be considered for the application of specific complexity management tools. Dedicated complexity management tools were received with more enthusiasm by project managers than by top management – the main reserves being related to the additional effort, prioritization of the tools deployed, and overlap with risk management.

An initial, automated, low-effort red-flagging of projects was therefore suggested, before considering the application of more specialized tools. This red-flagging could use numeric size-related information, already available, but which strongly correlate with complexity, such as project size: budget, number of stakeholders, subcontractors. Participants also argued that "high-risk" should also be an independent flag.

VIII.5.3. Discussion on the measurement tools

This study tested 3 measurement tools, for a comparative evaluation. Participants concur that only one tool should be standardized at the level of an organization. Such a tool should be as simple and objective as possible – and at the same time it should offer sufficiently detailed measurement criteria.

As argued in the previous section, simple projects should not be included in a detailed measurement. For complex projects, participants argued that an effort of 10-60 minutes is acceptable for a detailed complexity assessment. For very complex projects, a detailed tool such as Morcov tool can also constitute a very detailed checklist, that would support an in-depth project analysis, useful during project initiation for ensuring a better understanding of the project.

The CIFTER and Hass tools use similar criteria and scales. Accordingly, based on an odds ratio analysis, they yield reasonably similar results. Of course, the number of data points is too limited to allow for a significant statistical conclusion. The odd ratio analysis is presented in Table 17. An odds ratio is a measure of the degree of association between two events; it is suitable for analyzing the correlation between the results of the three ordinal scales concerned.

Table 17. Odds ratio analysis of the results of the measurement tools

	Prj1	Prj2	Prj3	Prj4	Prj5	Overall	Overall excl. outlier Prj2
Odds ratio CIFTER/Hass	112%	60%	113%	137%	112%	112%	101%
Odds ratio Morcov/CIFTER	28%	141%	117%	74%	86%	80%	89%
Odds ratio Morcov/Hass	31%	85%	132%	101%	97%	90%	90%

Between these 2 measurement tools, Hass was considered by participants to be better adapted to IT projects. It includes more numeric criteria; thus, it is more objective, simpler, and easier to apply. Participants argued that they could instantly provide answers to numeric questions such as project budget, team size, or duration, while significant effort would be needed for answering more abstract criteria, such as "Magnitude of legal, social, or environmental implications from performing the project" or "Level of organizational change". On the other hand, numeric criteria alone are not sufficient to describe and measure complexity, as they do not cover the non-quantifiable aspects typically associated with dynamic complexity.

In order to increase the accuracy of the measurements, the tools, their weighting system, and the scales should be adapted to the organization and environment. In fact, the same project may be considered small or large, simple or complex, in different contexts.

Similar to numerous other tools used in social sciences and even engineering, complexity measurement tools will always incorporate a certain degree of subjectivity. At the same time, the standardization of tools within a specific context ensures higher comparability between results.

VIII.5.4. Difference in measurement results between the tools

During the application of the measurement tools, it was observed that CIFTER and Hass tools do not discriminate well between projects of very different sizes. The reason is that these tools use: a) ordinal Likert scales, and b) a built-in maximum arbitrary threshold for criteria related to size. Thus, the tools give the same complexity score for all projects above the maximum threshold. E.g. for a maximum built-in threshold of 100k, then a project of 100k Eur has the same complexity score as a project of 1 bil. Eur.

On the other hand, as shown in section III.3.2, project size correlates very well with project complexity.

The Morcov tool attempts to improve this shortcoming by proposing a ratio scale for numerical questions. Thus, the answers are expressed in absolute values: Team size is expressed in full-time equivalents, Effort in man-days, Duration in calendar days. Morcov tool thus discriminates better between projects of very different sizes.

Because of this difference in the scales used, the project complexity measurement results obtained with CIFTER and Hass were similar, but the results obtained from the Morcov tool were divergent from these – as illustrated by the odds ratio analysis, Table 17.

VIII.5.5. Checklists and templates for analysis

The first application of a new tool, by a new user, in a new organization, is a difficult step, as there is no previous experience, no starting point, few clues and indications on where to begin. Templates are then gradually developed; previously developed artifacts are reused from other projects or examples.

The current project cases faced a similar challenge. Faced with the challenge to apply new tools, project managers asked for detailed guidelines on how to apply them; for templates, checklists, tutorials, a detailed methodology. While deploying the tools, the research participants looked for checklists; and developed templates when needed. The Complexity Register itself emerged as a checklist and template; it allows following a set of consecutive steps in the application of the evaluated tools.

The most useful tool for the identification and analysis of complexity was the measurement tool itself. The Morcov measurement tool was more useful from this point of view, being more detailed and precise, as well as more adapted to the IT industry. The mere application of such a detailed measurement tool generates, as a direct result, a list of complexity elements. Going through each criterion of a measurement tool, and answering the questions regarding the project, has thus important benefits, other than scoring project complexity. It is already a detailed project analysis activity that is done in practice for any project, as part of project initiation. It helps identify complexity elements as well as risks. As one participant suggested: *"Any tool that supports to identify and mitigate risks is super useful"*; or another participant: *"the items in the Morcov tool are the same elements that are typically included in the project charter, analysis which is done during the initiation stage of any large project. [...] The finality – the operational results – is the identification of complexity elements and risks."*. At the same time, checklists should not block creative thinking, nor limit the analysis to predefined patterns only.

VIII.5.6. The relation and overlap between risk and complexity

The research sub-project confirmed a strong relationship and even overlap between risk and complexity.

Participants concur that complexity generates risk. At the same time, two spontaneous arguments were made that risk also generates complexity;

which is aligned with the observation that ambiguity and uncertainty are aspects of both risk management, as well as complexity.

Overlap between different tools is common. A specific tool can be useful in a specific context, for a specific project. Project management theory suggests that the exact toolset should be selected by the project manager and/or PMO (Project Management Office) for each organization and project.

The fundamental **difference between risk and complexity** is that risks (including both threats and opportunities) are discrete events, occurring at specific moments in time, whereas complexity, similarly to vulnerability, is a description, a characteristic of a system.

- Events are one-time only; they occur at a certain specific moment. They are described with verbs: something *happens*, someone *does*. Risks, opportunities, issues, and action items are events. Events have a specific probability and a potential impact. In particular, issues are risks that already occurred, i.e. their probability is 100%. Actions are planned and undertaken by the project manager, to respond to the events or objectives of the project.
- Characteristics do not occur at a certain specific moment – instead, they describe a certain state or general behavior of a project system. They are named using adjectives: something *is*, or *has*.

Risks and opportunities can be derived from the analysis of complexity: a specific complexity characteristic can increase or decrease the probability that a certain event might occur, as well as the reaction of the system to the specific event. E.g., “Number and variety of stakeholders with different interests” is an aspect of complexity. It can generate risks such as “refusal or delay of the delivery (due to misunderstanding/unclear/conflicting project requirements, or due to communication overhead)”. It can also generate opportunities such as “Extend the project with additional product features or services needed by other stakeholders”.

Thus, risk management tends to be *reactive* to *negative external* events, whereas complexity is *proactive* and centered on *internal opportunities*.

It should be noted that, in practice, participants to the evaluation had difficulties differentiating between risk and complexity. Also, in practice, opportunities are considered mostly a business topic, related more to sales and marketing, and disregarded by participants in the context of project management. In fact, risk registers rarely list any opportunity. This made Positive Complexity a valuable tool in practice: *"I like the complexity register because it forces me to look at opportunities instead of only at risks"*, was an argument received. Thus, the concept of Positive Complexity can function as a catalyst for uncovering project opportunities.

Simple awareness of potential project complexity proved to be already beneficial, supporting systemic thinking and openness towards Positive Complexity and opportunities, in the actual project cases. It allowed for a better understanding of the project; and, in one case, even helped uncover a specific project opportunity.

A potential solution to the overlap between risk and complexity, suggested independently by 3 participants, is to extend risk tools with complexity management – this argument being suggested independently by three participants. As one suggested: *"Complexity should not be duplicated with risk. Deploying two separate registers will lead to rejection from project managers. As the concept is useful, the key question is how to combine complexity and risk management. A detailed complexity measurement tool could be used as a tool to fill in a risk register, rather than a finality in itself".*

VIII.6. Limitations, validity, and reliability of the evaluation project

The external validity of the research is affected by limitations regarding the project and organizational context. All projects included in the research were IT/software development projects that use similar project management and software development methodologies; but they cover a very wide range of technologies and business areas. The customers belong to several industry verticals, are both public and private organizations. All customers are Western European, but they are large multinational and multicultural organizations.

Construct validity and reliability were strengthened through:

- the use of multiple sources of evidence (triangulation), i.e. analyzing several projects and several stakeholders for each project;
- establishing and documenting the chain of evidence, through video recording, text transcripts, and rigorous configuration management;

- ensuring that stakeholders have open access for reviewing the collected information, including access to video recordings and data.

Triangulation supports proving convergence and exploring divergent, possibly new relevant insights. Multiple case studies are suitable for building new theories and their external validation (Gibbert & Ruigrok, 2010).

Face-to-face interviews are suitable for the niche topic, to obtain new insights and increase innovation and creativity. The interviews were structured in a standardized questionnaire, with open questions to drive exploratory qualitative research, but also with fixed-choice Likert-type and yes/no questions to increase reliability, allow for comparison and data analysis. As the topic is unfamiliar, respondents might misuse the midpoint e.g. as a non-answer or neutral answer, thus decreasing the reliability of the measurement; therefore, the evaluation scale did not have a midpoint (Chyung, Roberts, Swanson, & Hankinson, 2017). During the open questions, stronger importance was placed on negative rather than on positive feedback; on discovering arguments, causality, and context (Wieringa, 2014).

