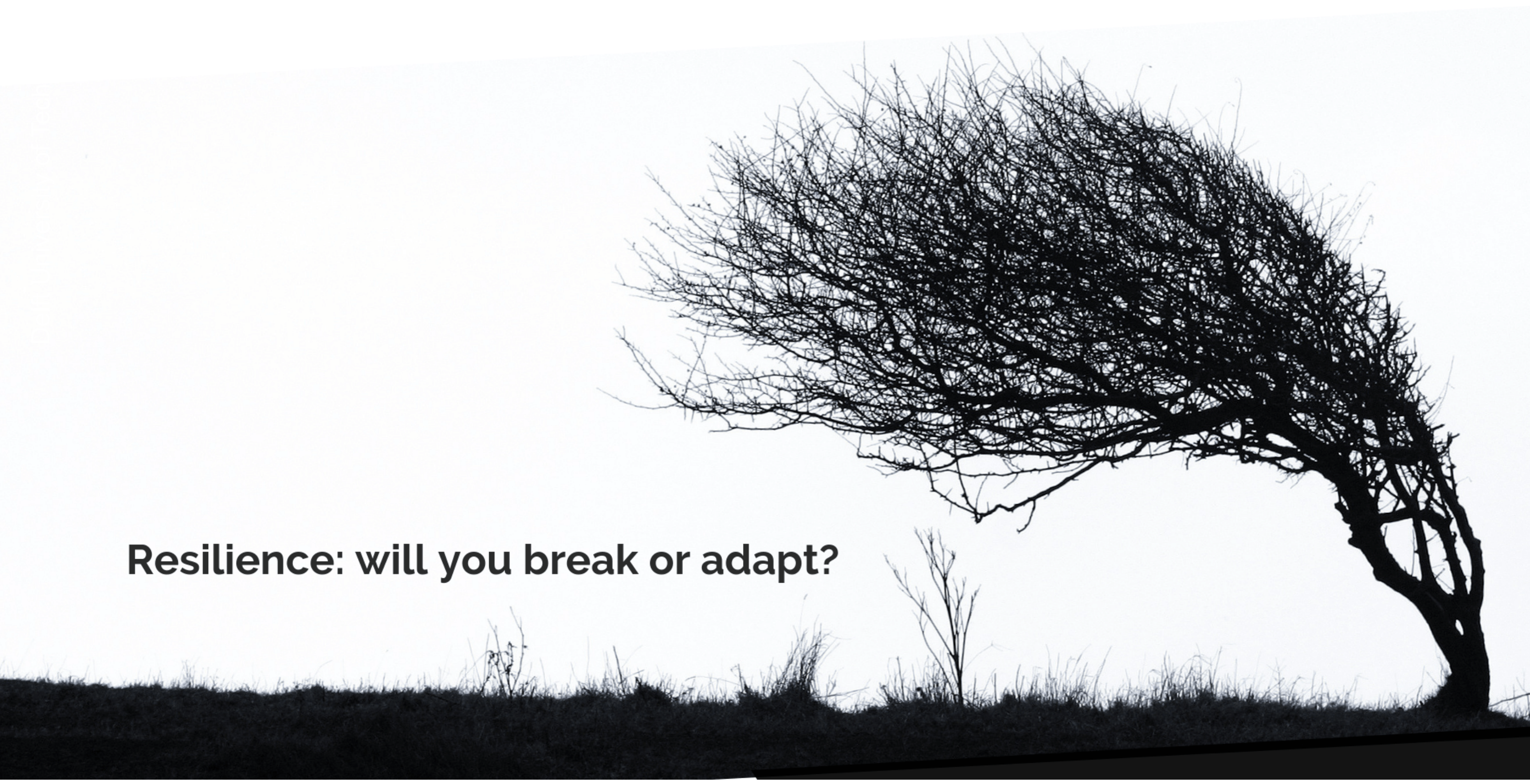
Towards resilient performance for construction projects

The PRL resilience framework

CME-5200

Leen Messi



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by

Leen Messi

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For everything there is a season, and a time for every matter under heaven: 2 a time to be born, and a time to die; a time to plant, and a time to pluck up what is planted. 10 In the beginning, Lord, you laid the foundations of the earth, and the heavens are the work of your hands. 13 For now, we see only a reflection as in a mirror; then we shall see face to face. Now I know in part; then I shall know fully, even as I am fully known. (Ecclesiastes 3: 1,2; Hebrews 1:10; 1 Corinthians 13: 12).

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Leen Messi
Delft, April 2023

Executive Summary

In the current fast-changing world, events like wars, energy scarcity, sea levels rise, natural disasters, earthquakes, and pandemics challenge not only our well-being but also our communities' ability to keep functioning. The pressure on the construction sector is increasing to perform on time, within budget, and needed qualities, where even a small-scale delay would cost someone to be homeless for another day or even lose his life. The construction sector, however, still owns a bad reputation in terms of performing on time and within budget. The inherent characteristics of large construction projects of complexity and uncertainty play an essential role in such deviations. While current project management and risk management approaches are not capable of fully predicting, preventing, and enabling the successful conquering of disruptions, the resilience-based project management approach seems like a promising solution. However, the resilience concept is still new in the construction industry and few literature works tackled this area with low consensus. Whereas in practice, the concept is still not explicitly used. It is not clear yet what constitutes a resilient construction project and what elements contribute towards resilience. Therefore, this research aims to uncover this area, namely, elements contributing towards building resilience. To that purpose the following research question was formulated:

" What elements contribute towards construction projects' resilience and how these can be combined in a framework to build (more) resilience in large construction projects?"

The following methodology was adopted to answer the research question: First, a literature study was performed to identify the Why, the What, and the How of resilience. To understand what is resilience in practice and what current practices contribute to it, interviews were conducted with 18 experts in the field of construction projects, namely infrastructure projects. Next, the needs and criteria of a construction project resilience framework were defined. In response to these, a framework, i.e., the PRL resilience framework of construction projects, was designed to introduce the main resilience dimensions and the empirical and theoretical elements found contributing towards it. The framework was tested and evaluated by applying three study cases. Also, the framework was sent to the 18 participating practitioners to survey their evaluation against the defined criteria.

Resilience has many definitions in literature from various perspectives: system resilience, organizational resilience, project resilience, and construction project resilience. A construction project resilience can be understood as the ability of a construction project to overcome disruptive events, as fast as possible, without bypassing the current most valuable project objectives thresholds, enabled by proactiveness, reactive capacities, and learning. Resilience then has three main dimensions; proactiveness (awareness, anticipation, alertness), adaptive capacities (Absorptive, adaptive, recovery), and learning. In practice, 15 project management areas were found mainly contributing to resilience: Client management, stakeholder management, monitoring and control, partners, mother organization, risk management, project manager, project team, schedule management, change management, contract management, project management approach, information management, tender management, and design management. The tender and the design phases were found essential phases to building resilience. Each resilience element is found to belong to one project management area, and to one or more resilience dimensions, depending on its contribution.

The framework consists of 87 elements. Elements from the three dimensions were mostly related to soft, organizational, and strategy aspects. For example collaboration with clients, teams, and stakeholders, communication, creativity, partnerships, creativity, and project safe open culture. While technical aspects were also found needed like buffers, crashing resources ability, flexible technologies, flexible contracts, and learning processes.

In practice, resilience is still a new concept and not explicitly recognized, planned, or applied in practice. Several resilience barriers are found: (1) Initial project choice which is built upon contractor contrasting interests (Business continuity/ tender for a project to stay in the business VS Project success/ tender for the project that fits contractor abilities) stimulated by the construction market conditions and

competitors, (2) client (tender settings, collaboration), (3) Contractor Organization (Size and scope diversity), (4) Personnel (resilience awareness, motivation and time), (5)Management (culture, mentality), (6) Learning processes. Amongst all, the importance of finding a solution for the learning barriers was stressed by practitioners.

The PRL framework could be used to (1)Aid resilience design and embed resilience elements into construction projects and their management plans, most importantly in the tender phase. (2) Aid evaluating and enhancing construction projects from a resilience perspective, through running the PRL resilience evaluation periodically (suggested quarterly). (3) Aid evaluating and learning from projects in a systematic way. The framework can be used by the tender team in the tender phase, the project manager, and the team (key personnel meetings) in their progress meetings, project control to help better understand project performance, and the internal audits for project auditing.

The framework was tested and used in three study cases (finished infrastructure projects) to assess its resilience prints and compare it to the project's financial and schedule performance. Results suggest that a larger resilience print hints at better project performance. Also projects strengths and areas of improvement were defined. The framework was evaluated by users to be acceptable to satisfactory.

Future research work related to the resilience of construction projects is suggested as follows: (1) further research towards identifying the weights and importance of each resilience element towards the overall resilience function and also towards the resilience dimensions, (2) link project complexity elements (suggested using TOE framework by Bosch-Rekveldt et al. (2011)), to be used to design and tailor resilience elements from the PRL framework based on project specific complexity scan, (3) further research is suggested towards applying the PRL framework to different types of projects (residential, industrial,..., etc.) and checking its variations and applicability, (4) One of the repetitively mentioned barriers facing resilience in construction projects, specifically in learning, is the low motivation of personnel to read and document evaluations, or lessons learned. It is suggested to study the effect of automation of these learning into more user-friendly and fast performing, (5) Investigate the concept of resilience on portfolio level and program level, and search the role of portfolio management in creating project resilience, (6) Investigate the relation between project resilience practices and project management best practices and how exactly these can be combined into practice.

Contents

List of Figures

List of Tables

1
Introduction

This chapter introduces research background information in Section 1.1, followed by the main research problem in Section 1.2. Research objectives and research questions are specified in Sections 1.3 and Section 1.4 respectively. This chapter concludes by drawing on the practical and theoretical relevance of this research in Section 1.5.

1.1. Background

Construction projects play an essential role in countries' well-being and growth (Bielenberg et al., 2020; Bosher et al., 2007). It is fundamental to have functional physical structures that enable our daily life activities such as residential buildings, health care facilities, road networks, energy and water networks, and infrastructures. These projects emerge in response to the continuously changing societal, economical, political, and environmental needs.

In recent years, the pressure on the construction sector is growing due to several factors. The growing population, energy sources scarcities, fast pace technological developments, forced displacements resulted from the war in several countries, and even extreme but possible crucial events like the recent global Corona pandemic disease. All of these changing elements create continuous requisites to adjust or create more construction facilities in various aspects (residential, commercial, industrial, and infrastructure). Take for example the recent event of the Corona pandemic that started in 2019. What happened is that healthcare facilities did not have enough capacity to absorb the related raised needs. Hence, more hospitals and health care centers had to be adjusted or newly built, as fast as possible, all over the globe(Alsharef et al., 2021). The construction industry was then faced with the unexpected challenge to build within budget, and on time, where even a few hours' delays may cost someone his life.

The construction industry has an unsatisfactory reputation in terms of delivering projects on budget and within time limits. Nine out of ten projects normally experience cost overruns, especially projects of high complexity(Aljohani et al., 2017). A key example of complex projects is infrastructure projects. Characterized by their high complexity and uncertainty, these projects often get delayed or run over their intended budget (Rao et al., 2016). In the Netherlands, for instance, the average cost overrun for infrastructure projects is 10.6% for rail and 18.6% for roads (Cantarelli et al., 2012).

Such overruns and delays affect people's daily life aspects. For example, having higher travelling and commuting time and cost (Hussain et al., 2017), or even not being able to reach emergency health care facilities on time due to roads occupation with delayed construction works. While at the level of a whole country, construction projects with delays and overruns harm the country's economy and growth and make less room to start new needed projects (Bosher et al., 2007; Salunkhe & Patil, 2014). Consequently, the construction industry is under high pressure to improve its project performance (Barlow, 2000).

Improving construction projects' performance is not a straightforward process. It is essential first to understand the project's main characteristics of complexity, uncertainty and its exposure to various adversity sources (Luo et al., 2017). Perturbation sources from natural hazards to man-made adversities can be to a large extent unexpected and differ throughout a project's lifetime(Manyena et al., 2019). To that matter, project risk management endeavours to predict and prevent disruptive events, and it does succeed in some cases. However, there will always be uncertainty in terms of foreseeing the event's exact timing, intensity, the affected object(s), and duration of the disturbance (Crosby, 2012). Uncertainty is almost inevitable in a construction project, and coping with it demands a different management approach than the traditional predict and control-oriented mechanisms (Pich et al., 2002).

As we can see, projects low performance harms not only the country's economy and growth but also the daily life of people. As an attempt to uncover how to enhance construction projects' performance, this research investigates the idea of building resilient construction projects that can perform in a resilient manner in face of various adversities. The resilience concept enables a better understanding of construction projects' behavior under perturbations and sets the way forward to enhance its performance. This is called then resilient performance and is associated with the notions of anticipation and adaptability (Jüttner & Maklan, 2011). Resilience, however, is a newly born concept in the fields of project management and the construction industry. There is still no comprehensive view on what is a resilient project and which factors exactly contribute to or hinder construction project resilience (Naderpajouh et al., 2020; J. R. Turner & Müller, 2003; Z. Zhu et al., 2020).

1.2. Research Gaps and Problem Definition

The need for resilience is strongly acknowledged by project management and construction management researchers as a way to prepare projects to face disruptions (Geambasu, 2011; Q. He et al., 2017; Hosseini et al., 2016; Mahmoudi & Javed, 2022; Rahi et al., 2021; B. Wang et al., 2022; Zarghami & Zwikael, 2022; J. Zhu, 2016). However, The question of what constitutes a resilient system and how to build it is still a debatable topic among current researchers (Wied et al., 2020).

The concept of project resilience is still ambiguous, new, and not defined to a large extent (Naderpajouh et al., 2020; Rahi et al., 2019; Thomé et al., 2016; Wied et al., 2020; Wied et al., 2021). " Within the few research that investigated resilience on the level of a whole project, several definitions are general and vague" (J. Zhu, 2016). For example Schroeder and Hatton (2012) defines resilience as:" the capacity to evolve successfully in the face of unexpected threats ". However explanatory questions may arise then, such as: What defines the status of successful? and what does evolve exactly mean in a construction project? Most resilience current definitions are general and open to wide subjective interpretations. **That is the first gap: literature lacks an adequate resilience definition**

Another gap is that very few research tackle resilience on the level of a construction project as a whole. Attempts were more directed to identify the resilience of specific project components rather than a whole construction project. For example: Supply chain resilience (Heckmann et al., 2015), resilience based safety management (Ranasinghe et al., 2020), schedule Resilience (Torabi Yeganeh & Zegordi, 2020), personnel resilience (Z. He et al., 2022). However, as Aristotle said, "The Whole is Greater than the Sum of its Parts". In other words, having resilient parts within a construction project doesn't necessarily imply that the project as a whole can perform in a resilient way. There is a need to integrate resilience factors from different aspects into the project level (J. R. Turner & Müller, 2003). Yet, this concept is still underdeveloped in construction projects in theory and practice (Naderpajouh et al., 2020; N. Turner & Kutsch, 2015).**This represents the second gap: Resilience understanding and recognition at the level of a whole construction project is underdeveloped in theory and practice.**

Furthermore, few studies have introduced practical operational models that specify elements and practices contributing towards construction projects resilience (B. Wang et al., 2022; Wiig & Fahlbruch, 2019). The majority of the models introduce a process to conceptualize or enhance resilience. Eight process-related models were found which don't define resilience practices or elements (Burnard et al., 2018; Cerè et al., 2017; Francis & Bekera, 2014; Madni & Jackson, 2009; Patriarca et al., 2018; Punzo et al., 2020; J. Zhu, 2016; Z. Zhu et al., 2020). These models (except J. Zhu (2016)'s model) don't specifically search into construction projects but rather organization or system resilience in general. Mainly, four models were found that include elements contributing towards resilience, introduced by: Q. He et al. (2017), Hollnagel (2015), Rahi et al. (2019), and the International consortium of organizational resilience © 2023 The ICOR. Only one of them focuses on construction projects (Q. He et al., 2017). Q. He et al. (2017), Hollnagel (2015), Rahi et al. (2019), and J. Zhu (2016)expressed a need for further research to validate and expand resilience dimensions and elements to create effective knowledge to be used by project teams. For a construction project team -to put the resilience concept in use-, it is crucial to have a clear understanding of what is resilience, which construction projects' elements contribute towards resilience, and which practices would help build and enhance construction projects' resilience (Wiig & Fahlbruch, 2019). "Understanding of the determinants of resilience in project systems is essential in improving project performance under uncertainty" (J. Zhu, 2016, P. 3). **That represents the Third gap: Operationalising resilience in construction projects is underdeveloped.**

In alignment with these gaps, the research problem is then stated as follows:

In construction projects, especially the large projects, literature proved that complexity and uncertainty are inherent characteristics. As a result, there will always be unpredicted aspects or events that projects will face through their life cycle, and where risk management practices have limited effectiveness to anticipate or prevent. Literature suggests that there is a need for a new management paradigm to overcome this problem, namely construction project resilience. In the construction management field, most resilience-related studies focus on a specific component of the project (e.g., supply chain, schedule, personnel). Few attempts were made to define the elements that build or enhance construction project resilience as a whole. The available few studies do provide valuable insights. Yet, there is no comprehensive overview or a solid framework that captures the diversity of resilience-contributing elements in construction projects and aids operationalize the concept in practice. Project management then would require a resilience framework that combines theory and practice, and enables embedding resilience-contributing elements into the various aspects of a project management plan. Construction projects' resilience should be further investigated in theory and practice to capture elements contributing towards building, and enhancing projects' resilience in face of disruptions

1.3. Research Objectives

The objectives of this research are in response to the gaps identified in the previous section. Essentially it goes in two main directions: Define and Develop. The first objective aims to formulate a better understanding in theory and practice of the resilience concept at the level of a construction project. The second objective is to help construction project management build and enhance resilience in construction projects by uncovering the elements that contribute to resilience, summarizing it, and introducing it in an operational useful way, namely a resilience framework. The ultimate objective achieved by this twofold is to help project management create (more) resilient behavior capabilities in construction projects.