Any **quantitative** analysis must be interpreted with caution, considering the number of data points and the use of multiple ordinal and interval Likert-type scales in the same research. Different tools use different scales, as they had been proposed by different authors. The research focused therefore on the qualitative analysis of the answers received, and of the type of arguments used by each participant, while taking into consideration the characteristics of the specific experts, organizations and projects involved.

The measurement tools were evaluated in comparison with each other.

The complexity analysis and management tools were deployed and evaluated as a set, making it difficult to differentiate with accuracy between the results and impact of each tool, independently of the others. In fact, the results of the data collection from all the analysis and planning tools were integrated into a single Complexity Register.

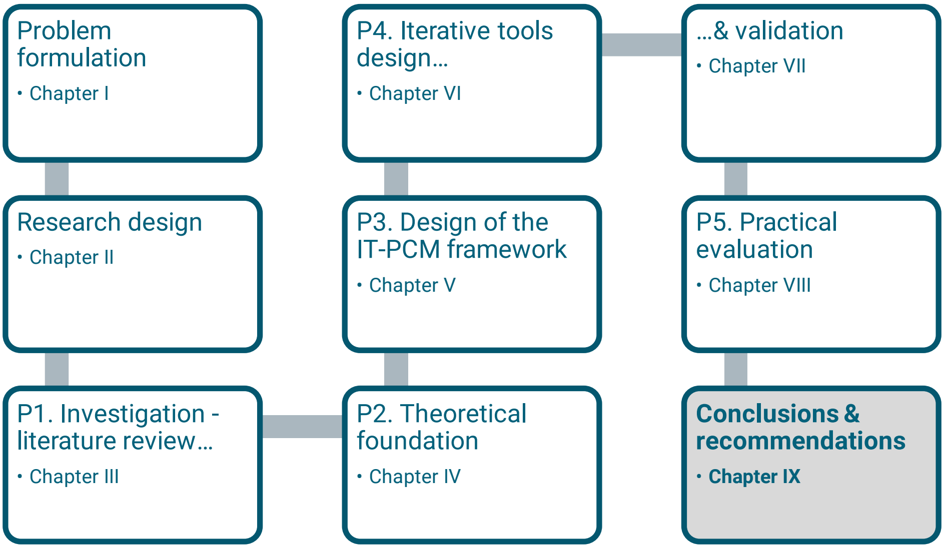
The **participants** in the case studies have a personal stake in the projects (with one exception), i.e. skin in the game (Taleb, 2018). They are personally interested in the success and results of the specific project cases. Their time is limited; nevertheless, they volunteered for this research. They have direct responsibility for achieving the project's objectives, including cost, quality, deadlines, and scope – hence personal interest to limit the cost and overhead, but willing to adopt new methods and tools if useful. They have a genuine interest in advancing project management knowledge, in improving practice, processes, and tools.

VIII.7. Conclusion

This chapter presented the results of research sub-project P5: implementation and repeated evaluation of a set of tools for complexity measurement, analysis, and management, in 5 actual industry IT project cases, over a period of 7 months. The tools evaluated were the specialized IT project complexity measurement, analysis, and management tools, proposed in Chapter VI. Two additional complexity measurement tools were evaluated. The study also investigated the use of traditional tools for managing project complexity.

The previous research sub-project P4 consisted of an iterative design-and-validation process formed of 2 *design-cycles* (Chapters VI and VII). Together, the sub-projects P4 and P5 form a full *engineering-cycle*.

Chapter IX.
Conclusions and recommendations



This project was a qualitative, cross-disciplinary, iterative-incremental, pragmatic research project based on design science. Its goal was to contribute to the understanding and management of complex IT projects.

The main outputs are:

- Review of the current state-of-the-art in project complexity research:
    - Establishing a common language for addressing the topic;
    - A structured literature review of definitions, models, characteristics, approaches (RQ1-3).
- Providing insights and new perspectives on complexity:
    - A holistic model of complexity; and the model of Positive, Appropriate, and Negative Complexity (RQ4);
    - Defining IT Project Complexity Management and the IT-PCM Framework (RQ5).
- Design, validation, and evaluation of a set of practical tools to support complexity measurement, identification, analysis, management, planning response strategies, and monitoring (RQ6-7).

Complexity is a ubiquitous reality in modern IT engineering & management. It generates risk, but it also creates opportunities.

Modern IT engineering uses complexity to deliver value. Positive and appropriate complexity can act as catalysts for opportunities.

The results of this project, the new model of Positive, Appropriate, and Negative Complexity, the IT-PCM framework, and the proposed IT project complexity management tools aim to constitute a step towards the goal to support building better IT engineering and products.

IX.1. Positive, Appropriate, and Negative Complexity

The model of **Positive, Appropriate, and Negative Complexity** is a new paradigm that emerged from this project.

Complexity is a challenge in all IT engineering projects and products. While it often correlates with risks and higher costs, it can also bring functionality, advanced technology, and better products. Complexity is everywhere; we are surrounded by complex engineering products that work.

Aligned with similar concepts from related domains, such as *opportunities*, *antifragility,* or *requisite variety*, this paradigm of positive and appropriate complexity has practical implications and applications. It allows for better understanding and management of complexity; recognizing its benefits, exploiting relevant opportunities; and designing better, more advanced, and useful technology.

IX.2. Designed tools

This project resulted in the design, validation, and evaluation of a set of tools for the identification, analysis, and management of complex IT projects, grounded on an innovative approach and project complexity perspective, with both theoretical and practical implications:

- The IT Project Complexity Management – IT-PCM framework: a structural framework in which specific tools and techniques can be anchored; a high-level process that adds rigor to the design of specialized tools and to the management of complex IT projects, systematizing the concepts and artifacts, supporting the practical implementation.

- The Complexity Effect Scale – CES: supports the identification, visualization and analysis of IT project complexity based on its effects: Positive, Appropriate, and Negative.
- The Complexity Source/Effect Segmentation Matrix – COSM: supports complexity analysis based on its sources and effects.
- The complexity Mitigation Strategies Matrix – MSM: supports the decision process for mitigating complexity. The proposed response strategies, depending on effects, are:
    - a) create/enhance;
    - b) use/exploit;
    - c) accept;
    - d) simplify/reduce;
    - e) avoid/eliminate.
- The Complexity Register – CoRe: supports the collection, organization, aggregation, management, monitoring, and update of the relevant information.

The designed tools aim to support practitioners to:

- recognize, understand, analyze, and manage complexity more effectively;
- deal with IT project complexity in a structured way;
- prioritize projects and resource planning;
- reduce associated risks and exploit opportunities;
- increase project success rates.

While this IT-PCM framework proposes detailed guidelines, best practices and tools, in practice there is no silver bullet and no unique universal answer to the question of which is the best tool or strategy to deal with complexity. As in all areas of project management and engineering, the appropriate solution is always contextual.

The appropriateness, selection, and implementation of a specific set of management frameworks and tools are specific for each particular organization and project. Each project and portfolio manager will, in practice, choose an appropriate toolset, decide when and to what degree to apply each tool to a particular situation, and adapt them to the project environment.

IX.3.Research summary

Project complexity is a challenging domain. Its study builds knowledge and brings value to IT engineering and project management practice.

This project consisted of a full *engineering-cycle*, and included:

- An investigation phase:
  - Research sub-project P1. Investigation.
  - P2. Theoretical foundation.
- Several *design-cycles*, i.e. design-and-validation loops, supported by semi-structured interviews with multiple experts:
  - P3. IT-PCM Framework design.
  - P4. Tools design-and-validation.
- A longitudinal evaluation of the designed tools and concepts in actual live IT project cases:
  - Sub-project P5. Practical evaluation.

The research started with a **systematic literature review** on project complexity and complex project management – research sub-project P1, Chapter III. Other areas investigated were IT/software and systems engineering. The literature review sub-project resulted in:

- A chronological list of approaches and definitions – summary and detailed versions – answering to research question RQ1.
- Classifications (or sources) of project complexity – RQ1.
- Characteristics of project complexity – RQ2.
- Complexity measurement tools and criteria – RQ3.

A **theoretical foundation,** appropriate for this project, was chosen in the research sub-project P2 – Chapter IV (research question RQ4). It consisted of choices regarding the definitions, approach, and language used throughout this research. It proposed a new paradigm of project complexity: a holistic perspective, with an approach based on the effects of complexity, and with theoretical definitions for Positive, Appropriate (requisite), and Negative Complexity.

The **IT-PCM framework** is the main result of sub-project P3 – Chapter V (research question RQ5). It aims to support IT Project Complexity Management in a structured way. Project Complexity Management is formally defined as a knowledge area that includes specific processes to understand, plan strategy and responses, monitor and control project complexity. The IT-PCM framework organizes the complexity management processes and activities, and their specific inputs and outputs. Additionally, an inventory of relevant tools and methods is proposed for each process and step in the framework, obtained from the literature review, drawing from all the related domains: project management, systems engineering, and IT/software engineering. This inventory revealed several gaps, that sub-project P4 attempted to fill with new tool designs.

Sub-project P4 (Chapters VI and VII) attempts the **design-and-validation of new methods and practical tools** for IT project complexity management (research question RQ6). It is based on the literature review (P1) and on the proposed theoretical constructs (P2). The new tool designs attempt to fill gaps in the inventory of tools of the IT-PCM framework (P3).

The **evaluation in practice** of the proposed tools was done in sub-project P5 – Chapter VIII (research question RQ7).

The tools design, validation, and evaluation, in sub-projects P4 and P5, were anchored in the IT-PCM framework. Due to its scale and detailed inventory of tools and techniques, complete empirical validation of the full IT-PCM framework is difficult to perform. Instead, the effectiveness and the application in practice of components of the framework were validated and evaluated during the research sub-projects P4 and P5. These provide implicit evidence on how the integrated framework can be deployed to support actual projects.