1.4. Research Question and Sub-Questions

The main research question is identified based on the defined research problem and objectives as follows:

" What elements contribute towards construction projects' resilience and how these can be combined in a framework to build (more) resilience in large construction projects?"

The following research questions are developed to answer the main research question:

SQ1: What does construction project resilience mean, based on literature?
This question aims to study and understand the concept of resilience and the reasons for its emergence in the context of a construction project, based on literature. Understanding construction project resilience implies first understanding the general concept of resilience as well as comprehending what are construction project characteristics, then mapping out the construction project resilience concept.

SQ2: What elements contribute towards construction project resilience, based on literature?
This question is answered by reviewing what previous researchers found regarding elements and practices contributing towards building resilience, and what specific components or knowledge areas of a construction project (contract management, schedule management, scope management, risk management,..., etc.) are linked to building resilience.

SQ3: What elements contribute towards large construction project resilience, in practice?
This question mainly aims to define the elements and practices that contribute towards resilience in practice, in the context of a construction project.

SQ4: What are the barriers of building resilience in large construction projects?
This question aims to understand what elements hinder resilience building to be aware of and try to overcome as much as possible.

SQ5: How should these elements be included in one framework to aid building and enhancing resilience in large construction projects?
This question aims to introduce the gathered knowledge from theory and practice, in one clear, effective, and usable framework that aids building and enhancing resilience in construction projects.

1.5. Research Relevance

1.5.1. Theoretical Relevance

In the scientific field, this research is a step forward to fulfilling the previously identified gaps both in the resilience theory and in construction project management.

1. Relevance to resilience theory :
   (a) This paper studies the applicability of the resilience theory at the level of a construction project. It demonstrates how the dimensions and elements of the resilience concept may be kept, changed or adjusted to suit the field of socio-technical systems (construction project). The empirical part of this study enriches the resilience body of knowledge via confirming (or not) the current knowledge as recommended by (Geambasu, 2011; Rahi et al., 2019), and adding any needed dimensions and practices in the field of resilience development.
   (b) This research is a step forward toward a more specific definition of resilience in construction project management. That is accomplished by comparing resilience definitions across fields of science, and then specifically across aspects related to the construction project(project resilience, system resilience, organization resilience, construction project resilience).
   (c) Where most research works focus on conceptualizing resilience and drawing the overall process of resilience (Burnard et al., 2018; Francis & Bekera, 2014; Madni & Jackson, 2009; Patriarca et al., 2018; Punzo et al., 2020; J. Zhu, 2016; Z. Zhu et al., 2020), this research goes a step forward to identify specific elements that contribute,e to build resilience.
   (d) This study supports the claimed link in the literature between resilience and projects' performance (Geambasu, 2011; Sáenz-Royo & Salas-Fumás, 2013), through empirical case studies.
2. Relevance to Project management :
   (a) A step forward into a more structured reference to design project management through the resilience lens.

1.5.2. Practical Relevance

In terms of the practical field, this research will mainly offer four the following benefits:

(a) In practice, organizations tend to have certain aspects of resilience-related practices like setting budget contingency and building up time buffers into schedules. However, these practices differ across projects and are not planned systematically. This research spreads awareness towards the rich variety of elements contributing towards resilience and aids practitioners in embedding resilience elements into their project management plans.

(b) Helps project teams to better understand the reasons behind the performance of their projects. In practice, project performance is mostly presented by figures and graphs that answer the questions of (what happened, and how severe was it?) but not the questions of (why did that happen, and how can we change it?). Project performance changes are mostly linked to the specific events that caused deviations, rather than looking at the underlying project management structures and processes. The PRL resilience framework increases the project management awareness toward these underlying aspects and helps to map out what is going well, and what may need further enhancements.

2

Research Design

This chapter introduces the chosen research design. Section 2.1 defines the research scope, then section 2.2 introduces the methodology chosen for answering the research question. The chapter is concluded with the study outline in section 2.4.

2.1. Research scope

Resilience-related research works illustrate the applicability of the resilience concept across multiple gradual levels of individuals, groups and teams, projects, organizations, industries, and societies (Naderpajouh et al., 2020) as illustrated in figure 2.1. This research focuses on the level of a project, namely a construction project, in relation to two main theories: the resilience theory and the project management theory. The intersection of these two defines then the main conceptual scope of this research demonstrated in Figure 2.1.

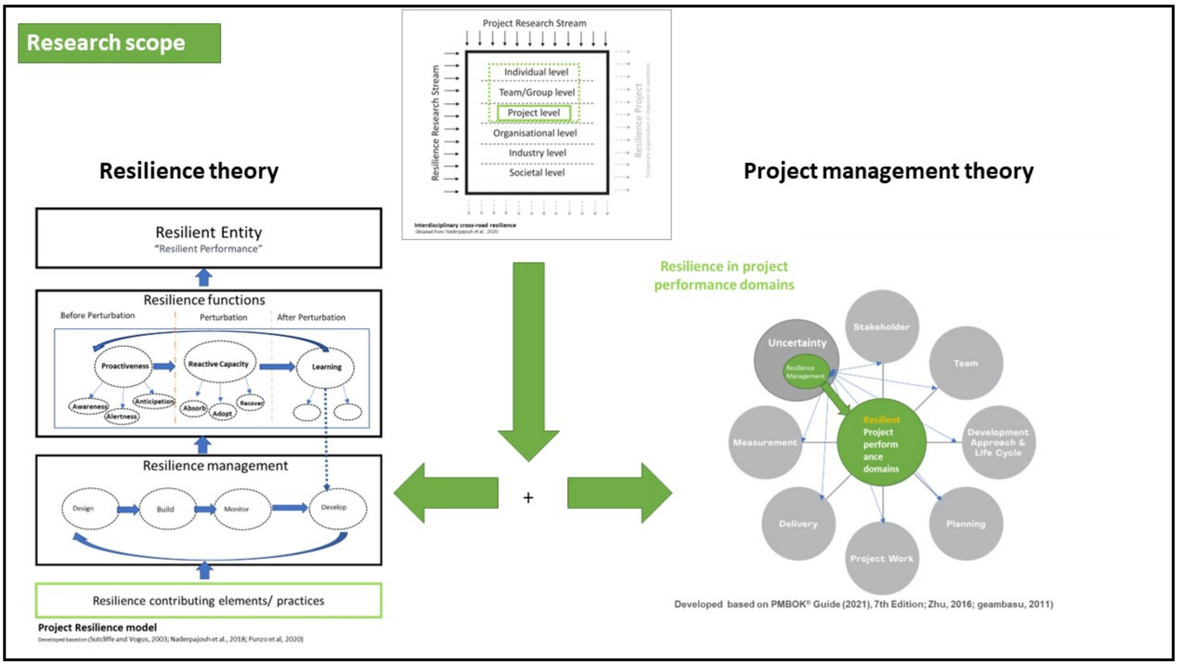


Figure 2.1: Research scope

2.1.1. In the resilience theory

Resilience needs to be designed into the system to enable resilient behaviors (Z. Zhu et al., 2020). To that matter, two main lines can be distinguished in literature: the first is focusing on the process to create resilience(Resilience management process). The management of resilience means the actions needed to define, plan, create, and control the desired resilience level. These actions are suggested in the literature to be as follows: specify the system and its boundaries, analyze vulnerabilities, set the needed level of resilience, chose suitable resilience-oriented practices to be applied, chose a strategy of application, learn and adjust (Francis & Bekera, 2014; Naderpajouh et al., 2020; Wied et al., 2020; J. Zhu, 2016). These could be logically summarized and translated into the following stages of resilience management: resilience designing, building, monitoring and assessing, and adjusting. The second line recognized in resilience research works is related to the elements contributing towards resilience. These are project elements and practices that enable the resilience functions of awareness, anticipation, absorption, adaptation, recovery, learning,..., etc. This research doesn't focus on the resilience management process but rather on the elements contributing to building and enhancing resilience.

2.1.2. In the project management theory

The project management institute (PMI), considers resilience as one of 12 project management principles in the PMBOK 7th edition (project management book of knowledge) PMBOK® Guide (2021). This edition focuses on the changing dynamics of project management and results in eight performance domains, as follows: Stakeholder, team, development and life cycle, planning, project work, delivery, measurement, and uncertainty. Each performance domain is defined as groups of activities that relate to each other and are essential to achieve efficient delivery of the intended project outcomes. This book further locates resilience-related practices in the uncertainty performance domain, explaining that having resilience processes is a way to deal with uncertainty. So, what used to be a risk management area of knowledge in PMBOk 6th edition, is now expanded to be an uncertainty performance domain, that not only deals with risks, but also with unknowns and ambiguities. The uncertainty performance domain includes all activities associated with exploring, assessing, and dealing with all kinds of uncertainties (e.g., unknown future events, risks, and ambiguities). Resilience-related practices are located to belong to this performance domain. However, the intended outcome of these processes, i.e., resilient performance, is on the level of a whole construction project. Therefore, it affects and gets affected by all the other performance domains PMBOK® Guide (2021).

2.1.3. The intersection of both theories

After viewing the position of a project in the resilience theory, and the position of resilience in the project management theory, we can conclude the intersection between both theories as follows: resilience management is part of the uncertainty performance domain, which substitutes what is used to be risk management knowledge area. As such what we used to call a risk management team or department in projects, may be now treated in a broader aspect, to be an uncertainty management department to manage all kinds of uncertainties: risks, unknowns, and ambiguities, through different approaches, such as resilience-based management. Management for resilience (plan, build, monitor, develop) will result in a set of strategies and activities to create needed resilience functions (proactiveness, reactive capacities (absorptive, adoptive, recovery), and learning), leading eventually to possible levels of resilient project performance.

The scope of this research then focuses on studying resilience at a project level, namely construction projects, which will be investigated in the empirical research part through a sample of infrastructure projects. In the project management theory, this research could be considered under the uncertainty performance domain. However, and since resilience mainly refers to resilient project performance, it affects and is affected by all the other performance domains. So, it is on the level of the whole project's performance and it includes all project's performance areas. Therefore no specific performance area will be excluded from the research scope. While resilience is mainly about resilient performance, this search will look at building resilience from the lens of a contractor (the main performer party), namely Bam-infra/ Netherlands engineering and construction company.

The reasoning behind each element of this scope is described through the following questions and answers:

1. Why project level? The resilience concept can be applied on various levels (social, industry, organizational, project, team, and individual). However, project-level studies offer a fertile ground to bridge and learn different aspects of resilience due to its interdisciplinary nature, its limited duration compared to organizations' resilience, and its inherent characteristics of uncertainty and risk (Naderpajouh et al., 2020)
2. Why contractor perspective? Since the aim of the resilience-based management approach is to create a resilient performance for the project, it is logical to start studying resilience from the construction project performer's perspective (contractor). The research is then conducted in collaboration with a Dutch construction and engineering company in the Netherlands (Bam infra), which is a sub-company of a bigger parent international construction company (Royal Bam).
3. Why infrastructure projects for the empirical study? Based on the contractor's available data three types of projects: piling projects, residential projects, and infrastructure projects were evaluated through three exploratory interviews to choose the main study sample for the empirical study. Infrastructure projects, eventually, were chosen to dive into the empirical part of this study. That was due to their high complexity and uncertainties. Infrastructure projects are normally faced with multiple types of disruptions and are rich with many examples of perturbations and solutions applied. Hence, these projects are capable to provide a richer overview of resilience-contributing elements compared to less complex types like piling projects or residential projects.

2.2. Research Methodology

The research methodology logic to answer the research sub-questions is illustrated in Figure 2.2

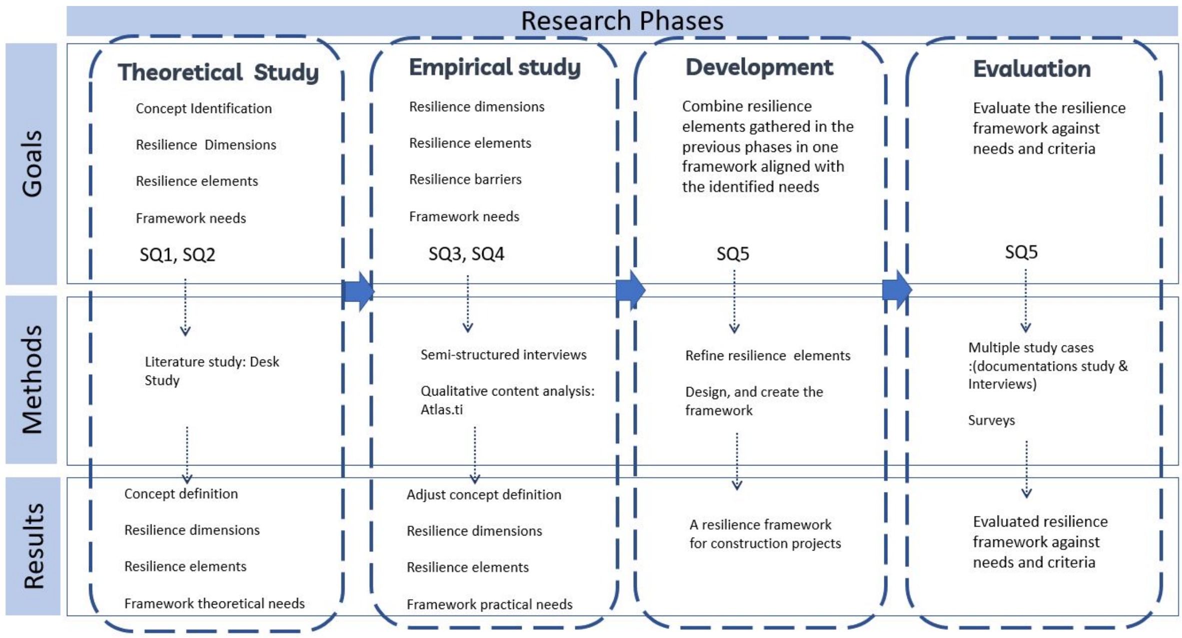


Figure 2.2: Research methodology

The research is composed of four main phases: literature study, empirical study, development, and evaluation. Research methods were chosen for each research phase in response to research goals and sub-questions as follows:

1. Literature study Phase: the method used in this phase is a literature study that aims to answer the questions of what is resilience (SQ1), and which elements contribute towards resilience based on literature (SQ2). Also in this phase, the needs for resilience elements framework are induced, based on theory.
2. Empirical study phase: the method used in this phase is the semi-structured interviews followed by a qualitative content analysis to answer the questions of what are the resilience contributing

elements in practice (SQ3), and what are the resilience barriers (SQ4). Also in this phase, the needs for resilience elements framework are induced, based on practice.

3. Development phase: this phase's main purpose is to combine the knowledge gathered from the two previous phases, e.i., resilience elements from theory and practice, into one overall framework in alignment with the identified needs. The main activities in this phase are listing, comparing, selecting (based on selection criteria), and grouping the resilience elements resulting from the previous phases. Then design the framework structure, intended usage, and outcome in alignment with the pre-defined needs and criteria. The refined resilience elements are then organized into the designed framework. Resulting, eventually, in the final suggested PRL resilience framework for construction projects, and (partly) answering through that research question (SQ5).
4. Evaluation phase: This phase's goal is to evaluate the designed framework against the needs and criteria defined in the first two phases. The methods used to that matter are multiple study cases (documentation study and interviews), and surveys. That completes then the answer of how can resilience elements be combined in one overall framework (question SQ5), which was partly answered in the development phase and completed in this evaluation phase.