IX.4.Implications

The research has both theoretical and practical implications for IT, engineering, and project management.

This project argues for a modern positive approach to complexity. It recognizes its ubiquitousness in contemporary engineering and management and acknowledges that "*it works*". This is congruent with the theories and concepts of opportunities, requisite complexity, viable systems, and antifragility, and is aligned with systems engineering. Complexity is thus more than just a threat; it also becomes a basis and catalyst for creating and exploiting opportunities and supporting overall project success.

As shown by the literature review, project complexity is difficult to understand and manage; its terminology is overloaded and over-used. Despite a growing importance and priority in research, there is still a strong need for solutions to its challenges and opportunities.

This thesis attempts to formally define the Project Complexity Management knowledge area and establish its standard common language. The introduction of new theoretical constructs supports the development of the domain, with proposed definitions for **Positive, Appropriate, and Negative Complexity**.

The thesis proposes the **IT-PCM management framework** for dealing with IT project complexity in a structured way, and specialized tools to support practitioners to better identify, understand, analyze, and manage complexity.

These proposed approaches and tools align project management theory and practice with systems and IT engineering, which recognize the importance of complexity and the need to manage and even exploit it, rather than only to avoid or reduce it.

The analysis of IT project complexity effects, and especially benefits, is a novel approach that changes how we look at it from both a theoretical and practical point of view. **Complexity is a ubiquitous reality.** Besides the difficulties and risks it generates, it also **creates opportunities**. In fact, we notice all around us that **complexity works**; it delivers value, functionality, creativity and innovation.

Accordingly, the traditional approaches that focus on simplifying and reducing complexity may not always be the best mitigation strategy. This research makes an argument for new tools to manage complexity and even use it for improving project success rates, for obtaining better project results and benefits.

IX.5. Limitations, validity and reliability

While a series of measures were taken for enhancing construct, internal and external validity, and reliability of the individual sub-projects as well as of the integrated research project, several limitations may impact the results. These refer to both the research methodology as well as to the execution.

A set of limitations are also specific to each research sub-project. These are presented in sections III.6, VII.5, and VIII.6, respectively.

IX.5.1. Research approach and methods

The overall reliability of the research is supported by the use of a **structured research methodology**, i.e. design science, and structured data collection methods, i.e. case-study research and interviews with predefined questionnaires for data collection. This methodology is aligned with our overall qualitative inductive approach.

Case study research is suitable for building new theories (Gibbert & Ruigrok, 2010). Face-to-face interviews with open questions are suitable for the niche topic, supporting uncovering new insights and increasing innovation and creativity during research.

Design science is widely used in engineering and IT as an incremental iterative process to build new models and tools, to develop solutions for practical engineering problems, and for solving wicked problems (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007) (Hevner, March, Park, & Ram, 2004).

Each research sub-project is a step in the engineering cycle, building on the previous sub-projects (Wieringa, 2014).

A series of choices were made regarding the methods of each research sub-project, which might impose **limitations** on their validity and reliability. Thus, in research sub-project P4 - design-and-validation (Chapter VII):

- The project cases were selected by the participants to the research themselves.
- The project cases were analyzed from a single perspective.
- A cross-sectional data collection method is used.

On the other hand, in research sub-project P5 – evaluation (Chapter VIII):

- The project cases were selected first; the project stakeholders were selected and invited to participate only after the selection of the projects.
- Multiple data points are collected: the project cases are analyzed from the perspective of multiple stakeholders.
- For each project case, the data collection was longitudinal, with several data points being collected during a period of several months.

Overall, the validity of the integrated set of sub-projects is thus higher than the validity of individual sub-projects. Nevertheless, some limitations remain, as will be discussed below.

IX.5.2. Construct validity

Construct validity is affected by some choices regarding the design of the research, as well as by aspects related to its execution.

A rigorous configuration management process was enforced throughout the entire research project. It included detailed version and variant control, covering all data, research items, and design artifacts. This process established and documents the entire chain of evidence, for the data, the activities, and for the intermediate and final results. Each iteration in the engineering-cycle was documented in order to enhance construct validity. After each sub-project and each iteration, configuration baselines were established. The intermediate versions of each artifact were documented for traceability and construct validity.

In sub-project P1 – Systematic literature review, the research query design limited the number of articles retrieved, in order to have a manageable research scope. This might have excluded relevant articles from the results.

This limitation was partially compensated by snowballing and backward-searching, i.e. we included articles that are referred by, or that refer to relevant literature. We also included in the research the results of relevant literature reviews which were published after our literature review.

A limitation on construct validity concerns the main method for data collection used in research sub-projects P4 (design-and-validation) and P5 (evaluation), namely face-to-face interviews. Thus, the main data collected for validation (P4) is formed of the subjective opinions of the participants to the research, based on hypothetical questions. While overall multiple data points were collected, each represents the single perspective of each respondent.

Also, during evaluation (P5), the main collected data is the *perceived* benefits from the deployment of the evaluated tools in their actual projects. As discussed in section VIII.3.1, this was the only practical method of gathering information in a reasonable timeframe regarding the impact of the tools in practice. A series of measures were taken to mitigate this potential weakness, such as triangulation – collecting multiple data points, from multiple perspectives, for each project case.

A potential limitation that can impact the quality of data collection for sub-project P4 is that the interviews were not recorded, therefore no detailed transcripts are available. The analysis of the data was based on the answers to the questionnaires and on the minutes of meetings kept by the author.

During sub-project P5, all interviews were video recorded, and the full transcripts of the interviews are available. This increases the construct validity of sub-project P5.

IX.5.3. Internal validity

Internal validity is enhanced by documenting the causality, the reasoning behind design choices, and by providing transparency to reviewers and to research participants.

The overall research approach, design science, can impose a potential limitation impacting this type of research, as it includes a series of choices during the design, re-design, validation, and evaluation loops. On the other hand, the iterative approach of design science, with its cycles of validation and evaluation, enhances internal validity. Overall, the entire process was transparent and documented.

The adoption of a qualitative research approach can also have implications and might impose limitations regarding the collection and analysis of the data. These can be affected by researcher bias. In order to reduce this limitation, data was collected and discussed transparently both with participants to the research, as well as during the reviews of the results and peer-reviews of the publications.

During the evaluation sub-project P5, the measurement tools were evaluated in comparison with each other, and all the tools were deployed and evaluated as a set, making it difficult to differentiate with accuracy between the results and impact of each tool, independently of the others. This can pose a limitation to the quality of the data collected, making it difficult to evaluate the perceived impact and benefits of each tool independently of the others.

The comparison of the results of different complexity measurement tools has to take into consideration that each of them uses different scales – as they had been proposed by different authors. This might affect the quantitative analysis regarding the possible correlation of the results of the 3 tools, during the evaluation sub-project P5. These issues might impose limitations to the interpretation of the results regarding the comparison between measurement tools, as well as regarding the conclusions on the benefits and impact of each tool.

IX.5.4. External validity

An important limitation to the external validity of the research is that inductive research is sensitive to its context.

This context limitation is typically managed by specifying the domain of applicability of the results as precisely as possible. We assumed therefore from the onset a limitation of applicability to the domain of IT project management. This limitation also supported specialization, thus increasing the usability of the results. Accordingly, all research sub-projects, starting from the literature review P1 and including all case-studies of sub-projects P4 and P5, were limited to the IT domain.

Two aspects are relevant to the external validity of this research:

1. The level of generalization of the results beyond the scope of the analyzed case studies, but still within the domain of IT projects.
2. The degree to which the overall results can be generalized beyond the IT domain.

A dedicated discussion is presented below for each of these 2 aspects.

1. Several case studies and interviews were conducted, enhancing the degree of variation of the results. Thus, the data collected supported extracting common characteristics, which allows analytical generalization and enhances external validity. At the same time, a limitation could be imposed by the fact that the number of cases analyzed was limited by the qualitative research approach.

The project cases have a significant degree of similarity, but they also provide a level of variation within the domain of IT projects. In fact, all projects have similar cultural and geographical backgrounds, which poses a limitation to their generalizability. All project cases were implemented in Europe, albeit across many different countries. All final customers are Western European, even if the projects have stakeholders around Europe. The projects are for large multinational and multicultural organizations. The customers belong to several industry verticals, and are from both the public and the private sector.

Within the IT domain, the projects cover a wide range of IT technologies and business areas. Also, the projects analyzed during the cycles of validation were different from the projects analyzed during the evaluation, which enhances the level of variation of the project cases within the IT domain.

These measures enhance the level of confidence in the external validity of the results, within the domain of IT project management, while taking into consideration the limitations expressed above.

2. On the other hand, the level of generalization of the results beyond the IT domain cannot be easily established.

In fact, all project cases analyzed were IT/software development projects, with a series of similarities between them. They use standard, thus similar project management and software development methodologies. They all use English as the main language.

Accordingly, while the results could be relevant to other domains, further research could be needed before asserting a possible generalization beyond the stated IT domain.

IX.5.5. Reliability

Reliability can be affected by the choice of a qualitative inductive research approach. This limits the repeatability of the findings, due to the involvement of the researcher, both as an actor in the collection of data from interviews, as well as to the mix of the role of researcher and consultant, i.e. the action research paradigm (Gummesson, 2000).

Due to their interactive nature, face-to-face interviews limit replication, hence reliability, and are susceptible to self-confirmation bias. Not all invited experts participated in the research, and some participants had limited time available. The participants were volunteers with a personal and professional interest in the topic. The participants in the case-studies were not neutral; rather, they had a personal stake – skin in the game, direct responsibility for achieving the project's objectives.

Reliability is enhanced by using predefined questionnaires and standardized data-collection tools, and by providing transparency to the data collection and analysis process.

The interviews were structured in a standardized questionnaire, with open questions to drive exploratory qualitative research, but also with fixed-choice Likert-type and yes/no questions to increase reliability, to allow for comparison and limited quantitative data analysis. As the topics are new and potentially unfamiliar, the evaluation scales did not have a midpoint, in order to avoid any potential misuse of such midpoint e.g. as a safe point, for non-answers or neutral answers (Chyung, Roberts, Swanson, & Hankinson, 2017). During the open questions, stronger importance was placed on the negative rather than on the positive feedback.

Participants had open access for reviewing the collected information, including access to video recordings and data.

This section presented a discussion on the reliability and validity of this research, and provided transparence regarding possible limitations that might affect the results of the research.

While we acknowledge that a series of limitations apply, a corresponding set of measures were taken for enhancing reliability, construct, internal, and external validity. These were discussed in specific sub-sections above. These measures refer both to the individual sub-projects, as well as to the overall methodology and the integrated research project.

We trust that these measures provide an acceptable degree of confidence in the validity and reliability of the research, and in the generalizability of the results within the IT project management domain.

IX.6.Recommendations and future directions of research

The thesis aims to constitute a building block in the study and management of complex IT engineering projects, and to contribute to future directions of research in this area.

This section presents research questions that have already been proposed by the literature review, as well as research questions derived from the current research project (Hall N. G., 2014).

The results of this project support the conclusion that complexity can be managed more effectively by deploying traditional project management tools such as risk management, stakeholder and communication management, agile development, program management. *Additional research could focus on:*

- *Developing further methods and tools for the management of complex IT projects, targeted on areas such as communication, stakeholder management, managing project objectives, scope, and requirements.*
- *Identification of other IT project management practice areas most impacted by complexity, through surveys, case-study analysis, and interviews.*

The results suggest that specialized complexity management tools such as those proposed by the current project can contribute to taming complex high-risk IT projects; also, that such tools are not appropriate in the case of small and/or simple projects. *Further research could be conducted for a definitive conclusion on the benefits of such specialized tools, and their role in supporting risk identification and management, and better prioritization and planning of projects and resources in complex IT project environments. Also, further research could investigate:*

- *the relation between complexity, risk, and vulnerability, and the potential practical use of these 3 knowledge areas combined.*
- *the relationship between project complexity sub-systems, such as product, process, market, and organization.*

By adopting a systematic and rigorous approach to complexity management, project managers can better understand and manage IT projects, mitigate the negative effects of complexity, reduce project risk, and support overall project success. *Further research could investigate the balance between personal skills, training and experience, vs. the application of a structured process, in managing complex projects successfully.*

This thesis proposed a structured IT Project Complexity Management (IT-PCM) framework, with processes, inputs, outputs, and an inventory of tools and techniques. *As this inventory cannot be exhaustive nor definitive, further research could support updating and enriching the inventory of methods and tools proposed in the framework, both with project management tools, as well as specific IT management tools.*

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Appendix A. Historical approaches to project complexity

Table 18. Historical approaches to project complexity

#	Author	Approach	Definition/model
1	(Baccarini, 1996)	First formal introduction of project complexity; with focus on structural complexity.	A complex project is consisting of many varied interrelated parts. Complexity is operationalized in terms of differentiation and interdependency. It is categorized (mainly) as organizational and technological.
2	(Turner & Cochrane, 1993)	Goals-and-methods matrix	An analysis of projects with uncertainty in goals and in methods, in a goals-and-methods matrix. While the study establishes a strong foundation to (dynamic) complexity, it does not introduce formally project complexity.
3	(McKeen, Guimaraes, & Wetherbe, 1994)	Analysis of user participation in system development, including aspects such as task and system complexity.	(System) complexity arises from ambiguity or uncertainty. It is related to the "task" (business, external, organizational) or to the "system" (technological).
4	(Williams T. M., 1999)	Model that combines: Structural complexity. Uncertainty.	Structural complexity: size and interdependencies. Adds uncertainty of goals and methods.

4	(Edmonds, 1999)	Delineates manifestations.	"Complexity is that property of a model which makes it difficult to formulate its overall behavior in a given language, even when given reasonably complete information about its atomic components and their inter-relations."
5	(Tatikonda & Rosenthal, 2000)	Framework that characterizes projects based on technological novelty and complexity, and their relation to outputs.	- degree of interdependence (product and process technologies); - the objectives' novelty; - the difficulty of the project.
6	(Pich, Loch, & De Meyer, 2002)	Structural complexity. Unpredictable, difficult to manage. Differentiation between ambiguity (unknown) and complexity (unpredictable).	Too many variables interact, leading to inability to evaluate the effects.
7	(Ribbers & Schoo, 2002)	Complexity in complex ERP implementations – large business IT systems. Combines the structural and dynamic aspects of complexity. Complex projects implemented as programs.	Variety: static, structural. Variability: changes, e.g. project goals and scope. Integration (of various elements).
8	(Jaafari, 2003)	Complexity in social sciences.	Complex society is characterized by open systems, chaos, self-organization and interdependence.

9	(Vaaland & Hakansson, 2003)	Size, innovation, interdependencies, variety.	Capital-intensive, innovation, interdependencies (including of actors), variety of stakeholders (interorganizational, active third parties).
10	(Bertelsen, 2004)	Description, based on complex systems theory.	Emergence, self-organization and self-modification, upward and downward causation, and unpredictability.
11	(Xia & Lee, 2005)	Focus on Information Systems development. Underlines 2 dimensions of IS development projects complexity: structural versus dynamic; organizational versus technological. Develops a measurement system based on these 2 dimensions.	Consisting of many varied organizational and technological elements that are interrelated and change over time.
12	(College of Complex Project Managers And Defence Materiel Organisation, 2006)	General description of effects and characteristics.	Disorder, instability, emergence, non-linearity, recursiveness, uncertainty, irregularity, and randomness.

13	(Remington & Pollack, 2007)	Comprehensive framework that analyzes:	Complexity types: Structural; Technical; Directional; Temporal. Characteristics of complexity: Hierarchy; Communication; Control; Phase transition; Non-linearity; Adaptiveness; Chaos. Sources of complexity: Ambiguity, uncertainty; Interconnectedness.
14	(McComb, Green, & Compton, 2007) (Kennedy, McComb, & Vozdolska, 2011)	Multiplicity and ambiguity.	Multiplicity, i.e. many approaches and end-states. Ambiguity, i.e. conflict and uncertainty in decisions.
15	(Cooke-Davies, Cicmil, Crawford, & Richardson, 2007)	Various theories, up to evolutions in biology.	Non-linearity, emergence, (in)stability: chaos and equilibrium, self-organization, evolutionary adaptation, radical unpredictability.
16	(Geraldi J. G., 2009) (Geraldi & Adlbrecht, 2007)	Model – types of complexity.	3 components of complexity: - of faith - uncertainty, uniqueness, unknown; - of fact –strong interdependencies; - of interaction – politics, ambiguity, multiculturalism.
17	(Mulenburg, 2008)	Causes.	• Details (size); • Ambiguity; • Uncertainty; • Unpredictability; • Dynamics; • Social structure; • Interrelationships.

18	(Whitty & Maylor, 2009)	Structural complexity, emergence (dynamic complexity).	Multiple structural elements interacting and changing as they progress. Many components whose behavior is emergent.
19	(Remington, Zolin, & Turner, A Model of Project Complexity: Distinguishing dimensions of complexity from severity, 2009)	Model of project complexity based on dimensions of complexity (sources and characteristics) and severity factors (that exacerbate complexity).	Dimensions: Goals Means to achieve goals Number of interdependent elements Timescale of project Environment Severity factors Difficulty Non-linearity Uncertainty Uniqueness Communication Context dependence Clarity Trust Capability
20	(Hertogh & Westerveld, 2010)	Structural complexity. Dynamic complexity.	Complexity can be: 1. Detail complexity: "Many components with a high degree of interrelatedness." 2. Dynamic complexity: "The potential to evolve over time: self-organization and co-evolution. Limited understanding and predictability."

21	(Wood & Ashton, 2010)	Empirical factors of complexity	1. Inherent complexity; 2. Uncertainty; 3. Number of technologies; 4. Rigidity of sequence; 5. Overlap of phases or concurrency; and 6. Organizational inherent complexity.
22	(Vidal, Marle, & Bocquet, 2011) (Marle & Vidal, 2016)	Model delineating manifestations and sources. Uses Systems Thinking for describing complexity and its aspects.	"Difficult to understand, foresee and keep under control". Ambiguity, uncertainty, propagation, and chaos not as sources, but as consequences of complexity.
23	(Geraldi, Maylor, & Williams, 2011)	Model combining major aspects.	Five dimensions of complexity: structural, uncertainty, dynamics, pace, and socio-political. Also simplified to 3 dimensions: structural, sociopolitical, and emergent (Maylor, Turner, & Murray-Webster, 2013).
24	(Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2011)	TOE Model	Technological complexity (goals, scope, tasks, experience, and risk), organizational complexity (size, resources, project team, trust, and risk), and environmental complexity (stakeholders, location, market conditions, and risk)
25	(Senescu, Aranda-Mena, & Haymaker, 2012)	Model based on 6 characteristics	1) Multiplicity - includes size. 2) Connections 3) Interdisciplinary 4) Openness 5) Synergy 6) Nonlinear behavior