The overall chosen research methodology is the inductive strategy (Soiferman, 2010). The reason behind this choice is that this paper mainly aims to establish a comprehensive realization of elements contributing towards resilience, from both theory and practice. Although this research eventually confirms (or not) the current resilience knowledge, its main purpose is not to test existing theories where this requires then deductive approach.

In terms of using a qualitative or quantitative approach, this research started with initial ideas toward a quantitative method to identify resilience through studying previous projects' data of delays and overruns and then trying to set the optimal amount of needed buffer to offer resilience for projects. However, it was revealed in the literature review phase that resilience building is way more than only setting optimal buffers. Buffers are needed of course, but more organizational aspects related to collaboration, communication, flexibility, management approach,..., etc, are also very important to be studied and specified. Therefore the qualitative approach was chosen over the quantitative approach because it allows more inclusiveness for resilience-contributing elements than the quantitative approach. The quantitative approach may allow a better illustration of projects' resilient behavior. However, it is most likely to lack some resilience aspects to be involved in the quantitative representation, due to the large number of resilience aspects and to the fact that some aspects can not be fully measured (e.g., collaboration, creativity, flexibility).

2.2.1. Literature review

The literature review is organized to answer three main questions related to resilience: Why resilience, what is resilience, and how to build resilience in terms of elements contributing towards resilience, as the figure below 2.3 explains:

The literature study investigates resilience triggers, definitions, and contributing elements. These are studied in this research, first, from a general relevant perspective (system resilience, organization resilience, project resilience) before zooming into the construction project perspective. The reason behind this choice of starting from the general towards the specific is not only to enrich the study with several views, but also due to the scarcity of research works focusing on construction project resilience as this concept is relatively new in the construction industry and project management fields.

Related articles, books, previous dissertations, and publications were reviewed. The search engine used is google scholar. Elsevier's database and TU- Delft repository are two databases that were searched as well for resilience-related papers. The following phrases were used in the search: "Construction project resilience " OR " resilience of construction projects", with setting the time range to anytime (since the resilience concept is a new topic in the construction management field, any possible relevant source is appreciated). The interesting part is that there was no results appeared till 2016 (J. Zhu, 2016). While, from 2016 to 2022, 3-5 articles appeared. However, going further to set the research year specifically in 2022, 30 articles were found using the same searching phrases. Within this, few tackled resilience on the level of whole construction projects. The paper's scope mostly tackled the resilience of project components: project personnel behavior, project supply chain, project sched-

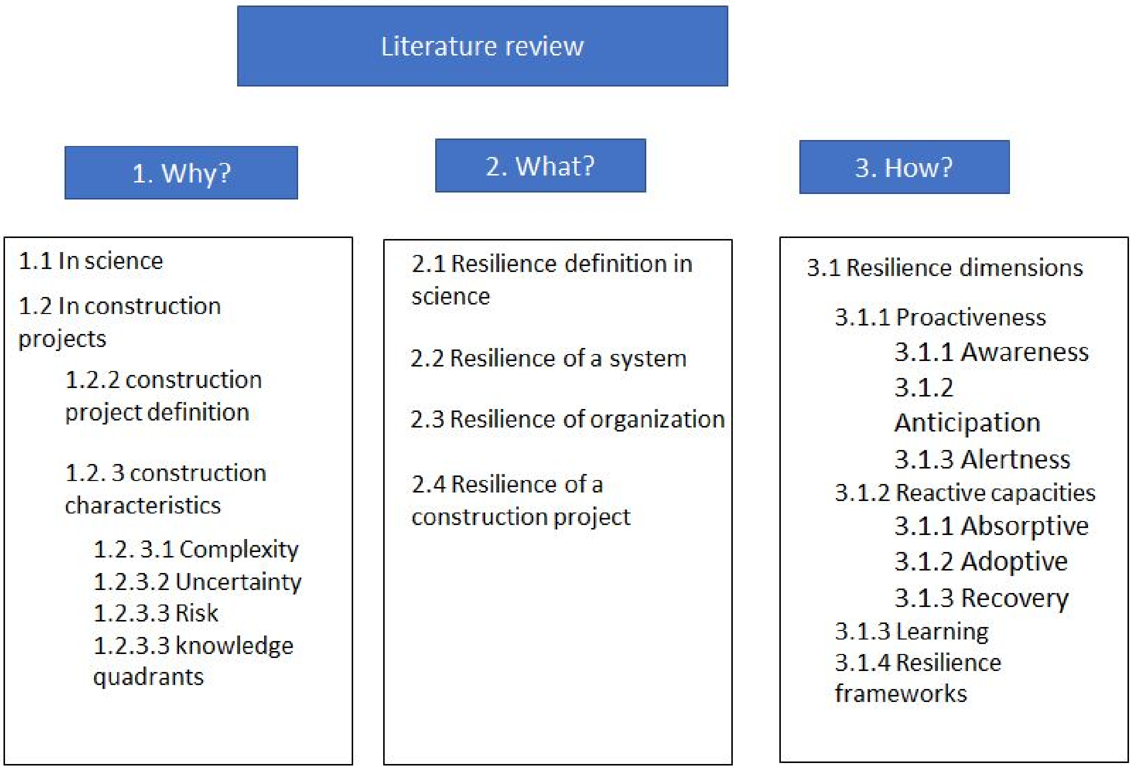


Figure 2.3: Literature review scheme

ule, project safety, and project organization. This fact indicates the newness of applying the resilience concept in the construction industry, and the very few attempts to apply it on the level of a whole construction project.

2.2.2. Empirical study: Semi-structured interviews

After viewing resilience's meaning and contributing elements in literature, the research continues with an empirical study of the resilience concept, through semi-structured interviews with experienced practitioners from the construction industry. The insights gathered from the literature study were used to inspire and prepare the empirical interviews. In selecting a suitable study sample for the empirical study, it was possible to choose between three types of construction projects: piling, residential, and infrastructure, based on the available data. Three exploratory interviews were made to evaluate these options. As a result, infrastructure projects are chosen to apply the empirical part of this research (check Section 2.1.3). The reason behind this choice is that infrastructure projects are found to be more complex compared to the other two types, with multiple stakeholders involved, a large area of execution in horizontal spread (e.g., a highway or a railway project that goes across several cities, municipalities, and geological areas), various types of objects and technologies could be involved in one single project (road, bridge, sea-lock, noise barriers). For these, amongst other reasons, infrastructure projects are normally faced with multiple types of disruptions and are rich with many examples of problems and treatments applied. Hence, this type of project may offer a richer view of the resilience contributing elements.

Semi-structured interviews are chosen to fulfil the empirical part of this research. As the name suggests, this type of interviews is used when it is possible to build an overall framework for the interview(interview guide/ protocol) but there is not enough knowledge about the research topic or phenomena to form structured or close-end questions. Semi-structured interviews allow freedom for the researcher to steer the data collection gradually once needed, building upon interviewees' answers, without deviating from the main lines of the topic specified by the interview guidelines (McIntosh & Morse, 2015). The Interview guide is presented in Appendix (.1). For this research topic, e.i., resilience in construction projects, general knowledge of the resilience concept is available and sufficient to draw the main key lines but not a specific questionnaire. Open-ended questions are needed to conclude the lacking knowledge. Therefore, semi-structured interviews were the most suitable for this research (Galletta, 2013). To strengthen the empirical evidence, interviewees were only aware of the research's main topic (resilience definition and dimensions) in the middle of the interview, then the main resilience dimensions were revealed but not the resilience elements found in the literature.

Eighteen interviews were conducted with a planned duration of 60-75 mins/ each, via Microsoft teams. The main guidelines are composed of 10 questions to fulfil the intended goals. A record of the interviews is saved, and transcribed into text, and analyzed via the Qualitative content analysis approach (QCA), using Atlas. ti tool. The reason behind choosing the QCA method is that this method allows to describe the gathered data in a systematic gradual way, by allocating the qualitative data to codes one after the other and then grouping the codes into coding frame categories. This allows to map out the large amount of the gathered data, and it is suitable to combine multiple categories of data in one frame (Kuckartz, 2019; Selvi, 2019). Atlas.ti is used to perform the Qualitative content analysis because it aligns with the core idea of this strategy, which is gradual coding for the data and grouping these codes to build up a coding frame that facilitates having more structured and related themes for the analysis. Also, the Atlas tool shows repetitive concepts across the analyzed interviews and helps by capturing main (existing or new) themes mentioned across interviewees' answers (Hwang, 2008).

2.2.3. Model development

After analyzing the interviews, empirical resilience elements emerged. The results then from both the literature study and from the interviews were used to develop a resilience framework to grasp elements contributing towards construction project resilience in large construction projects. Framework needs and criteria are concluded from the previous two research phases of literature study and empirical interviews. The framework was designed then in alignment with these criteria and based on the main dimensions found in literature, and emerged across the interviews. Resilience dimensions were used to set a matrix framework. The first dimensions group relates to the resilience theory (proactiveness, reactive capacity, and learning). The second group relates to construction project management (contract management, client management, schedule management,...., etc.). The resilience elements gathered from theory and practice were then assigned in relation to both groups. The First reason behind using a matrix framework is twofold. Firstly, to fulfill the objective of this framework of being useful both in practice and in theory. So, the elements were clustered in a way that aligns with both resilience theory and project management areas of practice. The second reason that led to the use matrix of dimensions is that several elements were found to belong to several resilience dimensions. For example, having a project culture of openness and safety, will not only helps to build more awareness regarding possible problems, but also will offer a timely escalation, faster responses, and more capacity to find solutions. Also, it will offer a suitable atmosphere to admit mistakes, discuss and learn from them. This resilience element, therefore, belongs to all three dimensions of resilience (proactiveness, reactive capacities, and learning), as well as belonging to the project management chosen strategy. Therefore, it can not be located in only one dimension.

2.2.4. Evaluation: Case studies and surveys

After developing the purposed resilience framework for large construction projects, it is needed to test and evaluate this framework against the needs and criteria concluded from the interviews and the literature study. It is suggested by Geambasu (2011) and J. Zhu (2016) that large resilience capabilities of a project should lead to better project performance. Based on that the content of the framework was tested through study cases. The aim is to test whether the existence of the specified resilience elements, e.i., the framework elements, in a construction project would hint (or not) at resilient project financial and schedule performance. To fulfil this aim, three cases were selected, and their financial and schedule performance was studied and illustrated through the different project phases. The framework was then used by the project manager and the process manager of each project, via interviews, to assess the resilience elements and generate a resilience print for each project. Project's management plans and progress reports were also reviewed to support the evidence of the interview assessment as much as possible. The resilience print and projects' performance illustrations were then compared and analyzed across cases to check whether a larger resilience print based on the developed framework, would hint at better project performance as claimed in literature (Geambasu, 2011; J. Zhu, 2016). The framework was also evaluated through surveys sent to the 18 experts who participated in the empirical study, based on criteria advised by (Hoseini et al., 2021) of completeness, usefulness, understandability, ease of use, and need for improvements. The framework was adjusted as much as possible accordingly.

2.3. Research outline

An overview of the different chapters of this report is presented in Figure 2.4. The initiation of this research is introduced in Chapter 1 and Chapter 2. The former explains background information, research gaps, questions, and relevance. The latter illustrates the chosen research design scope and methodology. After that, the exploration of the current resilience knowledge and practices was performed through a literature study presented in Chapter 3, and an empirical study in Chapter 4. Chapter 5 explains the development of the resilience framework based on the previous chapter's output. The framework is evaluated in Chapter 6. Eventually, the research concludes with the limitations, conclusions, and recommendations in Chapter 7. As Figure 2.4 reflects, each chapter aims to answer the specific research question(s). Chapters are firmly connected through a logical flow, where the outputs of a chapter are inputs for the following one(s).

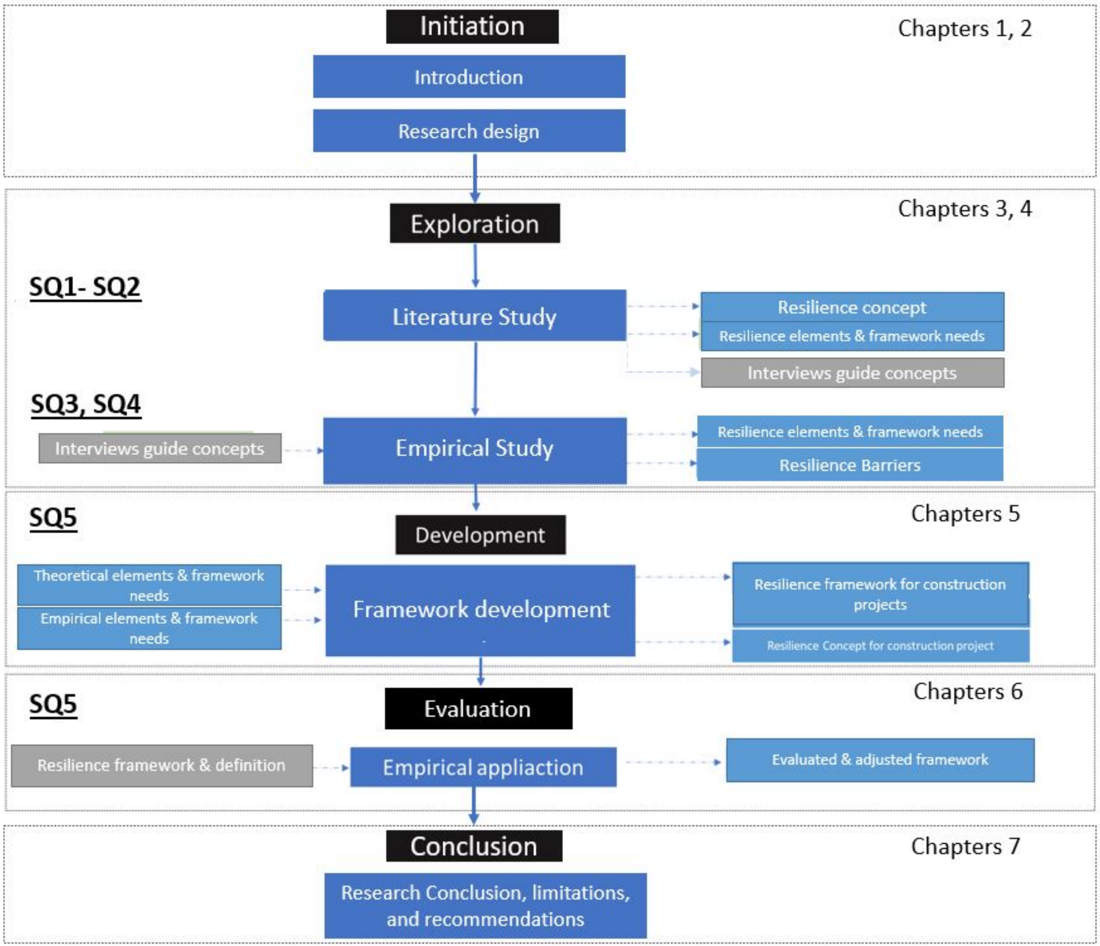


Figure 2.4: Research outline

3

Literature Study

The literature study sketches the development of the resilience theory, specifically the aspects of why resilience emerged, and what resilience is, through time and amongst different fields of science, arriving at the construction project resilience concept. Two main goals were intended for the literature review. The first goal is to understand the resilience concept at the level of a construction project. That understanding started by revealing why resilience emerged from the first place in science and project management, in section 3.1. Then, in section 3.2, different resilience definitions were reviewed and compared to conclude the criteria needed to sufficiently define resilience. The second goal is to identify which elements contribute towards resilience in construction projects based on current resilience literature, demonstrated in section 3.3. Fulfilling these two goals answers research sub-questions SQ1, and SQ2, respectively.

3.1. Why resilience?

Understanding why the resilience concept emerged helps to form a better perception of the concept and its characteristics. Therefore, resilience emergence was reviewed starting with the ecology field where the resilience concept mainly has begun to emerge in scientific works. Then, the review goes in time through other science branches that searched into the resilience concept, arriving at the specific scope of this study: Construction project resilience.

In science branches

The resilience concept started to emerge in scientific papers mainly in 1973, when C. S. Holling (1973a) introduced the word resilience into ecological research in order to understand the non-linear dynamics feature of the ecosystems and how to achieve sustained relationships between its components (C. S. Holling, 1973a). Ecologists experienced the need for resilience to preserve the ecological system functioning despite natural and human disturbances (Westman, 1986), and to understand and achieve complex ecological systems' recovery and adaptation to disturbances like hurricanes and fires (Gunderson et al, 2012).

Holling's pre-mentioned influential paper was a starting point that other branches of science have built upon further resilience research in their different fields. For example, in psychological studies, the resilience concept emerged in response to individuals' needs to form behavioral mechanisms in face of challenges, adversity, high risks, and stresses (Rutter, 1987; Jordan, 1992; Rutter, 2000; Windle et al, 2008). Another aspect where resilience emerged is Urban resilience. Natural disasters and human actions are considered a source of uncertain and unpredictable urban threats that require resilience capabilities to prepare and respond to them (Ribeiro & Gonçalves, 2019). While, in urban studies, resilience was essentially associated with inevitable problems such as the unavoidable rapid climate change and sea level increase, where cities need to be resilient against a wide variety of shocks and stresses (Côté & Darling, 2010; Leichenko, 2011). Sudden terrorist attacks (Hardy, 2015), the global scarcity of energy resources (Sharifi, 2016), and the recent Corona pandemic (Cheshmehzangi, 2020) set the focus even more on the need for urban resilience in recent years. Furthermore, Economics studies revealed the need for resilience within the economical planning of regions in order to actively respond to internal and external shocks through coping, recovering, and reconstructing (LI et al, 2019; Martin & Sunley, 2020; Hallegatte, 2014; World Bank, 2014). Supply chain management is another aspect where resilience needs came into the light to handle unpredicted disruptions of a supply chain. Resilience referred then to being adaptive to incidents such as large-scale disruptions, and shocks that are sustained over longer periods of time (Scholten et al, 2020; Black & Glaser-Segura, 2021; Ribeiro & Barbosa-Povoa, 2018).

Other essential fields where resilience emerged are safety and project management aspects. Safety management science responded to the need to prevent and manage safety accidents and dynamic risks through resilience engineering which aims to improve safety in complex systems and develop resilience at an operational level of relevance for different high-risk industries (Pillay, 2015; Hale et al, 2017; Zhu et al, 2020; Wiig & Fahlbruch, 2019). While in Project management, the resilience concept was associated with complex environments, socio-technical risks, management under uncertainty and variability, crisis and disaster management (Nonino et al, 2018; Vahanvati & Mulligan, 2017; Bigogno-Costa et al,2020; Kanjanasomkid & JE Lara Cartagena, 2021).

Across these areas, needs for resilience are illustrated in figure (3.1), and described through the following three levels:

1- Attributes: these are the features related to the studied entity or its surrounding environment which require the resilience functions to understand its nature, dimension, and effects. Across mentioned domains, the following attributes were described in reviewed literature: dynamicity, complexity, and uncertainty. Other two interesting features were also: unpredictability and inevitability, which have two opposite predictability.

2- Event classes: the pre-mentioned attributes, manifest through time into various sorts of events that require the resilience to be aware of, monitor, and anticipate. The following event classes were found in reviewed literature: changes, disturbances, stresses, emergent risks, threats, shocks, and accidents.

3- Specific events: these are specific events from the event's classes that require the resilience functions to respond, adapt and recover. Examples found are hurricanes, fire incidents, terrorism attacks, sea level arise, energy sources shortage, and Corona pandemic.

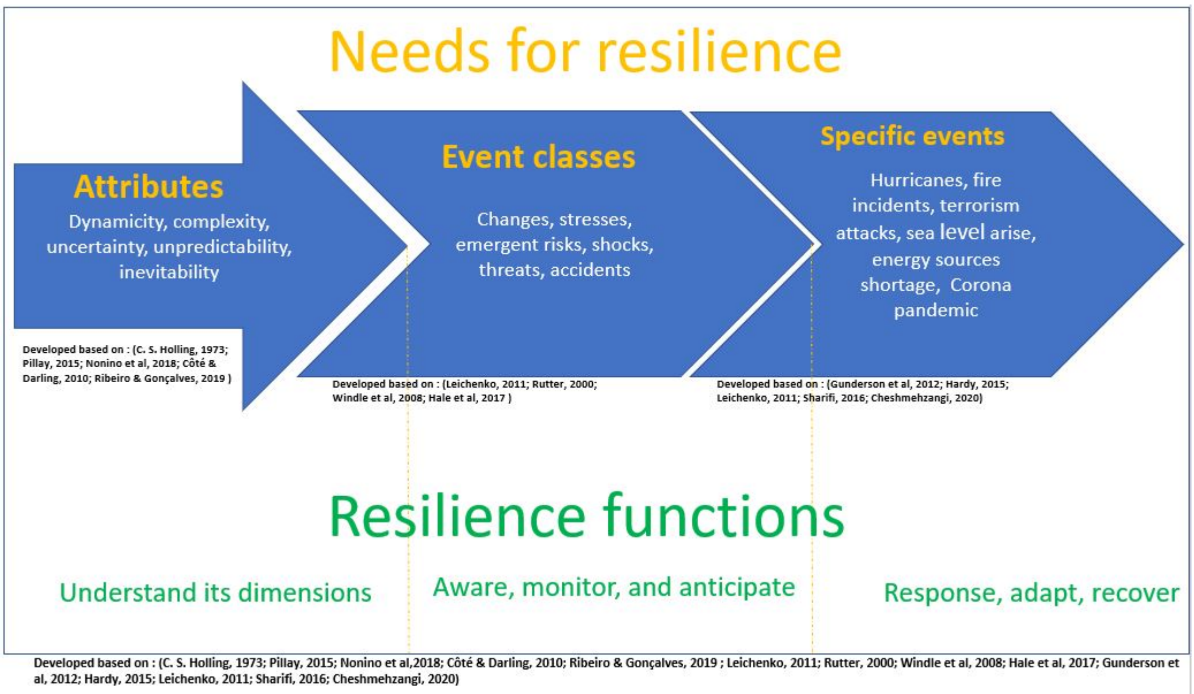


Figure 3.1: needs for resilience in science branches

Amongst the aforementioned events, resilience is observed to be needed mostly when an entity is not able to affect the predictability of a disruptive event either because it is of a very high unpredictability (Shocks, accidents, unexpected threats, Corona pandemics, terrorism attacks), or because it is of a very high predictability of occurrence but associated with incapability to be avoided or reduced (like Energy sources shortage and climate change). Opportunities were not mentioned within the aspects that require resilience, and the focus was on events with large negative impacts. The needs illustrated in the literature are to accept the fact that these events will occur and the focus is directed to create readiness to absorb or minimize its consequences on the affected entity. Resilience is then mostly needed when the focus is on withstanding disruptive events' impact rather than reducing their probability of occurrence. Another takeaway is that certain internal and external attributes such as (uncertainty, complexity, dynamicity, unpredictability, and inevitability) are the main source of the events that require resilience responses. Therefore, an efficient resilience function would not only targets the level of incidents but also creates counteracting inherent attributes in the entity itself. For example, dynamicity would be countered by flexibility.

In Construction projects

In construction projects, resilience is seen as a paradigm of management to face uncertainties associated with construction projects characteristics (Burnard et al., 2018; Francis & Bekera, 2014; Hollnagel, 2015; Madni & Jackson, 2009; Patriarca et al., 2018; Rahi et al., 2021; J. Zhu, 2016). To better understand construction project resilience, it is important then to comprehend construction project characteristics and definitions.

Construction project definition

Several definitions are found in the literature for a construction project. Traditional project management considers a construction project as a temporary organization created to achieve a predefined end state (Lundin & Soderholm, 1995). The construction project is also defined as a network of relationships (Pryke, 2012), or as a temporary organization (Thakurta, 2015). While another definition focuses on activities and a construction project is seen then as a series of required activities that take place within phases through a specific time span (Aaltonen & Kujala, 2010).

However, some scholars consider defining a construction project as a temporary organization, series of activities, or one-off production function, doesn't fully reflects reality (Elmar & Hall, 2020; Naderpajouh et al., 2020; Doorn, 2020; Geraldi & Soderlund, 2018). The reason is that construction projects usually consist of many teams, organizations, and systems with various disciplines that interact and have interdependencies not only between each other but also with the surrounding environment and systems to achieve their intended end values; the project values. This interaction should be acknowledged and understood when defining a construction project through the project's input, output, and processes (Geraldi & Soderlund, 2018). This complex composition of a construction project leads to inherent uncertainty and unpredictability. These characteristics deviate the concept of a construction project from the engineering-based conceptualization, where a project is seen as a series of smaller interconnected pieces that could be fully understood, executed, and controlled (one-off production) (Elmar & Hall, 2020). Thus, uncertainty is inevitable for construction projects. A construction project could be regarded as a process with high uncertainty that unfolds as time passes through its life-cycle (Naderpajouh et al., 2020). In the same orientation, Doorn extended the definition of a construction project to view it as a heterogeneous engineering socio-technical system of systems, that consists of technical infrastructure, institutions, and people (Doorn, 2020). Building upon that, a more dynamic perspective of a construction project was introduced by Kutsch and Hall (2020), where it was defined as mindful entities that form a living organic construct consisting of people, supported by structures and processes, exists for a finite period, and constantly faced by adversities where its success depends on its ability to remain resilient (mindfully interpret, prepare for, contain, and recover from adversity) (Kutsch & Hall, 2020).

Across all these construction project definitions, the main difference is related to the level of comprehensiveness and the aspect that an observer looks into a project from (organizational, system thinking, operational,...etc). Viewing a construction project as a dynamic living system offers a comprehensive view that illustrates its interactions with the surrounding environment. Therefore, this research obtains and builds on the system thinking of Doorn (2020) and Kutsch and Hall (2020) definitions to view a construction project as follows: **A construction project is an organic dynamic socio-technical system**

of systems, for a finite period, consisting of people, technical elements, and processes, organized through its temporary project organization to hold a series of connected activities which interact with each other and with the surrounding systems via input, output, and processes to achieve a pre-defined end value within a desired scope, budget and time frame. It holds dynamic inherent uncertainty evolving through its whole life cycle where its success depends on its ability to remain resilient . (This definition is developed based on: Kutsch and Hall (2020); Doorn, 2020; Naderpajouh et al. (2020); Geraldi & Soderlund, 2018; Lundin & Soderholm, 1995; Thakurta (2015); Aaltonen & Kujala, 2010)

Construction project characteristics

For construction projects as seen in the previous paragraph, two inherent characteristics are recognized: project complexity and uncertainty. Since the resilience concept is essentially linked to maintaining project functionality, it is important to understand what set this functionality at risk. Manyena et al. (2019) refer that there are three elements that trigger resilience response if they all exist together: a disruptive event, project exposure, and project vulnerability to that event. These elements are strongly affected by project characteristics. Therefore, it is important to have a good grasp of construction project attributes, namely complexity, uncertainty, and risks.

1- Complexity

Vidal & Marle (2008) describe project complexity as the property of a project which makes it difficult to understand, foresee and keep its overall behavior under control, even when given reasonably complete information about the project system. Complexity is considered a vital variable that needs to be identified and taken into consideration in projects design and planning (Luo et al., 2017). Especially in terms of construction projects where Baccarini (1996) considers it one of the most complex industries as he mentioned: ”In fact the construction process may be considered the most complex undertaking in any industry” (Baccarini, 1996, p. 201).

There are various definitions in the literature regarding project complexity. Turner and Cochrane (1993) had one of the earliest attempts to define this concept, where they see project complexity related to the degree of the good definition of the project goals and concepts. While Hatch and Cunliffe (2012) view a complex project as more related to the many and various elements that interact and own several feedback loops between each other. Cicmil and Marshall (2005) relate the complexity of a construction project to its setting conditions of time, space, and project organization processes. Furthermore, complexity among project components may be produced by several factors such as the number of tasks and stakeholders and the interdependence between them (Wang, A. 2019).

These definitions of complexity in most research works focus on identifying complexity through understanding its factors. Researchers attempt to classify elements contributing to complexity into classifications of general domains. Baccarini (1996) focuses on two aspects of complexity: organizational and technological. Within both of these aspects, he used two main dimensions to define the complexity concept, these are differentiation and interdependencies. Organizational complexity is considered related to the operational dependencies between organizational elements, and the amount of organizational differentiated parts: vertically (hierarchical structure) and horizontally (organizational units and needed personnel). While technological complexity is conceived in Baccarinis' paper as the difficulty of task performance, represented through task aspects diversity: input, output, number of actions, and specialities to complete the task. It is also linked to interdependencies between tasks, teams, inputs, and technologies used. In a similar direction, Bosch-Rekveldt et al. (2011) added an additional dimension to the technical, and Organizational complexity which is the environmental complexity. That was through the TOE framework of complexity assessment. Where technical complexity included elements related to project Goals, scope, tasks, experience dealing with technology, and technological risks. Whereas Organizational Complexity includes the project's size, resources, project team, trust, and organizational risks. While, environmental complexity is considered to cover elements related to stakeholders, location, market conditions, and environmental risks.

Another interesting source of complexity in projects is uncertainty ”project complexity is often considered as being caused by uncertainties” (Bosch-Rekveldt et al., 2011, p. 3). These two concepts have interchangeable relations, where complexity is considered to cause uncertainty (Vidal and Marle, 2008). Both concepts are closely related and each of them is attributed to the other. This interrelation between complexity and uncertainty can be further explained through the same aspects of Baccarini (1996); differentiation and inter-dependencies, where in alignment, Senge (2006) suggests two types of complexity: time-independent (Detail complexity; arise from the large different number of variables), and time-dependent (Dynamic complexity; stem from the relationship between components). In construction projects, detail complexity pertains to the structure of the project (e.g., project scope, stakeholders, project size, project components) where these are known to a large extent with a low probability to change over time. On the other hand, Dynamic complexity is related to the operational behaviors of the system. Uncertainty is a main attribute of dynamic complexity, illustrated in internal factors (e.g., material flow, human behavior), and external factors (e.g., changes in social, political, or economical environment and conditions). Most of traditional project management strategies of predicting, and planning are more effective towards time-independent complexity type while facing dynamic complexity which roots back to the project's uncertainty still underdeveloped J. Zhu (2016). Hence, the next section will look into the uncertainty concept in construction projects, and the role that complexity and uncertainty both play in a construction project's vulnerabilities, exposure, and disruptions.

2- Uncertainty

Modern construction projects are operated in extremely uncertain environments. Uncertainties affect the performance of projects (Zhu et al., 2015). Literature has different perceptions of the concept of uncertainty. Perminova et al (2008) refer to that uncertainty essentially has two types of sources: the first one, is the lack of knowledge, while the second is the fact that some events simply cannot be foreseen. Linder et al (2003) mention based on the British economist John Keynes, that uncertainty is: "a state in which individual actors find it impossible to attribute a reasonably definite probability" (Linder et al, 2003, p. 76). In other words, Uncertainty is subjected to the person who is trying to run an expectation of future events. Risk quantification practice in a construction project is a representation of that. Uncertainty then may be considered an immeasurable risk (Waddell, 2004). while in a more comprehensive view of uncertainty, Cleden (2017) refers to that uncertainty doesn't always yield harm for the project. That is because there can be three possible outcomes for uncertainty: threats, opportunities, and irrelevant consequences.

In projects, uncertainty and complexity elements allow small problems to cascade into several changes in the project bringing along major consequences (Wang, 2019). Construction projects are of high interdependencies by nature because they imply a sequential order of dependence between their various phases (e.g, design, then procure, then construct). Consequently, the chance is high that small failures would cascade rapidly and build on themselves to trigger larger sudden incidents. These connections and complex interdependencies are hard to be fully discovered and analyzed in large construction projects. The complexity in the interrelations of a construction project parts makes unpredicted events inevitable. In that sense, complexity and uncertainty make projects more vulnerable to disruptive events which can be either of internal source or external origin. Internal factors of disturbances mainly can be seen related to the human nature of possible optimism biases, performance mistakes (e.g., Poor planning), and even deliberate deception and opportunistic behaviour. While external factors are related to the unavoidable unpredictability of some life aspects like economical changes and environmental changes (Wied et al, 2021). Complexity and uncertainty factors put the project at potential vulnerability towards the unpredicted event, while conventional risk management methods will always be unable to comprehensively predict and consider all interdependencies and possible cascading effects resulting from the project's complexity. Therefore, it is important to formulate a further understanding of risk management and its limitations in construction projects.

3- Risk :

Risk definition The previously defined construction project characteristics of complexity and uncertainty are considered essential sources of risk events (Erol et al., 2020). The risk concept was defined by the project risk analysis and Management (PRAM) Guide, 1997 as:" An uncertain event or set of circumstances that, if should it occur, will affect the achievement of the project's objectives". Risk is defined in the ISO 31000 Risk Management – Guidelines as a deviation from the expected that can be positive, negative, or both, and can address, create, or result in opportunities and threats" (IRM, 2018). Hillson (2002) and Ward and Chapman (2003) viewed the risk concept the same way.