26	(PMI, 2013)	Characteristics of complexity in projects. Strategy to manage multiple stakeholders and ambiguity	Multiple stakeholders Ambiguity or unknown of project features, resources, phases, etc. Dynamic (changing) project governance Use of a technology that is new to the organization or that has not yet been fully developed Significant political/authority influences, external influences, internal interpersonal or social influences Highly regulated environment Project duration exceeds the cycle of relevant technologies
27	(PMI, Navigating Complexity: A Practice Guide, 2014)	Causes of complexity and strategies to manage or reduce them	Characteristic of a program or project or its environment that is difficult to manage due to: - Human behavior - from group, organizational, political and individual behavior, organizational design and development, communication and control - System behavior - from connectedness, system dynamics and dependency - Ambiguity from emergence and uncertainty

28	(Dao B. P., 2016)	Model, definition, indicators	Project complexity is the degree of differentiation of project elements, interrelatedness between project elements, and consequential impact on project decisions. 40 complexity attributes identified using complexity theory variables, the literature review results, and industry experience.
29	(Qureshi & Kang, 2015)	Structural equation modeling of complexity	Various variables on 5 constructs of complexity: size, interdependencies, variety, context. Measures of project complexity: non-linearity, uncertainty, and uniqueness.
30	(Zhu & Mostafavi, 2017)	New framework: Complexity and Emergent Property Congruence (CEPC)	Two dimensions of project complexity (detail and dynamic complexity) and three dimensions of project emergent properties (absorptive, adaptive, and restorative capacities)
31	(Morcov, Pintelon, & Kusters, 2020b)	Analyzes the effects of complexity	Classifies complexity as Positive, Appropriate (requisite), or Negative, based on its effects.

Appendix B.
Project complexity measurement factors and criteria

- Size
    - Stakeholders
        - Staff quantity
        - Team size
        - Number of companies / projects sharing their resources
        - Number of organizations/departments involved as customers/users
        - Number of hierarchical levels within the organization
        - Number of investors
        - Number of users
        - Number of subcontractors/partners directly managed
        - Number of stakeholders in general
        - Number of stakeholder organizations (subcontractors, customers, partners, investors, users…)
        - Number of structures/groups/teams to be coordinated
    - Size of the project
        - Largeness of capital investment (budget), including resources
        - Number of external information systems that will exchange data
        - Number of IT components/modules in the system
        - Quantity of resources available (budget)
        - Largeness of scope (number of components, etc.)
        - Number of deliverables
        - Number of objectives
        - Number of activities
        - Estimated effort required (man-days)
        - Duration of the project
        - Scope size for development

    - Size of the product
        - Number of function points
        - Number of business areas involved
        - Data communications - How many communication facilities are there to aid in the transfer or exchange of information with the application or system?
        - Distributed data processing - How are distributed data and processing functions handled?
- Product characteristics
    - Performance - Was response time or throughput required by the user?
    - Heavily used configuration - How heavily used is the current hardware platform where the application will be executed?
    - Transaction rate - How frequently are transactions executed daily, weekly, monthly, etc.?
    - On-Line data entry - What percentage of the information is entered On-Line?
    - End-user efficiency - Was the application designed for end-user efficiency?
    - On-Line update - How many ILF's are updated by On-Line transaction?
    - Complex processing - Does the application have extensive logical or mathematical processing?
    - Reusability - Was the application developed to meet one or many user's needs?
    - Installation ease - How difficult is conversion and installation?
    - Operational ease - How effective and/or automated are start-up, back-up, and recovery procedures?
    - Multiple sites - Was the application specifically designed, developed, and supported to be installed at multiple sites for multiple organizations?
    - Facilitate change - Was the application specifically designed, developed, and supported to facilitate change?
    - Required reliability
    - Quantity of data to be stored
    - Product complexity
    - Memory constraints
    - Volatility of the virtual machine environment

  - Required turnabout time (hardware)
  - Analyst capability
  - Software engineering capability
  - Applications experience
  - Virtual machine experience
  - Programming language experience
  - Use of software tools
  - Application of software engineering methods
  - Required development schedule
- Risks
  - Percentage of the contingency fund in the total budget (i.e., importance of known unknown risks)
  - Percentage of the management risk fund in the total budget (i.e., perceived unknown unknown risks)
- Diversity - mostly functional aspects
  - Diversity of staff (experience, social span …).
  - Geographic location of the stakeholders (and their mutual disaffection)
  - Geographic distribution of the project team (collaborating frequently)
  - Geographic distribution of external stakeholders (customers, management, investors, sponsor, which are involved at specific points in the project)
  - Variety of resources to be manipulated
  - Variety of the interests of the stakeholders
  - Variety of information systems to be combined (number of application types)
  - Variety of skills needed
  - Variety of interdependencies
  - Variety of the product components
  - Variety of the technologies used during the project
  - Variety of financial resources
  - Variety of hierarchical levels within the organization
  - Variety of project management methods and tools applied
  - Variety of the resources to be manipulated: tools, methods, technologies
  - Variety of activities in the project plan
  - Variety of possible alternative solutions
  - Variety of external interfaces

    - Competing objectives
    - Uncertainty and stability of the objectives and requirements
    - Stability of requirements
- Interdependencies and interrelations
    - Availability of people, material, and of any resources due to sharing
    - Availability of people, material, and of any resources due to scarcity of supply on the market or in the organization
    - Combined transportation (combined transportation of project inputs and outputs)
    - Dependencies between schedules
    - Relations with permanent organizations
    - Level of interrelations between phases
    - Dependencies with the environment
    - Dynamic and evolving team structure
    - Interconnectivity and feedback loops in the task and project networks
    - Interdependence between actors
    - Interdependence between sites, departments, and companies
    - Interdependence of information systems
    - Interdependence of objectives
    - Specifications interdependence
    - Interdependence between the components of the product
    - Resource and raw material interdependencies
    - Stakeholders interrelations
    - Processes interdependence
    - Number of interfaces in the project organization
    - Team cooperation and communication
    - Number of decisions to be made - uncertainty in the project methods
    - Uncertainty of the project plan - level of detail and expected stability
    - Uncertainty and stability of the methods (clear project management methodology, clear software development methodology, risk management, communication, etc.)
- Context-dependences
    - [Impact of] Local laws and regulations (both technical and organizational)

- [Impact of] New laws and regulations (both technical and organizational)
- Unknown and/or unstable legal and regulatory environment
- Demand for creativity/innovation (both technical and organizational) (The methods were used before? New methods are required?)
- Significance on the public agenda of the organization (visibility, strategic importance, critical project for internal political reasons, visibility on the stock market, etc.)
- Variety of the interests of the stakeholders
- Cultural configuration and variety
- Environment organizational complexity (networked environment)
- Environment technological complexity (networked environment)
- Organizational degree of innovation
- Technological degree of innovation (similar work was done before?)
- Institutional configuration
- Competition
- Knowledge in the organization - organizational (business and industry; e.g. new business or new type of customer)
- Knowledge in the organization – technical (technology, infrastructure, external interfaces, development platform, tools...)
- Knowledge (including seniority) in the team – organizational (business and industry; e.g. new business or new type of customer)
- Knowledge (including seniority) in the team - technical (technology, infrastructure, external interfaces, development platform, tools...)
- Level of change imposed by the project on its environment.

Appendix C.
Mitigation Strategies Matrix MSM - with examples

Table 19. Mitigation Strategies Matrix – MSM, including examples, tools and techniques for IT Project Complexity Management

Strategy	Complexity Effect			Examples, typical tools and techniques
	Positive	Appropriate	Negative	
a. Create, enhance	X			Expand the product portfolio to address new customers and new markets. Add product functionality. Integrate or connect distinct systems. Encourage creativity and innovation by building cross-disciplinary teams, adding communication channels, open-space environments, loose-distributed teams, networked teams and self-organizing teams. Merge companies/units for economies of scale and synergies. Deploying non-deterministic algorithms or methods, with results that cannot be fully explained, such as metaheuristics, genetic/evolutionary algorithms, genetic programming, as used in artificial intelligence applications, machine learning. Deploying a management framework or a project management tool. Distribute a project's costs across many stakeholders, financers, users. Adding stakeholders to a project/product increases the number of potential users and customers.

Strategy	Positive	Appropriate	Negative	Examples, typical tools and techniques
b. Use (exploit)	X			Allow a product to be used differently than initially designed and intended, and change its market accordingly – typical examples are the current widespread use of SMS, Viagra, and Coca-Cola. This is a typical positive external complexity. Exploit a product that goes viral unexpectedly (Giles, 2018).
c. Accept / ignore	X	X	X	Manage, monitor, and control.
d. Simplify /reduce			X	Decomposition, X-BS: WBS, OBS, PBS, CBS, PBS, RBS, ResBS. Modularization, reuse, using COTS, standardization. Deploy rapid or simple software development methodologies such as prototyping or RAD (Rapid Application Development). MVP – the Minimum Viable Product principle, Scrum Agile. MDD – Model-driven design & development. Object-Oriented Analysis and Design (OOAD) (Booch, Object-oriented design, 1982) (Pressman, 2001). Implement the project as a program. Simplify organizational processes, by eliminating and/or merging conflicting internal procedures.

Strategy	Positive	Appropriate	Negative	Examples, typical tools and techniques
e. Avoid/ eliminate			X	Scope management - reduce requirements or functionality. Terminate products or product lines, reduce portfolio. Split an organization into separate independent entities. Close business units.