On the other hand, in another stream of research, the risk is considered to express the uncertainty that has only negative effects on project goals(Cleden, 2017; Ramasesh & Browning, 2014). For example, Baloi and Price (2003) defined risks as “the likelihood of a detrimental event occurring to the project”, and Jaafari (2001) considers it as ”the probability of losses in a project”. This research stream did not deny the existence of events of positive or neutral impact on projects but did not name them as risks then. The word risk in their view expresses negative effects on project aims. The difference between these two streams of Literature is in their terminology. This research will obtain the second terminology. Based on the Oxford Dictionary risk as a word is defined as:” A chance of bad consequences” and ”An exposure to the chance of injury or loss, and hazard ”. This also reflects how the social majority understand the word risk and use it in their daily life including construction project team members who perform project and risk management in their jobs. If we want to include opportunities and non-relevant events with risks in a single terminology, a wider more neutral term should be used then such as uncertainty, suggested by Klemetti et al. (2006).

The depicted characteristics of construction projects are illustrated in figure 3.2 below:

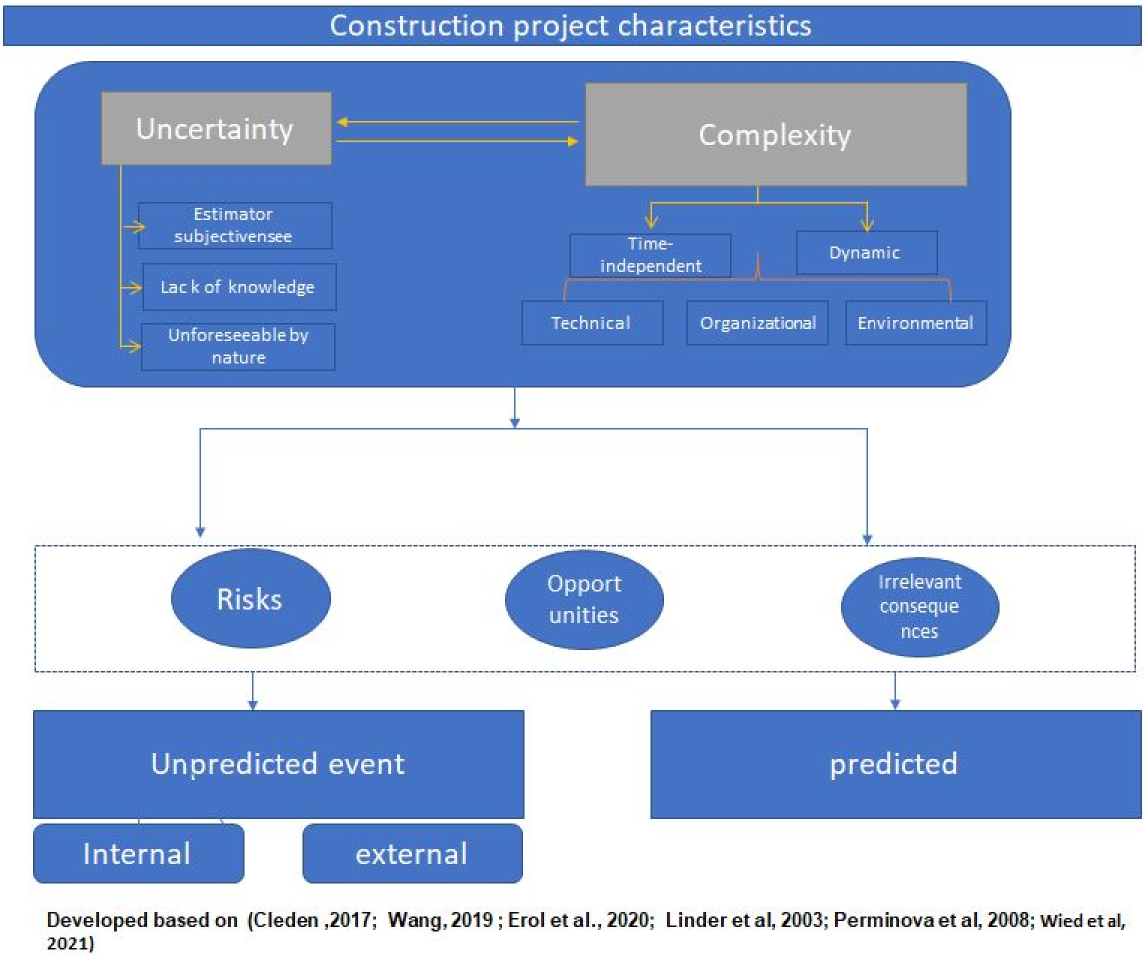


Figure 3.2: Construction project characteristics

Risk types and knowledge quadrants

Risk occurs in a construction project throughout its various phases. Broadly, risks can be categorized based on their source or by project phase (Klemetti et al., 2006). The most used classification found in the literature is based on the source of the risk. For example technical, legal, natural, logistic, social, economic, financial, commercial, and political (Baloi & Price, 2003; Rastogi & Trivedi, 2016). Through these aspects, the project team tries to forecast risks depending on their knowledge, risk appetite, level of uncertainty, and available information. Based on the project’s team knowledge three classifications of threats were suggested by Rumsfeld (2002): ”There are known knowns. These are things we know we know. We also know there are known unknowns. That is to say, we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know" (Shermer, 2005).

Later, this ideology was extended in the risk management-related studies to a fourth quadrant: the unknown knowns. These quadrants were understood then in risk management literature as follows: Knowledge (known-knowns), untapped knowledge (Unknown-knowns), risks (Known- unknowns), uncertainty (unknown-unknowns) Cleden (2017). These terms were further modified by Kim (2017) to consider Known-unknown as identified risks, while Unknown-unknown as unidentified risks. This research obtains the view of Kim (2017) which is further explained in a construction project context as the following:

1. The Knowns (Tapped knowledge or untapped knowledge)
   (a) 1.1 Known-knowns (Tapped Knowledge): stands for the facts that the project management team is aware of and used for project planning and setting
   (b) Unknown-known (Untapped knowledge): Denotes facts that the project management team is not yet aware of, where these facts are existed within the project organization and known by other personnel
2. The unknowns (Identified risks or unidentified risks)
   (a) Known-unknowns (Identified risks): Represent identified risks that may be estimated. Typically formulated through risk management practices. These are the risks that we know it may occur but we can not specify firmly when, where, or why they may happen
   (b) Unknown-unknowns (Unidentified risks): unknown unknowns are unidentified risks that a project team could not predict, these are surprising unexpected events. Kim (2017) presents examples of these risks as follows: inherently unknowable risks, time-dependent risks, risks that are progress-dependent, and risks that are response-dependent, i.e., secondary risks.).

In these quadrants risks are presented mainly in two parts, that is the two unknown categories: known-unknowns (identified risks), and unknowns-unknowns (unidentified risks). The former refers to events that we can only set scenarios for, and try to estimate, which illustrate the coverage of risk management practices of identification, quantification, and response. While the latter, are risks that we do not recognize we do not know. It is the surprises that the project team couldn't foresee. Consequently, in such socio-technical complex systems like construction projects, a clear need emerge to develop adaptive and reflexive capabilities to cope with unknown future events where risk management practices have limited effectiveness (Öbrand et al, 2018).

Risk Management

The process to manage known unknowns (identified risks) will not work to manage through unknown unknowns (unidentified risks) (Rahi et al., 2021). Therefore this section focuses on these two risk quadrants to explore the appropriate approach to manage each of them efficiently and explore how this links to the concept of project resilience.

Kim (2017) refers to that conventional risk management can be applied to the Known unknowns (identified risks) which are possible to be estimated in a probabilistic manner. Based on [ISO Guide 73: 2009, definition 3.1], the risk management process is identified as: "a systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring and reviewing risk. Moreover, the Project Management Institute (PMI, 2017) identifies the risk management process via five main phases performed through the project life cycle (planning, identification, analysis and assessment, plan responses and implementation, and Risk monitoring), where the ISO 31000:2009(E) advise adding one more dimension that is Recording the risk management process. Overall, the risk management process includes the following phases:

1. Risk management Planning: this is the process of defining the risk management plan of the project that involves identifying the techniques used for each following stage, who should be involved, how risk management activity shall be executed, monitored, and documented, and in which sequence (PMI, 2017). This planning should be performed at the beginning of the project.

2. Risk identification: In this phase project related team attempts to forecast possible project risks, it starts in the project's early phases and continues to be carried out iteratively throughout the project as some risks will only emerge through the course of the project. Identification methods generally include brainstorming, risk checklists, expert analysis/interviews, modelling, and analyzing different scenarios project plans (Ward & Chapman, 2003). Risk identification involves identifying risk causes, the risk event, and its effects. It is important to differentiate between these aspects (Raz & Hillson, 2005). ISO 31000:2009(E) stresses the importance of relative and up-to-date information availability and the availability of personnel with appropriate knowledge to be involved in risk identification. It is important to understand that the risk identification stage is very critical and essential since: "since the risk management process builds heavily on the primary identification phase, the success of later risk management phases is directly comparable to the quality of the first identification phase" (Chapman, 2001).
3. Risk analysis and assessment: Risk analysis involves developing an understanding of the risk identified in the first stage. Risk analysis is mainly to identify causes and sources of risk, their consequences, the likelihood of occurrence, and the factors that may affect both of these aspects (ISO 31000:2009(E)). To analyze risks, quantitative or qualitative approaches could be used. Using simple scales, e.g., from 1 (low) to 5(high), is considered the most common way to estimate risk probability and impact.
4. Plan responses and implementation: Through this stage response strategies are established, and the category of response is selected to be one of the following: avoid, reduce, transfer, or accept the risks. A response, in detail, then is designed (PMI, 2017). A treatment plan is the outcome of this stage, which involves not only the main ranked treated risks, their treatments, and accountable personnel but also should include any residual risks assessed and treated as well.(ISO 31000:2009(E)).
5. Risk monitoring: this stage aims to monitor the implementation of the chosen response plan defined in the previous stage, to check its effectiveness, and to track and update risks status (PMI, 2017).
6. Risk management recording: this process aims to record the executed risk management practices, and make it traceable to build a foundation of risk management learning and improvement. However, it is optional as mentioned before for an organization to use it or not.

To summarise, risks represent a source of changes in the project's original planning. Due to the construction project's inherent complexity and uncertainty, these risks need to be carefully managed. Risk management practice is one way to manage through. However, its success depends heavily on the risk identification phase. This identification depends on the knowledge of the project team. So, the coverage of risk management will always equal project team members' knowledge coverage(members who perform risk identification). That is the known-unknowns. That leaves two categories of event out of the risk management range of work, these are: unknown knowns, and unknown unknowns, and a question arise: How would projects face successfully these unknowns?

Managing through the unknowns

" Unknown unknowns have traditionally been outside the scope of project risk management"(Kim, 2017). The main problem of the traditional risk management approach is that it focuses on the ability to predict, control, and avoid being surprised. Therefore, it fails to assure project functions stability in face of unpredicted events (Rahi, 2021; Blay, 2017; Geambasu, 2011). Projects always deviate from the plan due to among other reasons the inevitability of unpredicted events (Miller & Lessard, 2001). For example, Wied et al. (2021), applied a study on 21 projects, and all of them were found to face unpredictable events throughout the project cycle. Half of these events had harmful effects on the project's final results. The root causes of these events were understood based on mainly two management paradigms: anticipatory and resilience paradigms. The former links back the occurrence of unexpected events to poor planning, optimistic bias, and forecasting inaccuracies. While the resilience paradigm considered unforeseen events inherent in construction projects' nature. A synergy between these views is important, and efforts should focus to set the best possible planning, but with an ability of project reinforcement in face of unknown future events which emerge after the project launching.

Understanding and dealing with the unknown is a major challenge in project management (Ramasesh

& Browning, 2014).To successfully survive Sudden and unexpected changes and variations a project needs to build preparation and inherent capability to cope with these events (Crosby, 2014; Nicholas, 2004; Hallgren et al., 2018; Naderpajouh et al, 2020). Since Risk management practices are not intended to create capacities to withstand unpredicted disruptions and shocks (Blay, 2017), it was recently, a topic of research for risk management researchers and practitioners to find approaches to counter unknown risks. One stream of research like (Browning & Ramasesh, 2015; Loch et al., 2008; Parsons, 2007; Ramasesh & Browning, 2014) focuses on the idea of trying to understand sources and features of the unk-unks (unknown unknowns), to set techniques that reduce the amount of these risks. This attempts build up initially on the idea of the distinction between what is knowable and what is actually known about the project. Many of the so-called unknown-unknowns aren't really unk-unks at all, rather risks which the project team was not able or did not try enough to predict (Browning & Ramasesh, 2015). Browning and Ramasesh (2015) suggested the use of a method called directed recognition to convert some of the unknown-unknowns into known-unknowns. However, these attempts still don't find a way to deal with the truly undefinable unk-unks. Other solutions suggest accepting the inevitability of the unknowns and building capability within the project to deal with it. These are vulnerability management, agility, and resilience (Rahi et al., 2021). Table 3.1 summarises areas of the effectiveness of each of these approaches:

Managing through the unknowns strategies

Strategy	Proactive/ reactive	Known- Unknowns		Unkown-Unknowns & Unknown-Knowns	
		Cope with probablity	Cope with Impact	Cope with probablity	Cope with Impact
Risk management	Proactive	X	X		
Vulnerability management	Proactive	X		X	
Agility	Reactive / proactive	X		X	
Resileince	Reactive / proactive	X	X	X	X

Developed based on: (Rahi et al., 2021; Vidal & Marle, 2012; Conforto et al., 2016; Bhamra et al., 2011; Blay, 2017; Geambasu, 2011)

Table 3.1: Managing through the unknowns techniques

1. **Vulnerability management (Proactive):** Vulnerability is "a characteristic of a project that makes it susceptible to disruptive events" (Vidal & Marle, 2012). The vulnerability management goal is to limit project weaknesses within project characteristics to avoid possible exposure to disruptive events(Zhang, 2007). It is a proactive strategy. The vulnerability management process has phases similar to risk management: vulnerability identification, analysis, response preparation, monitoring, and controlling (Vidal & Marle, 2012). The lower the vulnerability, the lower the project is exposed to disruptive events. The shortcoming is that it reduces exposure to risks, but does not offer a solution to act upon disruptive event impact once it occurs.
2. **Project agility (Proactive and Reactive)**: Agility is identified as "the project team's ability to quickly change the project plan as a response to customer or stakeholders needs, market or technology demands in order to achieve better project and product performance in an innovative and dynamic project environment" (Conforto et al., 2016). Its limitation is that it focuses on adopting and changing the project, based on specific areas centred around stakeholders and market-changing needs, which may -but not necessarily- be disruptive events. It doesn't offer solutions to deal with the variety of possible unknowns a project may face through its life-cycle (Rahi et al., 2021). However, by adapting to changes, agility plays a proactive role in reducing the probability of disruptions that may be caused by the dis-alignment with the surrounding changes.
3. **Project resilience (Proactive and Reactive)** Resilience is mainly related to the system's capacity to maintain its functions and the relationships between its various entities when faced with disruptive events. Resilience includes actions to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance (Bhamra et al., 2011). Authors refer to resilience as the ability to deal with changes, emerging risks, shocks, unexpected events, and uncertainties. While the shortcoming of resilience is that it is still a novel concept with no specific measurement, and

tangible practices to apply (Q. He et al., 2017).

Overall, it is recognized that resilience is the most comprehensive strategy to face not only unknown-unknowns but also other sorts of disruptive events in general. However, it doesn't eliminate the relevance of the other approaches but rather complements the shortcomings of these practices. Table (3.1), illustrates the effect of the reviewed techniques on the unknowns in terms of probability and impact. These events can potentially lead to project failure because they can affect: "everything from technical feasibility to cost, market timing, financial performance, and strategic objectives"(Thamhain, 2013, p.1). The project should be aware of its surroundings and adapt when faced with disruptive events, regardless of whether or not these events are known at the beginning of the project (Rahi, 2019). Figure 3.3 represents concluded risk management and resilience coverage based on (Kim, 2017; Rahi et al., 2019; Shermer, 2005)

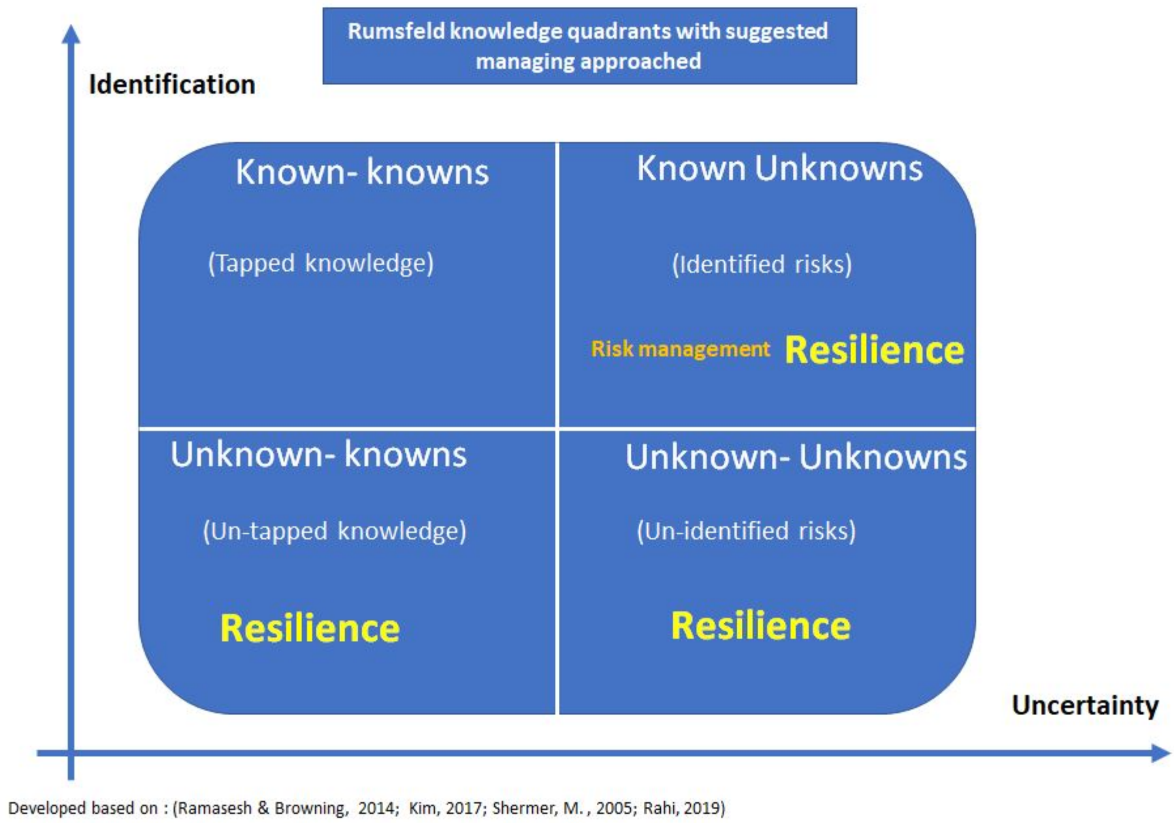


Figure 3.3: Rumsfeld knowledge quadrant & suggested managing approaches

3.2. What is resilience?

3.2.1. In science branches

The concept of resilience is identified in the Cambridge dictionary as: "the ability to quickly return to a previous good condition". Resilience as a term is not newly born, it was existed and has been used for centuries in various aspects like pharmacy manufacturing, mechanics, and social sciences. One of the earliest uses of this term was in the 1950s by physicists to describe the material resistance to external shocks. After that, while systemic thinking was growing in the 1960s, resilience as an expression started to be used and explored more by ecologists (Amirzadeh et al., 2022). Ecological research was one of the very first fields where the resilience concept emerged in scientific papers. Here, it is important to mention the ecologist CS Holling - the father of resilience theory- with many research papers related to resilience conceptualization, applications, and measurement in the ecological, economical, and socioeconomic systems (Allen & Holling, 2010; Folke et al., 2002; Gunderson et al., 2012; C. S. Holling, 1973b, 1973c, 2004; C. S. Holling & Gunderson, 2002; C. S. Holling, 1996; Levin et al., 1998; Peterson et al., 1998; Walker et al., 2004). In 1973, C.S. Holling introduced resilience in the ecological literature in order to understand the non-linear dynamics feature of ecosystems (C. S. Holling, 1973a). In Holling's influential paper "Resilience and Stability of ecological systems" published in 1973, he identified resilience as follows: "Resilience, that is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (C. S. Holling, 1973b). He further pointed out an important distinguishing between resilience and stability concepts, as it is essential to understand that resilience is different and wider than the concept of stability. Stability is identified as the ability of a system to return to an equilibrium state after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it would be. Stability is only achieved if a system troves to a specific equilibrium point. On the other hand, resilience focuses on preserving the system's well- function, which may be achieved with the previous equilibrium point or a new one. Holling's research refers also that in several actual cases, the instability of an ecological system yielded more resilience behaviour for that system.

After Holling's leading paper, the resilience concept started to arise significantly in different branches of science. For example, psychology, management, and safety engineering. The conceptualization of resilience has partly homogeneous recognition across these fields as follows: "the capability and ability of an element to return to a stable state after a disruption" (Thomé & Scavarda, 2015). In the safety branch, E.Hollnagel and D.D.Woods carried out much research works in the direction of connecting safety and resilience engineering in projects (Hollnagel, 2006, 2008, 2013a, 2016, 2017a, 2017b; Hollnagel et al., 2006; Patterson & Deutsch, 2015). They define resilience as follows: "Resilience is the ability of systems to prevent or adapt to changing conditions to maintain (control over) a system property". (Hollnagel et al., 2006). In this definition, we notice resilience concept is extended to the prevention aspect, which was not mentioned in the Cambridge dictionary or Holling definitions. Furthermore, research was carried out to investigate infrastructure transport network resilience. Nogal et al. (2016) define in their research that an adequate resilience definition should specify resilience abilities in the perturbation stage including the system breaking point, and recovery stage including the targeted system equilibrium point. In the same field, Adams et al. (2012) defined resilience as: "The capacity to absorb the effects of a disruption and to quickly return to normal operating levels". In this definition, they specify the system property that resilience aims to preserve, mentioned in Hollnagel and Wood's definition as operating or performing (performance). While both of them set the criteria of the time needed for the resilience function to fulfil its goal(quickly return). Another criterion of resilience is the level of harmful effects that resilience enables the system to face, demonstrated by Batelle et al(2007). They define resilience as: "The characteristic that indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance required for restoration to its original functional state" (Batelle et al, 2007).

Across these definitions, mutual elements to adequately define resilience can be concluded, illustrated in Figure (3.4), and explained in the following:

1. Resilience of what? The studied **entity**: For example, System, element, network
2. Resilience against what? Resilience response's **trigger**: unusual conditions, changes, disruptions, disturbances, and accidents.
3. Resilience for what? Desired resilience response's **outcome**. All definitions describe the ultimate goal as preserving the entity's ability to perform (entity well functioning) through enabling withstanding disruptive events. The resilience concept as such is linked to the entity's desired performance. Two visions exist here: the first vision considers the desired outcome to go back to the original functional state and return to the good previous condition. While the second view considers the existence of several sufficient points that the resilience function can aim for.
4. Resilience through what? Desired resilience **functions and dimensions**. Resilience definitions describe functions of proactiveness (prepare, predict, anticipate, prevent), and reactiveness (respond, adapt, absorb, return, recover, and restore) which emerge through time: before, through, and after perturbation.

Resilience emergence phases

It was concluded that resilience is a time-dependent concept in terms of its functions' emergence. Resilience emerges when the entity is faced with perturbation, and it is reflected in fulfilling different func-

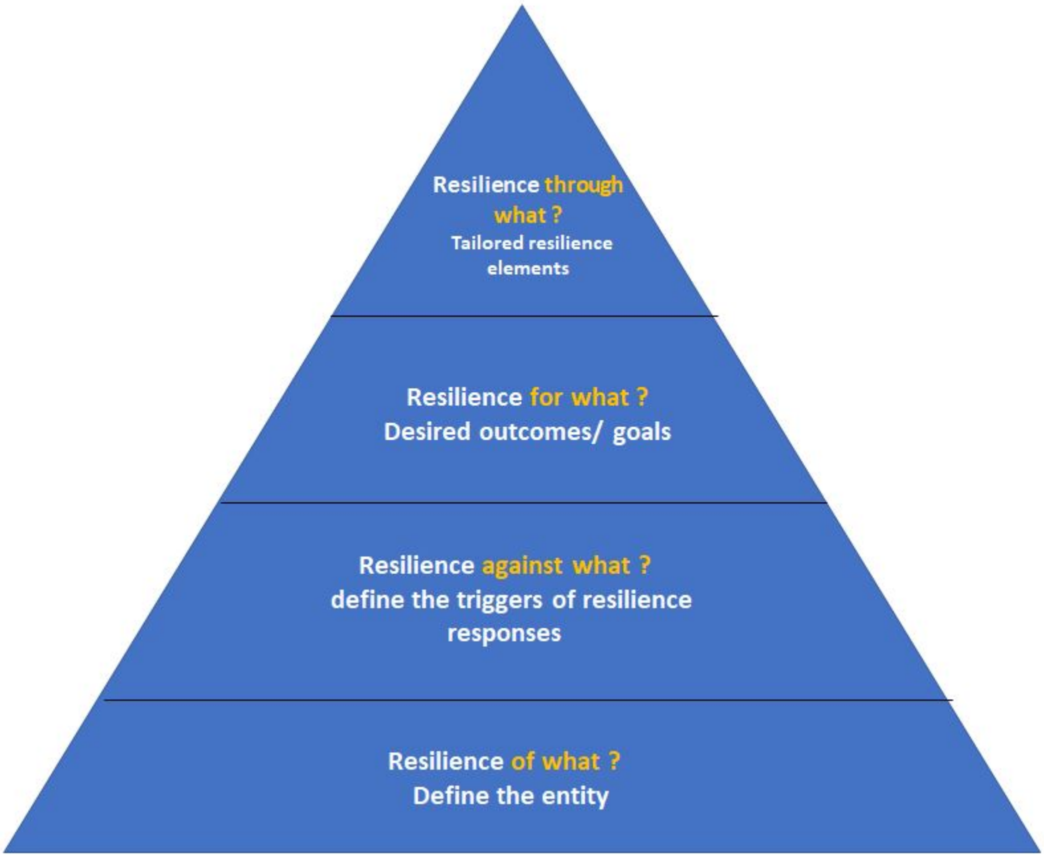


Figure 3.4: Adequate resilience definition

tions before, during, and after a disruptive event. It is usually illustrated through a curve (resilience curve; also named as project performance curve) initiated by the engineering field and used later by other science branches including project management fields to model the resilience of systems and the perturbation process. It is also used to quantify resilience. The resilience curve delineates system performance as a function of time, showing how project performance (represented by a chosen KPI) diverge through time once a disruptive event occurs (Kurth et al., 2019; Wied et al., 2021; Zarghami & Zwikael, 2022). Supporting this direction, (Wied et al., 2021) consider resilience as a mediating concept between project performance and disruption through different phases. Resilience exists inherently within the system before, through, and after a disruptive event. However, it only emerges to be noticed and possibly measured once a disruption occurs. Therefore, understanding resilience can not be fulfilled without understanding these phases.

Some researchers set the focus on two phases of resilience emergence: perturbation (disruption) and recovery phases (Pastor et al., 2015; Wied et al., 2021). While other streams include these two phases and extend them to compridivergese-disruption" and "Post-recovery" phases (Kurth et al., 2019; Zarghami & Zwikael, 2022; Z. Zhu et al., 2020). Overall, resilience emergence phases consist of four stages, these are Pre-disruption, disruption, recovery, and post-recovery.

A comparison of different illustrations of the resilience curve is introduced in Figure (3.5). The aim is to understand crucial moments that Identify the start and ends of resilience emergence phases. To this matter, Geambasu (2011) refers in her study of construction projects' resilience to another important point in time which is the moment of communicating the problem to the decision-makers or parties who are able to solve it. It is emphasized that there should be no elapse between this moment and the moment of first acknowledging the problem. The introduced resilience curves were used to illustrate resilience for different systems under different disruption types. Curves (1) and (2) study the resilience of projects under unpredicted but not devastating disruptions, as they illustrate the degradation in the

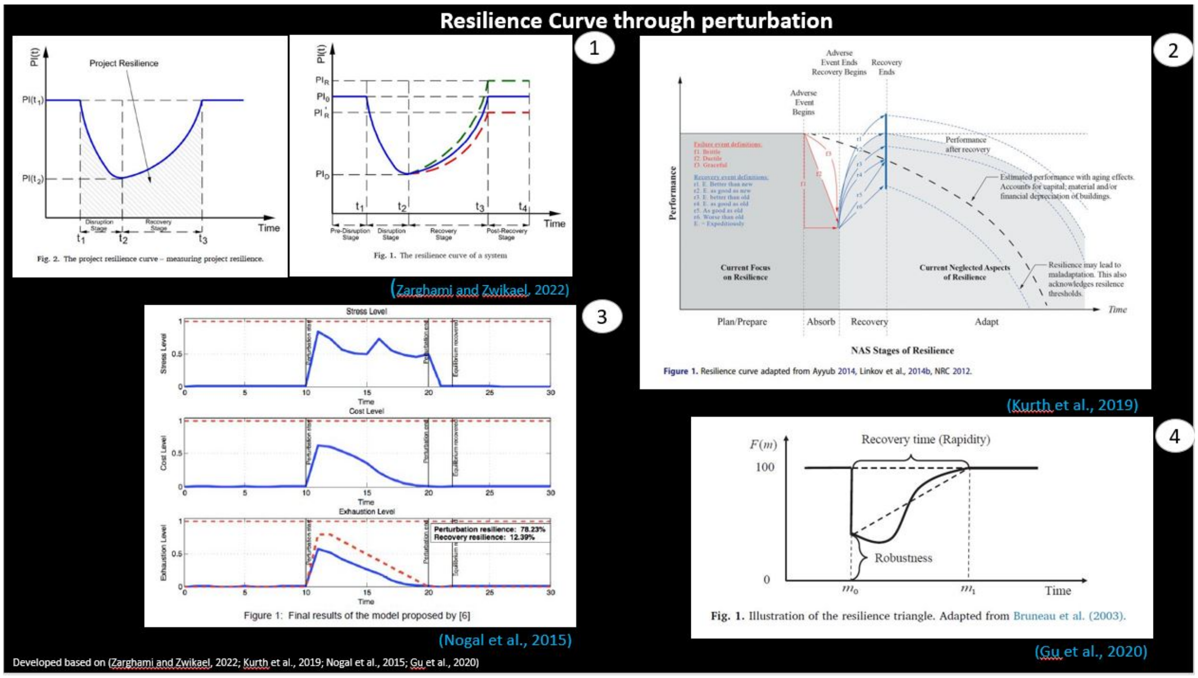


Figure 3.5: The resilience curve and phases

project performance once disruption occurs, as a gradual decrease. Similarly, curve (3) studied a transportation network under weather disruption conditions, where the effect of disruption increases in a gradual way. However, for the curve(4) we notice an instant decrease in the performance, the reason is that it reflects the effect of seismic disruption events on society, which is devastating and causes fast damage on a large scale. However, despite that the type of performance loss differs depending on the type of disruptive events, still we can recognize the same phases for resilience emergence (before, during, and after disruption). From a time perspective, there are two mutual essential milestones illustrated in the discussed figures, these are the start of a perturbation, and the end of a perturbation. Resilience then implies specific functions for each phase.

A summary of these views is presented in table 3.2, to identify the most repetitive functions per phase, where functions with the most consensus (most repetitive by different authors) are obtained to be linked with emergence phases as follows: (1) Pre-disruption phase: predict and prepare, (2) Disruption phase: Absorb, resist, (3)Recovery stage: recover and restore, (4)Post recovery: Learn.

To that matter, Z. Zhu et al. (2020) in their study of the resilience of a construction project's safety system, introduce a logical descriptive flow of resilience functions per phase in the following: "Before the accident, "resilience" requires the safety management system to be able to feel the accident and predict the impact of the accident. When the accident occurs, the "resilience" requires that the safety management system is capable of controlling the accident well and minimizing the wastage caused by the accident. After the accident, resilience requires the safety management system to have a better emergency and rescue system and to be able to recover as quickly as possible from the accident attack. Meanwhile, after the accident, "resilience" also requires the safety management system to selectively summarize the safety management process and learn from the experience".

3.2.2. Resilience in construction projects

Since a construction project is a system and a temporal organization, the concepts of system resilience and organization resilience are reviewed to help understand and conclude the resilience of a construction project.