Appendix D.
Common project risk identification methods

Table 20. Common project risk identification methods. Adapted by (Marle & Vidal, 2016) from (Marle & Gidel, 2014)

Category	Simple methods	Average methods	Complex methods
Direct risk identification	Brainstorming	Systems analysis, constraints analysis	Scenario analysis
	WWWWHW (who what when where how why?)	FMEA (failure mode and effects analysis)	TRIZ
	SWOT analysis (strengths, weaknesses, opportunities and threats)	Stakeholder analysis	
Direct/indirect risk identification	Ishikawa diagram (combined with 5M)	Expert opinion, questionnaires, Delphi technique	Hazard and operability studies (HAZOP)
	"5 why," root-cause analysis	Cause tree, event tree analysis, fault tree analysis	Influence diagrams
	Balanced scorecard		
Indirect risk identification	Pareto analysis	Affinity diagram (KJ)	Data sampling, design of experiments
	Checklists, experience feedback, risk breakdown structure		
	"Non-identical twins" method	Peer review	Benchmarking
	Matrix diagram, diagraming techniques	Correlations method	Data analysis, variance analysis

Appendix E. Validation details: questionnaire template, and answers to the closed questions

Table 21 and Table 22 present the questionnaire used during the interviews of research sub-project P4.

The answers to section B – project descriptions were not aggregated; their aggregation would offer little value or would not be valid, because of the limited number of data points, and because of their descriptive nature.

Table 21. Validation questionnaire: introduction and project case overview

#	Section and question in the questionnaire
A	**Introduction**
	Basis for discussion: slides describing the model and framework, including a definition of complex projects, and detailed description of the tools proposed. Document version.
B	**Case overview**
	Case-study name
	Interviewee name
B.1	Interviewee description/experience
B.2	Interviewee role/function in relation to the project
B.3	Duration / period
B.4	Domain, industry
B.5	Type of beneficiary organization (e.g. customer or user)
B.6	size
B.7	Type of implementing organization (e.g. supplier)
B.8	size
B.9	Description, e.g. problem, needs, business objectives, solution
B.10	Technologies
B.11	Methodologies
B.12	Management tools/frameworks
B.13	Project team size
B.14	Budget

B.15	No of stakeholders
B.16	Number of stakeholder organizations (subcontractors, customers, partners, investors, users…)
B.17	Variety of stakeholders and stakeholder interests (1-5)
B.18	Variety of interdependencies 1-5
B.19	Number of locations
B.20	Variety of locations (1-5)
B.21	No. of users
B.22	No. of business areas, function-points
B.23	Variety of business areas, 1-5
B.24	Competing objectives 1-5
B.25	Uncertainty and stability of the objectives and requirements 1-5
B.26	Knowledge in the organization - organizational (business and industry; e.g. new business or new type of customer) 1-5
B.27	Knowledge in the organization - technical (technology, infrastructure, external interfaces, development platform, tools...) 1-5
B.28	What information should be kept confidential ?

Table 22 presents the quantitative results of the validation questions. The Likert scale used is 1-5, where 1 means strongly disagree/very low, 3 means neutral/normal, and 5 means strongly agree/very high. Some of the questions are y/n, meaning yes/no.

Some questions are open; the corresponding qualitative results are presented in Chapter VII - Validation of the tools with experts.

Table 22. Validation questionnaire and results

#	Section and question in the questionnaire	Average score (1-5, with 5 highest)
C	**Analysis of how complexity was managed in practice in the case-study**	
C.1	How familiar were you with the concept of “complex projects” before this discussion	3.7
C.2	How much did you use the concept of “complex project” in practice, separately from other concepts e.g. risk management, vulnerability, or resilience	3.43. Very dispersed answers

C.3	Did you use formal tools to measure the complexity of projects in your portfolio	43% yes
C.4	Did you use a formal methodology to manage complex projects	43% yes
C.5	If yes: did this tool help manage positive complexity	66% yes
D	**Hypothetical "what-if" questions regarding the potential value of the proposed tools and concepts, as if they would have been deployed in the actual project**	
D.1	How long should the assessment/evaluation of project complexity take	4-8 hours, but 3 outliers: 0.5 hours, 2 weeks
D.2	How useful it is to measure project complexity	4.6
D.3	How much do you agree with the concept of "complexity of complexities"	4.3
D.4	How useful it would have been to deploy similar tools to manage project complexity	4.6
D.5	Should we manage positive complexity	4.6
D.6	Suggestions to improve the tools (qualitative question)	n/a
D.7	Suggestions for additional tools (qualitative question)	n/a
E	**Validation of the final versions of the tools – phase P6**	
E.1	How useful is the Complexity Effect Scale – CES tool (Positive, Appropriate, Negative)	4.4
E.2	How useful is the Complexity Source/Effect Segmentation Matrix - COSM tool, for identification, analysis, understanding; and for planning, management	4.1
E.3	Examples of Positive and Appropriate Complexity in the actual IT project case (qualitative question)	n/a
E.4	Other comments (qualitative question)	n/a

Appendix F. Evaluation of the tools – detailed results

F.1. Summary of the project case studies

Table 23 describes the execution of the case studies, in terms of number of participants, number of interviews, distance between interviews – per each project included in the research. The discussions with top managers covered all projects simultaneously, being therefore counted separately.

Table 23. Summary of the project cases used in the evaluation

	Prj1	**Prj2**	**Prj3**	**Prj4**	**Prj5**	**Top mgmt.**	**TOTAL**
No. of participants (data-points)	4	2	3	1	1	7	18
No. of interviews	5	3	5	1	2	7	23
Longitudinal analysis – number of follow-up interviews with the same person	1	1	2	0	1	0	5
Distance between first and last interview (months)	4.0	4.3	3.6	n/a	2.0	3.0	4.3
Project phase at the moment of the case-study	Early	Early	Months 6-10	Early	Mid-project		
No. of stakeholder organizations	9	5	48	4	2		2-48
Project size (man-days)	500-1000	500-1000	2500-5000	500-1000	15000		500-15000
Project duration	0.5-3 years	0.5-3 years	4 years	1-2 years	4 years		0.5-4 years

Table 24. Initial, subjective perception of the project complexity for the evaluation project cases

	Prj1	Prj2	Prj3	Prj4	Prj5	Average
How complex is the project? Subjective opinion, from 1 = least complex, to 4 = most complex project of the organization	2.6	1.0	2.3	4.0	4.0	2.8
Do you plan to manage complexity? From 1 = not at all, to 4 = yes, mandatory, specifically	2.6	2.0	3.3	n/a	2.0	2.5

Each tool uses a different scale: CIFTER uses a scale of 1 to 4, Hass a scale of 1 to 3, and Morcov an absolute numeric scale. In order to allow for a graphical comparison between the results, all scores were normalized to a scale of 0-100%.

Table 25. Number of measurements performed with each measurement tool

	Prj1	Prj2	Prj3	Prj4	Prj5	Total
CIFTER tool	2	2	3	1	1	9
Hass tool	3	2	3	1	1	10
Morcov tool	1	1	1	1	1	5
Total	6	5	7	3	3	24

F.2. Detailed results: CIFTER complexity scale measurement tool

Table 26. Detailed results: CIFTER complexity scale – averages per project

#		Scoring				Prj1	Prj2	Prj3	Prj4	Prj5
	No. of data points (respondents)					*2*	*2*	*3*	*1*	*1*
		1	*2*	*3*	*4*					
1	Stability of the overall project context	Very High	High	Moderate	Low	3.0	2.0	2.7	4.0	2.0
2	Number of distinct disciplines, methods, or approaches involved in performing the project	Low	Moderate	High	Very high	1.5	1.0	3.7	4.0	3.0
3	Magnitude of legal, social, or environmental implications from performing the project	Low	Moderate	High	Very high	2.5	2.0	1.0	3.0	4.0
4	Overall expected financial impact (positive or negative) on the project's stakeholders	Low	Moderate	High	Very high	3.5	1.5	3.0	3.0	4.0
5	Strategic importance of the project to the organization or the organizations involved	Very Low	Low	Moderate	High	3.5	1.0	3.0	2.0	4.0
6	Stakeholder cohesion regarding the characteristics of the product of the project	High	Moderate	Low	Very low	2.5	2.5	3.7	4.0	2.0
7	Number and variety of interfaces between the project and other organizational entities	Very Low	Low	Moderate	High	4.0	1.0	3.7	4.0	3.0
	AVERAGE					2.9	1.6	3.0	3.4	3.1
	Average normalized to 100%					64%	19%	65%	81%	71%

F.3. Detailed results: Hass complexity scale measurement tool

The scale used has 3 values, 1, 2, 3; meaning independent /low, moderate, and high complexity.

For criteria related to project size, Hass' scale was adapted to the specific context, as presented in Table 27:

Table 27. Adapted scale for Hass complexity measurement tool

Small project	Medium project	Large project
1-3 FTE	4-5 FTE	> 5 FTE
50k Eur, 180 md	200k Eur	> 200k Eur
1-3 months	4-6 months	> 6 months

Table 28. Detailed results: Hass tool – averages per project

		Prj 1	Prj 2	Prj 3	Prj 4	Prj 5
	No. of data points (respondents)	*3*	*2*	*3*	*1*	*1*
1	Time/cost	2.3	2.0	2.7	2.0	3.0
3	*Team size **	*2.0*	*1.5*	*3.0*	*1.0*	*3.0*
4	Team composition and performance	2.7	2.5	2.3	3.0	3.0
5	*Urgency/flexibility of cost/time/scope **	*2.7*	*2.0*	*1.0*	*1.0*	*2.0*
6	Problem/solution clarity	2.3	1.0	2.7	3.0	2.0
7	*Requirements volatility and risk **	*1.7*	*1.5*	*2.0*	*2.0*	*1.0*
8	Strategic/political sensitivity/importance, multiple stakeholders	3.0	2.0	3.0	2.0	3.0
9	*Level of organizational change **	*1.3*	*1.0*	*1.0*	*2.0*	*3.0*
10	*Level of commercial change **	*1.3*	*1.5*	*2.0*	*2.0*	*1.0*
11	Risk, external constraints and dependencies	3.0	2.0	2.0	3.0	2.0
12	*Level of IT complexity **	*1.3*	*1.0*	*2.0*	*3.0*	*2.0*
	Average	2.2	1.6	2.2	2.2	2.3
		58%	32%	58%	59%	64%

*) These criteria appear in the extended version of the Hass tool, but not in the simplified version.