Systems' resilience

A resilient system is a system that is able to cope successfully with unpredicted threats and shocks(

Resilience phases and cooperated activities				Source
Pre-Disruption stage	Disruption stage	Recovery stage	Post-Recovery stage	(Zarghami & Zwikael, 2022)
	Absorb, resist or accommodate	Restore, return or recover		Pator et.al, 2015
Anticipate and predict	Control and mimize effect		Learning and documentation	Zhu, 2020
preparation	Adjustment	Adaptation		Bhamra et al, 2011
Awareness, notice, monitor, interpret,	Restore capacity, evolve in response, overcome, cope			Rahi, 2019
Prevent, reduce possible impact	Absorb initial mpact , minimize consequences and cascading effects	Collect information, assesment, deciosn making , resource allocation	Learn and improve	Ouyang, 2012
Detect, understand, and plan for changes in environment	Minimize damage	Adapt to new realities		Turner, 2015
Understand variations	Absorb	Respond		Nachbagauer, 2019
Anticipate	Manage	Rebound, recover	Reverse improvement	Pavez, 2021
	Resist,withstand	Cope, recover		Wang, 2022
Decline; Accept that an incident may occur, prepare	Survive	Bounce back: recover quickly	Bounce forward: improve risk management , nurture resilience culture, take advantage of shocks, , grow ,	Mowbray, 2011).
Predict, prepare	Absorb, minimize impact, resist	Adapt, recover	Learn , improve	Most Repetative

Table 3.2: Resilience Phases and cooperated functions

Walker et al., 2006; Andersson, 2006; Jackson, 2007). This view includes only facing the negative and predicted type of events, stressing only the phase of perturbation. This vision expanded through time to include expected and unexpected events, as well as changes and opportunities. The focus also expanded to include the phases of before, during, and following the event (Hollnagel, 2015; Tengblad & Oudhuis, 2018; Vidal & Marle, 2012; Z. Zhu et al., 2020). In systems engineering resilience is mostly seen as related to four abilities of a system: **anticipate** future events, **monitoring** changes in the internal and external environment, **responding** to it either by already prepared plans or reactive actions, and then **learning** from failures as well as successes (Hollnagel, 2013b; Patriarca et al., 2018; Tengblad & Oudhuis, 2018). Similarly, Z. Zhu et al. (2020) suggests two main dimensions of system resilience: defense resilience and recovery resilience where these can be further divided into five dimensions of perception ability, prediction ability, response-ability, recovery ability, and learning ability.

Organizational resilience

Organizational resilience is the organization's ability to manage through disruptions without interruptions in its operations (pavez, 2021; McManus, 2008). The resilience of organizations is viewed to be related mainly to capacities the organization owns: absorptive capacity, adaptive capacity, and restorative capacity (He et al, 2017; Lee et al., 2013). Dimensions of awareness and alertness are also acknowledged by researchers, where there is a need for the organization to be aware of possible sources of internal and external changes and the effect it may have on its essential operation resources (tangible and intangible). A resilient organization is also expected to be able to forehead detect signs of possible disruptions and respond to it(Burnard et al., 2018; Rahi et al., 2019; Tengblad & Oudhuis, 2018). Organizational resilience is mainly seen to be achieved by continuous processes that are able to retain current resources or create new resources once needed. Q. He et al. (2017) consider human resources resilience and management, adequate redundancies, information and communication, and resourcefulness important factors that build organizational resilience in a construction project. Moreover, learning from previous positive and negative events is considered essential to building and improving organizations' resilience (Chen et al., 2021; Duchek, 2020; Vogus & Sutcliffe, 2007).

Construction Projects' resilience

In the domain of the construction industry, few research works identify the resilience concept at the level of a whole construction project (Rahi et al., 2021). In order to understand project resilience, it was conceptualized either as an attribute (capacity or ability) or as a process. The process view stresses the dynamic feature of resilience evolving over time once a project is faced with a disruptive event (Naderpajouh et al., 2020). Across these aspects, researchers viewed a construction project from two perspectives: the first is as a temporary organization (**Rahi**; Geambasu, 2011; D. Wang et al., 2022), and the second is as a system (Hosseini et al., 2016; Z. Zhu et al., 2020). In literature related to construction projects, only three definitions were found that explicitly define construction project resilience. The first one is introduced by Q. He et al. (2017) as follows: ”The capacity of an organization of a construction project to **absorb** pressure, develop positive **adaptive** behaviours, and **quickly recover** from adverse impacts in order **to preserve functions** to **achieve expected targets** despite of being subjected to disruptive events in a **complex and dynamic environment**”. Essential words are highlighted in this definition to point out that it included all the points identified in the previous section 3.2.1, where the main aim of resilience is to preserve project functions and achieve project planned targets and the way to do that is specified through three abilities of the project to absorb, adapt, and recover. The trigger for these resilience responses is complexity and dynamicity. Another important element used to define resilience is the speed of recovery (to be fast), and that is actually logical because most projects eventually recover from disruptions and arrive at the delivery phase, with or without delays and cost overruns. So, what makes a project actually resilient is to recover in a fast manner without harming project objectives, as specified in this definition. Mahmoudi and Javed (2022) mention that: ”All projects can face troubles at any stage of project execution; however, their ability to achieve the maximum level of recovery in the minimum level of time is the key distinguishing feature and defines the project resilience”.

The second definition found of construction project resilience is the following: ”For construction projects, resilience is the process of **resisting** and **recovering** from **adversity**. The whole process in which the **positive interaction** between component units enables the project collectively to **withstand shocks**, **cope with challenges** and **recover** (D. Wang et al., 2022). In this definition interesting view is set on the role of collaboration and interactions between construction project components. The stress is again on the functions the project should perform through the perturbation (resist; withstand and cope), and after perturbation (recover). Priemus et al. (2013) introduce a third definition of resilience in construction projects as: ”The ability of the **decision-making process** to deal with **unexpected influences**, **without risking indefinite delays** or, **stalemate** in the process. The process should be able to **learn and adapt**. This involves an ability to accept **’flexibility and adaptability, and preparedness** to cope with **uncertainties and unanticipated situations**. Resilience is a characteristic of both the decision-making process and the (mega-) project itself”(Priemus et al., 2013). This last definition adds two more dimensions of resilience in construction projects, these are preparedness (before the event) and learning (after the event). It also refers to that resilience is needed to deal with not only negative events rather than all kinds of influences which could be understood as threats, changes, or opportunities. Moreover, it consists of two important elements of resilience: the decision-making process, and flexibility. In addition to these previous definitions, few research works investigated resilience-related topics at the level of a construction project. These did not specify directly a construction project resilience but introduced a resilience definition to lead their research. These last are presented in the table 3.3 for a further understanding of the concept definition and dimensions.

3.3. How to build resilience?

To answer the question of How to build resilience? one may think in two aspects: process and elements. The first is about what processes or steps can help build resilience. The second is about what elements contribute towards resilience. This research doesn’t focus on the process, but rather on the elements. That is because even if we create a perfect process to build resilience, without knowing the elements and the exact practices contributing towards resilience, the process will be ineffective. To identify resilience-contributing elements in a construction project, it is essential first to understand what are the key pillars that actually synthesize resilience, these called dimensions. When we say resilience we should directly think of these dimensions that together compose the concept of resilience. It is similar to when we say cuboid, directly think in three main dimensions: length, width and height. Similarly, resilience dimensions are the essential aspects that configure the different manifestations of resilience. another essential point to be identified is the areas of construction projects which affect and get affected by resilience.

Definition	Definition type	Entity	Trigger	Resilience function	Function constraints		Desired outcome	Reference
Resilience is the project's capacity to **maintain** positive adjustments when confronted with **critical events** that are **inherent** in its life-cycle	Capacity	Project	Inherent critical events	Maintain positive adjustments	–	–	–	(Geambasu, 2011)
Resilience is an integrative property of complex systems which is **aggregated from dynamic behaviors and interdependencies** between constituents in systems but cannot be attributed to any single constituents	Property	System	–	–	–	–	–	(Zhu, 2016)
Resilience is then not a resource but a constant process of relating to the environment through a process of **understanding**, **responding** to, and absorbing variations	Constant process	–	Variations	Understand, respond, absorb	–	–	–	(Nachbagauer, 2019)
The ability to recover **timely and cost-effectively** from a disruption to the original or more desirable (improved) state	Ability	Project	Disruptions	Recover	Timely and cost-effectively		Original or more desirable (improved) state	(Mahmoudi & Javed, 2021)
Resilience is defined as a **set of interrelated capabilities** that are needed **before and after** the occurrence of a disturbance refers to the ability of a system to recover from disturbances either to the pre-disruption stage or to an even stronger performance level	Ability	System (the study is about construction projects)	Disturbances	Recover	–		Same/ stronger	(Zarghami, 2022)

Table 3.3: Resilience definitions in the construction industry

3.3.1. Resilience dimensions

To understand resilience dimensions, it is substantial to start by recognizing what is a dimension and a conceptual dimension. Then studying these in terms of resilience in literature works.

What is a conceptual dimension?

In the Oxford Dictionary, a dimension refers to the measurement of something in a specific direction. Also, it is defined as a feature, part, or way of considering something. Williams (2014) refers that dimensions are the different facets of what we perceive to be reality. It comes from the Latin word dīmēnsiōnem (nominative dimensio) "a measuring". While specifically "Conceptual dimensions are meant to identify the breadth of the concept as well as to aid its understanding" (Burget et al., 2017, p. 15). As such for resilience, resilience dimensions would refer to the different orientations that compose resilience, and the direction of measuring it. The resilience concept is considered multidimensional and complex (Q. He et al., 2017).

Resilience dimensions

In searching resilience dimensions, researchers incorporate resilience dimensions understanding with a time dimension (Francis & Bekera, 2014; Punzo et al., 2020; Rahi et al., 2019; Tengblad & Oudhuis, 2018). To that matter, there are three resilience emergence phases in face of perturbations, concluded in the previous Section (3.2.1). These phases are: before a disruptive event (pre-disruption phase), during the event (disruption phase), and After the event (recovery and post-recovery stage).

Research works define resilience dimensions based on their conception of the gradual emergence of resilience through the perturbation phases. That starts from the before perturbation phase by understanding the cause of disruptions, which is expressed through several similar terms as follows: vulnerability analysis (Cerè et al., 2017; J. Zhu, 2016), anticipation (Tengblad & Oudhuis, 2018), awareness (Rahi et al., 2019), perception and prediction ability (Z. Zhu et al., 2020).

Then resilience dimensions are centred around the main goal of acting upon anticipated disruptions sources using the following terms: effective planning (J. Zhu, 2016), preparation (Burnard et al., 2018; Punzo et al., 2020), risk management (Geambasu, 2011), and prevention (D. Wang et al., 2022). Then, dimensions are set to monitor these sources (Hollnagel, 2015; Patriarca et al., 2018). All of these dimensions belong then to the before perturbation phase enabling proactive behaviour of the system. While, once a perturbation occurs resilience dimensions are expressed as responding (Hollnagel, 2015; Patriarca et al., 2018; Tengblad & Oudhuis, 2018), adapting capacity (Burnard et al., 2018; Cerè et al., 2017; Madni & Jackson, 2009; Rahi et al., 2019), absorptive and recovery capacities (Francis & Bekera, 2014; Q. He et al., 2017). Then afterwards, after concluding a perturbation, dimensions expressed as recovery capacity (Cerè et al., 2017; Punzo et al., 2020; Z. Zhu et al., 2020), and learning (Hollnagel, 2013b, 2015; Madni & Jackson, 2009; Patriarca et al., 2018; Tengblad & Oudhuis, 2018; Z. Zhu et al., 2020). Some researchers focus only on the phases during perturbation and right after perturbation. Resilience is then seen to be composed only of three dimensions of capacities (Absorptive, adaptive, and restorative), where aspects like awareness and learning are considered parts that contribute to building these capacities Francis and Bekera, 2014; Q. He et al., 2017.

Table (3.4) illustrates the various adaptation of resilience dimensions in construction projects-related literature

Num	Reference	Dimenesions	Dimensions in Project	Entity
1	(Madni & Jackson, 2009)	Anticipating ability, adapting capacity, learning		System resilience
3	(Francis & Bekera, 2013)	Absorptive capacity, restorative capacity, and adaptive capacity	Project management , risk management, stakeholder management, systems engineering	Systems (focus on socio-technical systems)
4	(Hollnagel, 2015)	Anticipating, monitoring, responding, learning		Systems (focus on socio-technical systems)
5	(Zhu, 2016)	Vulnerability understanding, effective planning, and adaptive capacity	Human agents, information, resources, and tasks	Complex engineering projects: from a system view
6	(He et al, 2017)	Absorptive capacity, adaptive capacity, restorative capacity		Resilience in a construction project : organizational perspective
7	(Patriarca et al, 2017)	Anticipating, monitoring, responding, learning		Complex socio-technical systems
8	(Cerè et al, 2017)	Vulnerability understanding, adaptive capacity and recoverability		System resilience
9	(Tengblad & Oudhuis, 2018)	Anticipating, monitoring, responding, learning		Organizations and companies: Organizational resilience perspective
10	(Burnard & Tsinopoulos, 2018)	Preparation (reactive, proactive), Adaptation (rigid, agile),		Organizational resilience
12	(Rahi, 2019)	Awareness, adaptive capacity		Projects resilience: an organizational perspective
11	(Punzo et al, 2020)	Long before disruption (Awareness, planning, preparation), before (monitor, detect, recognition), during(containment, mitigation), after (repair, reconfigure, replacement), long after(learn and improve resilience)		Resilience in complex engineering and engineered systems (CES)
13	(Zhu, 2020)	Defense resilience (perception ability,prediction ability) and recovery resilience (response-ability, recovery ability and learning ability).	Organization, personnel, material, technology and information	System resilience

Table 3.4: Resilience dimensions from literature

As we can see, there is no explicit consensus in the literature on the way resilience elements are grouped into dimensions, or on how many dimensions resilience consists of. For example: Rahi et al. (2019) considers awareness as a dimension itself, while Francis and Bekera (2014) and Geambasu (2011) considers it a segment leading to larger dimensions of adaptive and absorptive capacities. Similarly Hollnagel (2015), Madni and Jackson (2009), Patriarca et al. (2018), Tengblad and Oudhuis (2018), and Z. Zhu et al. (2020) consider learning as a dimension by itself, while Francis and Bekera (2014), Q. He et al. (2017), and Rahi et al. (2019) consider it part of the adaptive capacity. However, what we do see is that this research works confirms that awareness and learning aspects are essential for resilience. So, there is an implicit alignment of the core ideas, while the main difference is in the way these elements are grouped and linked together into dimensions.

As such, the literature doesn't show one straightforward way to define resilience dimensions. However, we may identify three main aspects across the pre-discussed various visions:(1)**Proactivness:** There are aspects related to the level of preparation a system has in its normal status. (2) **Reactiveness:** referring to the capacities the project owns to successfully perform in reaction to a perturbation. (3)**learning:** It represents how the project and the organization learn after a perturbation. Resilience is then mainly built by preparing the project on purpose, and ahead to perform pro-activeness, reactiveness and learning-related functions. Jia et al. (2020), McEntire (2021), and Rahi et al. (2021), suggest summing up resilience dimensions into proactive and reactive resilience. Samewise, Giezen et al. (2015) support the same idea but with different labelling as Passive resilience and active resilience. Therefore, in this research the main dimensions of resilience are considered to be:

1. Proactiveness
2. Reactive capacities
3. Learning

1. **Proactivness: Awareness, Anticipation, alertness**

   Proactiveness is linked to the phase of ”before disruption” where the system is performing under the normal design conditions (Punzo et al., 2020). To that matter, three main sub-dimensions can be recognized: Awareness, anticipation and alertness.

   (a) **Awareness**

   Awareness represents the ability to be aware of internal and external changes and possible sources of disruptive events. That is built essentially on having knowledge and information about the input and output of the project (available VS needed). Indicators of awareness are considered to be: clarity of roles and responsibilities, availability of risk management methods, alertness to scope and performance deviations, sensitivity to environmental changes, the efficiency of external resources, and leadership and involvement of stakeholdersRahi et al. (2019). A project organization needs to have awareness regarding internal (operations, structures, available resources, and dependencies) and external factors (surrounding environment and its demands). Awareness enables managers to evaluate the available capabilities of the organization and assess the possible disruptions and impacts (Burnard et al., 2018). Tengblad and Oudhuis (2018) refer to important enablers for resilience functions of having personnel self-awareness of their own skills and performance, risk awareness culture, decentralising risk management tasks at the various levels of an organization, and creating risk awareness throughout the entire supply chain.