F.4. Detailed results: Morcov complexity scale measurement tool

Only one measurement was done per project with this tool. The table below presents the final results, using a heat map for better visualization of the main complexity aspects per project.

Table 29. Detailed results: Morcov tool

	Absolute values					Normalized values - to 100%				
	Prj1	**Prj2**	**Prj3**	**Prj4**	**Prj5**	**Prj1**	**Prj2**	**Prj3**	**Prj4**	**Prj5**
Staff quantity (Team size)	10%	10%	14%	10%	50%	20%	20%	28%	20%	100%
Number of stakeholder organizations (subcontractors, customers, partners, investors, users…)	267%	133%	1567%	100%	33%	17%	9%	100%	6%	2%
Largeness of capital investment (budget), including resources	133%	83%	3000%	167%	667%	4%	3%	100%	6%	22%
Number of deliverables	5%	5%	50%	30%	150%	3%	3%	33%	20%	100%
Estimated effort required	47%	20%	167%	48%	1056%	4%	2%	16%	5%	100%
Duration of the project	33%	33%	389%	200%	400%	8%	8%	97%	50%	100%
Number of function points	10%	30%	300%	50%	100%	3%	10%	100%	17%	33%
Number of business areas involved	25%	25%	175%	75%	100%	14%	14%	100%	43%	57%
Reusability - Was the application developed to meet one or many user's needs?	0%	100%	75%	75%	0%	0%	100%	75%	75%	0%

Geographic distribution of the project team (collaborating frequently)	40%	40%	400%	10%	30%	10%	10%	100%	3%	8%
Variety of the interests of the stakeholders	25%	75%	75%	50%	25%	33%	100%	100%	67%	33%
Variety of information systems to be combined (number of application types)	0%	0%	50%	75%	100%	0%	0%	50%	75%	100%
Variety of skills needed	25%	25%	75%	50%	75%	33%	33%	100%	67%	100%
Variety of interdependencies	0%	0%	50%	75%	100%	0%	0%	50%	75%	100%
Competing objectives	0%	0%	50%	50%	75%	0%	0%	67%	67%	100%
Uncertainty and stability of the objectives and requirements	25%	25%	100%	50%	25%	25%	25%	100%	50%	25%
Availability of people, material, and of any resources due to scarcity of supply on the market or in the organization	25%	25%	75%	100%	25%	25%	25%	75%	100%	25%
Specifications interdependence	0%	75%	75%	50%	50%	0%	100%	100%	67%	67%
Interdependence between the components of the product	0%	0%	50%	50%	50%	0%	0%	100%	100%	100%
Uncertainty of the project plan - level of detail and expected stability	0%	25%	50%	100%	50%	0%	25%	50%	100%	50%
Uncertainty and stability of the methods (clear project management methodology, clear software development methodology, risk management, communication, etc.)	25%	25%	50%	100%	25%	25%	25%	50%	100%	25%
Unknown and/or unstable legal and regulatory environment	0%	0%	25%	50%	25%	0%	0%	50%	100%	50%
Cultural configuration and variety	50%	25%	100%	50%	25%	50%	25%	100%	50%	25%

Environment organizational complexity (networked environment)	75%	50%	75%	75%	63%	100%	67%	100%	100%	83%
Environment technological complexity (networked environment)	25%	25%	50%	50%	75%	33%	33%	67%	67%	100%
Knowledge in the organization - organizational (business and industry; e.g. new business or new type of customer)	25%	25%	100%	75%	50%	25%	25%	100%	75%	50%
Knowledge in the organization - technical (technology, infrastructure, external interfaces, development platform, tools...)	50%	50%	75%	50%	50%	67%	67%	100%	67%	67%
Level of change imposed by the project on its environment	0%	25%	25%	100%	100%	0%	25%	25%	100%	100%
AVERAGE SCORE	33%	34%	260%	70%	128%	18%	27%	76%	60%	62%

F.4.1. Description and scoring

In Table 30, the “Max. value” column is the number for which the absolute value is 100%. While this value can be adapted to the organization, to represent the maximum possible value for the whole project portfolio, it is still possible that the value for a particular project to exceed this value. Therefore, the scale is absolute - it accepts numeric scoring without a maximum ceiling; therefore, the absolute value in Table 29 can be higher than 100%.

The S3: T/O column details if the criterion is Technological (T), Organizational (O), or both (OT).

Table 30. Morcov complexity measurement tool – detailed description

	Family	**S3: T/O**	**Measurement unit**	**Max. value**
Staff quantity (Team size)	Size	O	FTE	50
Number of stakeholder organizations (subcontractors, customers, partners, investors, users…)	Size	O	no. of organizations	3
Largeness of capital investment (budget), including resources	Size	O	mil. Eur	0.3
Number of deliverables	Size	OT	units	100
Estimated effort required	Size	OT	man-days	1500
Duration of the project	Size	OT	calendar days	365
Number of function points (FP)	Size	T	FP count	100
Number of business areas involved	Size	T	Likert: 0…4	4
Reusability - Was the application developed to meet one or many user’s needs?	Interdependencies	T	0-4	4

Geographic distribution of the project team (collaborating frequently)	Variety	O	no. of locations	10
Variety of the interests of the stakeholders	Variety	O	0-4	4
Variety of information systems to be combined (number of application types)	Variety	OT	0-4	4
Variety of skills needed	Variety	OT	0-4	4
Variety of interdependencies	Variety	T	0-4	4
Competing objectives	Variety	T	0-4	4
Uncertainty and stability of the objectives and requirements	Variety	OT	0-4	4
Availability of people, material, and of any resources due to scarcity of supply on the market or in the organization	Interdependencies	O	0-4	4
Specifications interdependence	Interdependencies	T	0-4	4
Interdependence between the components of the product	Interdependencies	T	0-4	4
Uncertainty of the project plan - level of detail and expected stability	Interdependencies	T	0-4	4
Uncertainty and stability of the methods (clear project management methodology, clear software development methodology, risk management, communication, etc.)	Interdependencies	T	0-4	4
Unknown and/or unstable legal and regulatory environment	Context-dependences	OT	0-4	4
Cultural configuration and variety	Interdep./context-dep.	T	0-4	4
Environment organizational complexity (networked environment)	Interdep./context-dep.	O	0-4	4

Environment technological complexity (networked environment)	Interdep./context-dep.	T	0-4	4
Knowledge in the organization - organizational (business and industry; e.g. new business or new type of customer)	Interdep./context-dep.	O	0-4	4
Knowledge in the organization - technical (technology, infrastructure, external interfaces, development platform, tools...)	Interdep./context-dep.	O	0-4	4
Level of change imposed by the project on its environment	Interdep./context-dep.	O	0-4	4

Appendix G. Detailed tools assessment – results of the practical evaluation

G.1. Traditional tools used/recommended for managing complexity

The questions were yes/no. Not all questions were answered by all participants. A few reserves answers were recorded as "Partial".

Table 31. Traditional tools assessment: Answers from project managers

	How will complexity be managed, if any (yes/no)	Total number of answers	Yes	No	Partial	Average
1	Stakeholder map	8	6	2	0	75%
2	Risk register	8	7	1	0	88%
3	Communication Plan	8	3	3	2	50%
4	SWOT	8	3	5	0	38%
5	Agile	8	7	1	0	88%

Table 32. Traditional tools assessment: Answers from top management

	How will complexity be managed, if any (yes/no)	Total number of answers	Yes	No	Partial	Average
1	Stakeholder map	5	5	0	0	100%
2	Risk register	5	5	0	0	100%
3	Communication Plan	4	2	0	2	75%
4	SWOT	5	1	2	2	40%
5	Agile	3	3	0	0	100%

Table 33. Traditional tools assessment: Spontaneous answers to the open question - project managers: what other tools are useful

	No. of times mentioned
Project management methodology	2
IT governance, ITIL, architecture document, security plan	1
Prioritization	1
WBS, decomposition	3
Delegation	2
Dependency modeling	1
Requirements traceability matrix	1
Project management tools, e.g. Jira	3
Knowledge management, collaboration and communication tools, e.g. Confluence, Slack	3
Quality control tools - Sonar	1
Corporate resources - support services	1

Table 34. Traditional tools assessment: Spontaneous answers to the open question – top management: what other tools are useful

	No. of times mentioned
Project management, planning, and scope management tools e.g. Jira	2
WBS	1
Time tracking, e.g. Intervals	1

G.2. Specific complexity measurement and management tools

G.2.1. Analysis of the opinion of project managers, based on their application of the tools to their own projects

The question was: ”how useful is the following tool for your project? (Benefits > Effort)”.

The Likert scale used is from 1: not useful, to 4: very useful.

An open question was asked for each tool: How did this help? When, why, why not?

Table 35. Specific tools assessment: Answers from project managers

	Tools assessment	Prj1	Prj2	Prj3	Prj4	Prj5
a	Measuring/red-flagging complexity (see section 1 of the questionnaire)	3.0	1.0	3.3	n/a	3.0
b	Morcov tool (see section 1.1)	3.5	n/a	n/a	n/a	3.0
c	CIFTER tool (section 1.2)	2.0	1.0	2.4	n/a	3.0
d	Hass tool (1.3)	2.8	1.0	3.0	n/a	2.0
e	SWOT (2.1)	3.8	4.0	2.3	n/a	2.0
f	Positive & negative effects of complexity (CES)	3.4	3.0	2.5	n/a	3.0
g	COSM (2.2)	3.8	3.0	n/a	n/a	3.0
h	Complexity Register (2.3)	3.6	1.0	3.0	n/a	3.0
i	Mitigation Strategies MSM (2.3.a)	3.6	1.0	3.7	n/a	3.0

Project Prj4 did not have sufficient data points to be included in the longitudinal analysis.

Participants to Project Prj2 gave low scores to most project complexity management tools (with the notable exception of tools related to Positive Complexity), because the project was evaluated to not be an actually complex project; so the deployment of specific complexity management tools did not bring significant value in its specific case.

Table 36. Specific tools assessment: Evolution in time of the assessment of the tools by project managers

	Number of answers	Average - Likert	Variation	Std. deviation	Longitudinal		
					Average answer during 1st interview - at the start of the case-study	Average answer during 2nd interview with the same person	Modification of the answers in time
Measuring/red-flagging complexity	12	2.8	0.70	0.83	3.4	3.0	-0.4
Morcov tool	4	2.9	0.40	0.63	3.0	3.0	0.0
CIFTER tool	10	2.3	0.51	0.72	2.5	2.5	0.0
Haas tool	11	2.4	1.34	1.16	2.8	3.0	0.3
SWOT	12	2.9	1.54	1.24	2.8	2.5	-0.3
Positive & negative effects of complexity (CES)	12	2.7	0.66	0.81	2.8	3.0	0.3
COSM	6	2.9	1.04	1.02	3.0	4.0	1.0
Complexity Register	11	2.8	1.07	1.03	2.8	3.7	0.9
Mitigation Strategies Matrix MSM	11	3.0	1.22	1.11	3.3	4.0	0.8

G.2.2. Analysis of the opinions of top- and portfolio-management

The question repeated for each tool was: *how useful is the following tool for your organization? Are the benefits higher than the effort?*

The answers use Likert scale without midpoint, with 1 meaning not useful, and 4 very useful.

Open questions were asked for each question: *How did this help? Why? Why not? When?*

With top- and portfolio-management, a single individual discussion was performed, covering all projects in the same discussion.

Table 37. Specific tools assessment: Answers of top- and portfolio-management

	Number of answers	**Average - Likert**	**Variation**	**Std. deviation**
Measuring/red-flagging complexity	6	3.5	0.30	0.55
Morcov tool	2	2.3	3.13	1.77
CIFTER tool	4	1.9	1.06	1.03
Hass tool	4	3.1	0.40	0.63
SWOT	6	2.1	1.04	1.02
Positive & negative effects of complexity (CES)	5	2.3	1.20	1.10
COSM	2	1.5	0.50	0.71
Complexity Register	5	2.4	2.30	1.52
Mitigation Strategies Matrix MSM	2	2.5	4.50	2.12

G.2.3. Analysis of the opinions of top management only

Table 38. Specific tools assessment: Answers of top management

	Number of answers	Average - Likert	Variation	Std. deviation
Measuring/red-flagging complexity	3	3.7	0.33	0.58
Morcov tool	2	2.3	3.13	1.77
CIFTER tool	2	1.8	1.13	1.06
Hass tool	2	2.8	0.13	0.35
SWOT	3	2.5	1.75	1.32
Positive & negative effects of complexity (CES)	3	1.8	0.58	0.76
COSM	2	1.5	0.50	0.71
Complexity Register	3	1.3	0.33	0.58

G.2.4. Analysis of the aggregated opinions

Table 39. Specific tools assessment: Aggregated results

	Number of answers	Average - Likert	Variation	Std. deviation
	18	3.1	0.64	0.80
Morcov tool	6	2.7	0.97	0.98
CIFTER tool	14	2.1	0.63	0.79
Haas tool	15	2.6	1.15	1.07
SWOT	18	2.6	1.46	1.21
Positive & negative effects of complexity (CES)	17	2.6	0.79	0.89
COSM	8	2.6	1.25	1.12
Complexity Register	16	2.7	1.36	1.17
Mitigation Strategies Matrix MSM	13	3.0	1.44	1.20

Curriculum vitae

Stefan Morcov

IT expert & architect
Project and product manager
Business development & entrepreneur
http://stefanmorcov.com

- *Computer Science Engineer, MBA, PMP.*
- *20 years' experience in IT, management, strategy, business development, marketing, sales, presales, project management.*
- *Setup and management of complex projects and several new operations on 3 continents, management of hundreds of IT projects in education, e-learning, R&D, capacity building, e-government, consumer, financial, web portals, online communities & collaboration, mobile apps, AI, document & workflow management, GIS, semantics, cloud, DevOps.*
- *Passionate about technology, AI, complexity, transformation, innovation.*

Experience

Managing Director @ Tremend Benelux SA (2018-...)

- Setup, sales, management of a new operation on a new market.
- Projects with EU institutions and the private sector in Belgium, Denmark, Italy, Luxembourg, Spain.

Managing Director @ SIVECO Belgium Sprl (2015-2018)

- Setup, staffing and management of a new company on a new market.
- Signing and managing a portfolio of 28 Framework Contracts, worth 34 mil. Eur.
- SIVECO Belgium Sprl became a major supplier of the European Commission and other EU institutions in Brussels, Luxembourg and Strasbourg.

EU Business Director @ SIVECO Romania SA (2008-2018)

- International business development, contract and project management.
- Established new IT operations and managed large projects in Cyprus, Benelux, Morocco, Middle East etc.

Line of Business Senior Director @ SIVECO Romania (2007-2008)

- Managing 4 business units: eLearning, document management, custom software development, EU projects; with a team of 140 permanent and 200 short-term consultants.

Line of Business Manager – eLearning division @ SIVECO Romania (2004-2006)

- Managed a new business unit, 52-strong.
- Product management, marketing, business development, setup new teams, processes and tools for software development, support, configuration, issue tracking, QAC, HR, training, career development, marketing, PR, sales.
- Supervising more than 100 projects. Acting as Senior Project Manager for large complex IT projects in education, in Romania, Moldova, Cyprus, UAE, Lebanon, Azerbaijan.

Project manager, Technical Leader, Senior Architect, Software Engineer, QA Lead @ SIVECO Romania (2000-2004)

- Software development, architecture, design, deployment; on various tools and technologies; of IT systems for recruitment, job search, HR, skill management, video-on-demand, web, eLearning.
- Project Director SEI – the national eLearning/education project, 300 mil. Eur in 6 phases (2001-2009), with development and rollout for 190,000 computers in 15,000 schools; training of 150,000 teachers; millions of end-users.

IT consultant (1997-2000)

- Software development, support, system administration: the National Institute of Statistics; Soros Foundation for an Open Society; K.H. Dietrich International Spedition; ARDOR Foundation for Oratory and Debate; School Sports Club 6.

Education

- PhD in IT project complexity management – KU Leuven (2021).
- Executive MBA – Tiffin University Ohio, US (2005-2007).
- Software Engineering – Open University UK (May-Oct 2002).
- Project Management – CODECS & Open University (May-Nov 2001).
- Computer Science Engineer – Politehnica University Bucharest (1995-2000).

Training, certifications, events

- Trainings and certifications in project management (HP Global Method, PMI), EU funds, product management, Solution Selling, requirements engineering, programming in .net, R; statistics, six-sigma, negotiation, communication.
- PMP certification.
- Participant and speaker at: UN World Summit for the Information Society Geneva and Tunis; IST-Africa Johannesburg, Online Educa Berlin, MS Innovation Day - Brussels, World Education Market - Lisbon, Oracle OpenWorld - San Francisco, Microsoft Education Partner Conference – Redmond, Intel Partner events in UAE, Oracle Technology Day, Romanian Academy symposium, the International Conference on Virtual Learning, etc.
- Lectures, conferences and seminars on project management, software engineering, analysis and decision tools, eLearning, project complexity, public-sector infrastructure projects; innovation.

Awards

- Gold Winner at the EU eLearning Awards 2010 for the SEI project.
- European IT Excellence Award for the SEI project (London 2008).
- Finalist for the IPMA International Project Excellence Awards (Warsaw 2007).
- National Project Management Excellence Award from IPMA and PM Romania (2006).
- ICT Prize nomination for AeL eContent (2006, European Commission).
- World Summit Award for AeL eContent (WSIS, Tunis 2005, UN) – and the nomination of "best eContent in the world".
- IST Prize nomination for AeL eLearning platform (2005, European Commission).
- Nomination and Honorable Mention for eEurope Awards for e-Government for the AeL eLearning platform (Manchester 2005, European Commission).
- "Best Practice" label for the ADLIC project (Brussels 2001, European Commission).

Main areas of expertise

- Management, strategy, operations, finance, HR, quality, legal.
- Business development, sales, presales, bid, marketing, PR, product.
- Contract, customer, program and project management.
- International and multicultural experience, in 36 countries in Europe, Asia, America, Africa – with a strong focus on EU affairs.
- All aspects of software engineering, from analysis, design and development, to architecture, deployment, and support of large-scale distributed systems.
- Hands-on technical experience with a wide range of IT architectures, platforms, tools and methodologies: PC, PowerPC, RISC, gcloud, Azure; on MS Windows, MacOS, Linux, AIX; in Java/J2EE, C++, ASM, Pascal, SQL, DHTML, js, VBA/VBS, php, Python, R; on Oracle DB, MS Access, FoxPro, mySql, PostgreSql; with various app/web servers: Oracle, Websphere, Apache, Orion, IIS; with OOAD, RAD, FDD, Waterfall, RUP, Agile.

Languages

- Romanian, English, French, Italian, German.

Other interests

- History, SF, etymology, philosophy, psychology, motorcycles, sailing, guitar.

List of publications

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