   (b) **Anticipation**

   In the Oxford dictionary, anticipation means to imagine or expect that something will happen and to take action in preparation. In other words, it involves: expecting and preparing. Anticipation is enabled by predictive and look-ahead capabilities to discover how the environment is expected to change and take actions aiming to avoid future disruptions (Madni & Jackson, 2009). Hollnagel (2015) views this concept as the ability to deal with the potential in the distant future through anticipating future conditions, opportunities, threats, changes, and novel demands and constraints, that may have a negative or positive effect on the system functioning. He considers risk management as a viable way of anticipation for well-specified and stable systems, where risks don’t change radically and rapidly or obsolete over time. While in less specified socio-technical systems with partial knowledge of its principles of functioning, risk management is considered inadequate. Hollnagel (2015) further specifies elements that enable the anticipation capabilities as follows: having the expertise to rely upon for the anticipations, efficient communication and timely share expectations, explicit anticipation processes, and risk awareness culture. To this matter, Geambasu (2011) indicates that effective risk management practices, using warning indicators, monitoring warning indicators, and preparing response plans, are important to create fast and timely responses and build more resilient projects. Anticipation should be distinguished from monitoring through the time scale that each covers. Monitoring focuses on detecting and coping with near-term issues of daily activities and it utilizes leading and lagging indicators for that purpose. While anticipating focus on long-term analysis of possible disruptions through understanding the characteristics of the system and the surrounding environment that stands behind these events. In relation to anticipation, historic data may serve to forecast future events to some extent but it doesn’t enable discovering new or never-happened events (Patriarca et al., 2018).

   (c) **Alertness**

   Alertness is the detection and sufficient understanding of internal and external signs (changes, performance deviations, Performance indicators) of possible disruptive events. To come to the stage of alertness, two important functions should be in place: being aware of what to look at (e.g., what are the possible characteristics, dimensions and sources of possible disruptions?), and monitoring the system and its environment, in general, and also with paying special attention to the areas of adversity that the system is already aware of. More elements found participating towards alertness are: incessant exchange of information across the organization and its supply chains, having a clear process to manage information exchange, and continuous monitoring of environmental fluctuations (Burnard et al., 2018)

2. **Reactive Capacities**

   (a) **Absorptive capacity**

   Absorptive capacity is the capacity of a project system to absorb and minimize the repercussions of disruptive events with little effort and without changing its original processes, components or initial structure (e.g., governance structure). It enables projects to operate more successfully in the context of complexity and uncertainty. Factors that contribute to absorptive capacity are defined in literature based on empirical case studies to be: complexity-based planning and management methods, team building, early involvement of project team members and stakeholders, the use of BIM (Building Information Modeling), and early purchase orders for procurement (Vugrin et al., 2011; J. Zhu, 2016). Absorptive capacity is represented also in research by the robustness concept, which enables a system to withstand shocks through having shocks' absorbers (e.g., buffers in resources, in time, or money) (Madni & Jackson, 2009). This capacity is a pre-disruption capacity that the system owns in the normal operational status. However, it emerges to absorb disruptions effects, to a certain extent, once they occur. This extent is affected by the related decision-making of the project management, for example, deciding how much time or money to invest to overcome a disruptive event depending on the project and the organization's interests. Therefore, it is related to planning and management features (Francis & Bekera, 2014).

   (b) **Adaptive capacity**

   Adaptive capacity is the ability of a project to reconfigure its components, structures (e.g., organizational structure), or processes (e.g., execution processes) in face of disruptions. This capacity relates to the level of ease and quickness of the project to make internal changes (Folke et al., 2005). It is a continuous process of adapting to changes through the project life cycle. Adaptive capacity roots back to an important aspect of ecological resilience (changing into new configurations of equilibrium state) (Geambasu, 2011). The need for adaptive capacity emerges especially if the absorptive capacity has surpassed (Francis & Bekera, 2014). J. Zhu (2016) suggests factors that enable complex construction projects' adaptive capacity. These factors are: having proper information sharing, collaboration, creativity, flexibility in work arrangements, availability of a third-party consultant, and timely decision-making. Moreover, it is identified that preparedness to face unfavourable events, capabilities to predict adverse events, having awareness about the existence of unpredicted ones, and applying risk management practices are considered elements that increase the adaptive capacity through enabling fast and already planned responses (Francis & Bekera, 2014; Geambasu, 2011).

   (c) **Restorative capacity/ Recoverability**

   It is the capacity to sustain the project's performance after facing a critical event. Fundamental elements that contribute to this capacity are diversity (team skills), flexibility (technology, contracts), positive relationships, proactive planning strategies (parallel planning), team motivation and work experience (Geambasu, 2011). If the project's absorptive and adaptive capacities were not fully adequate to face disruptions, then the effects of these events may lead the project performance to deviate from desired levels which require restoration capabilities to be maintained as much as possible, to preserve the previous operation level or to move into a more improved one. It is important here to identify specific requirements to represent the desired level of performance that a restorative capacity aims to sustain. An important description of this capacity is to enable quick recovery of a desired performance level. Therefore, Stakeholders' good and cooperative relations and ability for timely reactions are two identified factors that contribute to creating projects' restoring capacity (Francis & Bekera, 2014; J. Zhu, 2016). However, this capacity may be challenging to create due to the possible conflict of interests amongst project stakeholders towards the recovery costs and its liability (Francis & Bekera, 2014). This is one of the reasons that may lead to unideal restoration that entails some degradation in the performance.

Similar concepts but different terminology: cope & response

Concepts of cope and responses were considered in some literature amongst resilience dimensions. However, based on the explanations and examples associated with these two concepts, it is possible to conclude that the abilities to cope and respond are represented through the overall three capacities of absorb, adapt, and restore.

Cope:
Based on the contingency theory J. Zhu (2016) coping is seen as the project's ability to adapt its characteristic (e.g., structure) to the changing contingencies that represent the current reality of the project. For example, project complexity is considered a contingency element, and projects should be able to cope with this complexity over time to achieve their performance goals. That illustrates actually what the pre-mentioned concept of adaptive capacity is all about, to adjust the system structure in face of perturbation as we saw in the previous section. Therefore this concept is considered already covered with the adaptive capacity concept.

Response:
The response-ability is defined as the actions taken to **mitigate the disruption's impact**. Three main abilities are important to be in a function to enable the response. It starts with environmental (internal and external) **scanning and monitoring** for possible symptoms of disruptive events, detection of the event, and impact evaluation (Burnard et al., 2018). Important elements that enable the ability to respond in face of disruptions are the access to resources, which is seen to be achieved through stakeholders' solidarity and common vision aligned with the project team, and the client's vision. Furthermore, effective communication and trust enable this resourcefulness. Informal and good relations with suppliers enable decision-making (and hence the response to critical events) to be fast and based on knowledge and skills rather than authority (Geambasu, 2011). Burnard et al. (2018) refer to proactive planning, risk management, resourcefulness, contingencies, effective utilization of available resources, Managers' decision-making skills, flexibility and agility as response capacity enablers. They further explain that a response can be through two directions: either executing pre-planned responses or improvising reactive novel responses. However, a resilient system should own an essential key feature, which is a balance between both of these response directions (planned and improvised). It is essential to balance proactive planning (develop robust plans for predicted events) with resourcefulness (overcome the unexpected through allocating resources). Since this concept is mainly focused on the ability to respond through proactiveness and reactiveness which are both covered in the pre-mentioned dimensions, the responding concept is therefore seen as covered by proactiveness, adaptive capacities and restoring abilities.

3. **Learning**

   Learning is the ability to timely know, document and share what has happened in the system and most importantly being able to learn the right lessons from the right experiences. Successful learning implies having an efficient learning plan and allocating sufficient resources to make valid choices of what events should be taken or not taken into account. It is fundamental for the learning process to go beyond only counting how often a specific event occurs, but to learn also why it did or didn't happen. Learning should assist to modify what was not satisfactory, strengthen what actually worked well and reinforcing system abilities to anticipate and respond (Hollnagel, 2015). Patriarca et al. (2018) builds on Hollnagel (2015) suggested vision and suggests that learning from large disruptive events needs to be integrated with learning from minor consequence events and from normal daily activities. They further suggest elements to enable effective learning through empirical examples as follows: mentoring, team discussions, training and theoretical teaching, learning from other organizations' experiences, learning from failure and successes, and learning checks. Another vision of learning for resilience is introduced by Madni and Jackson (2009), they view learning as the ability to stay updated and constantly obtain new knowledge from the surrounding environment to grow and reconfigure the system. It is enabled by continuous monitoring, internally (e.g., system components, management and operations) and externally (e.g., market, stakeholders, nature) to depict changes that may cause disruptions. Furthermore, Tengblad and Oudhuis (2018) refers that having structured procedures for learning, a transparent learning process that is open to making and correcting mistakes, multi-functional teams (delegating some tasks across disciplines to learn and form a better understanding for own discipline), cooperative learning through informal conversations amongst team members, learning by doing from daily activities, flat organization, learning process imposed by the mother organization, learning incentives and awareness, and learning by repeating activities. They view learning as the positive side of disturbances that enable managers to make efficient long-term strategic decisions towards greater organizational growth.

Project-related resilience areas

Geambasu (2011) research revealed three project-related dimensions to achieve resilience in a construction project: **Strategy level** (common goals, mission, and vision, **Culture level** (risk, safety, network relations, proactivity), and **structure level** (flat structure, financial structure, flexibility through contract and technology). Likewise, J. Zhu (2016) find in her study of construction projects resilience that this concept's emerging properties can be captured and assessed through simulating project behaviour from a system perspective. The project then consists of four relevant levels: base level, activity level, process level, and project level. Each combination of the components in one of these levels produces an element from the next level. For example, personnel (base level) in the project use resources (material, equipment.., etc.) based on described and owned information to perform and create a certain assigned activity (activity level). The base level of a construction project comprises resources, human agents, and information. Project systems can be simulated as meta-networks consisting of different human agents, resources, information and task nodes. Resilience is needed to be embedded in all of these levels.

3.3.2. Resilience elements from theory

Top resilience elements from literature					
Element	**Element from literature**	**Source**	**Element**	**Element from literature**	**Source**
Network-based mobilising	Network and partnerships to mobilize resources once needed	Petit et al., 2013; Rahi, 2019; Sapeciay et al. , 2017; He et al., 2017; Gambesu, 2011	Escalation plan	Efficient escalation plan/system	Rahi, 2018; Akgün and Keskin, 2014
Team members diversity/ expertise	Qualified, inclusive and diverse team member to rely upon in anticipation and reactiveness	Hollangel, 2015; Geambasu, 2011; Tengblad and Oudhuis, 2018; Hanna and Sawalha, 2014	Learning strategy	Availability of official learning strategy to insure that lessons learned are analysed to further identify project vulnerabilities and apply enhancements	Rahi, 2019; Hollangle, 2015; Tengblad and Oudhuis (2018)
Project management methods aligned with project complexity	Complexity and uncertainty evaluation before choosing management style	Vidal, 2010; Zhang, 2007; Vugrin et al., 2011; J. Zhu, 2016	Learn from failure and successes	Learn from failure and successes, and celebrate small successes	Patriarca et al. , 2018; Hollnagel , 2015
Emergency response plan	Emergency response plan and guidelines	Rahi, 2018; Akgün and Keskin, 2014; Geambasu ,2011	Personnel continuous training	Continuous training, theoretical teaching and improving the knowledge level of personnel	Patriarca et al. , 2018; He et al., 2017
Stakeholders alignment	Stakeholders aligned vision, legitimacy, cooperation and solidarity	Gambesu, 2011; Sapeciay et al., 2019;Francis & Bekera, 2014; J. Zhu, 2016	Clarity of roles	Personnel clear understanding of their tasks through the project life cycle	McManus, 2008; Rahi, 2019
Timely communicate changes	Timely escalations, and share project changes and expectations within the team, with the mother organization, with clients and with stakeholders	Rahi, 2019; Hollangle, 2015; Sullivan-Taylor & Branicki ,2011	Risk management ownership	Personnel understanding and performing their role in risk management through the project life cycle	Hollangle, 2015; Rahi, 2019
Resources monitoring	Monitor changes and resources availability in the market and within the organization	Borekci et al., 2014; Otulana, 2011; He et al., 2017	Participation in industry-related events	Participate in networks and events related to the construction industry	Jones, 2015; Rahi, 2019
KPIs usage and monitoring	KPIs are used and monitored for budget, schedule, quality, and other objectives	Geambasu ,2011; zhu, 2016; Patriarca et al., 2018.	Effective risk management	Effective risk management practices	Geambasu, 2011; Rahi, 2019; He et al. 2017
Effective communication	Effective communication with monitor and minimize communication barriers between departments	Sonnet, 2016; Sapeciay et al., 2019; Hollangle, 2015	Flexibility through contract	Clauses that offer flexability and possible changes to the contract to find solutions once needed	Rahi, 2019; Geambasu, 2011
Proces for information management	A clear process to manage information exchange, and having efficient information system across departments	Rahi, 2019; Pasteur, 2011; Burnard et al., 2018	Information platforms	Recognize Information sources and information platform training to assure that all project personnel and related parties know where and how to find the needed information	Stephenson, 2010; Thomé, 2016
Nurture Innovation and creativity	Test, develop, and use new products, methods, and technologies to solve existing problems	Sapeciay et al., 2019; Zhu, 2016; He et al., 2017	Schedule buffer	Slack for critical activities to create flexibility in schedule	Gunasekaran et al., 2011; Madni and Jackson, 2009.
Project OBS choice	Project OBS timely completeness, and efficiency	Zhu et al., 2020; McManus, 2008	Contingancy budget	Contingency budget per project, and on the level of the mother organization	Rahi, 2019; Madni and Jackson, 2009.
Risk management methods aligned with project complexity	Complexity and unceratnity evaluation befor choosing risk management style	Vugrin et al., 2011; J. Zhu, 2016	Project parties good relations	Maintain good relations with all project parties through communication, collaboration and mutual goals alignment	He et al., 2017; Rahi, 2019
Early involvement	Early involvement of project team members and stakeholders in the project's early phases (e.g., tender, design)	Vugrin et al., 2011; J. Zhu, 2016	Supply chain management	Supply chain integration management and agility	Tengblad and Oudhuis, 2018
BIM usage	Use of BIM (Building Information Modeling)	Vugrin et al., 2011; J. Zhu, 2016	Planning and commitment to ptoject resilience	Planning for project resilience and commitment to it	® 2023 The ICOR; Hollangle, 2015
Early purchase orders	Early purchase orders for procurement	Vugrin et al., 2011; J. Zhu, 2016	Redundancy in resources	Redundancy in resources	Thomé, 2016; He et al., 2017
Operational flexability	Operational procedures flexability and alternative execution technologies	Francis and Bekera, 2014; He et al., 2017			

Table 3.5: Top resilience elements from literature

In addition to literature sources referred to in section (3.3.1), multiple sources of literature were used to specify elements that contribute to project resilience, from a literature point of view. Literature was chosen based on its relevance to the following keywords: project resilience or system resilience or organization resilience, and based on its date of appearance (2007 or later). The process involved studying the articles and their resilience-related references, listing the elements contributing to project resilience, compare these to identify the key elements. Once no new relevant elements were found, the process stopped. Elements contributing toward resilience, based on literature are shown in Appendix (.3). While the top repetitively mentioned elements are illustrated in the table (3.5) above.

Overall, 68 elements from the literature were found. Elements included soft organizational aspects among the most repetitive elements are: stakeholders alignment, effective and timely communication, unity of goals, early involvement of project team and main sub-contractors, networks, team building, complexity-based project management, early purchase orders, clarity or roles and ownership, good relation across project parties. While more elements were mentioned in relation to technical aspects, and the top mentioned are: technical-based-flexibility, KPIS usage, resources redundancy, information management processes, BIm usage, escalation plan, contract-based flexibility, information platforms usage, contingency budget, and schedule buffer. However, the most repetitive elements overall were in relation to the soft organizational aspects. These are network relations with sub-contractors, partners and suppliers, team member expertise and diversity, complexity-based methods for project management and risk management, stakeholders alignment, emergency response plan, and timely communication.

3.3.3. Available frameworks for resilience elements

In building resilience, searchers mainly looked into two main aspects: the process of building resilience, and the strategies, actions, and elements contributing towards resilience. The found research is mostly of a qualitative nature, with few papers found to mix qualitative and quantitative methods.

Eight process-related models were found which don't define resilience practices or elements (Burnard et al., 2018; Cerè et al., 2017; Francis & Bekera, 2014; Madni & Jackson, 2009; Patriarca et al., 2018; Punzo et al., 2020; J. Zhu, 2016; Z. Zhu et al., 2020). These models (except J. Zhu (2016)'s model) don't specifically search into construction projects but rather organization or system resilience in general. Mainly, four models were found that include elements contributing towards resilience, introduced by: Q. He et al. (2017), Hollnagel (2015), Rahi et al. (2019), and the International Consortium of organizational resilience (© 2023 The ICOR). Only one of them focuses on construction projects (Q. He et al., 2017). Figure 3.6 presents the advantages and disadvantages of the four frameworks found focusing on resilience contributing elements.

Searching into resilience contributing elements, the International Consortium of Organizational Resilience (© 2023 The ICOR), introduces the Organizational resilience framework. The framework consists of 12 management disciplines to improve organizations' resilience. Each is seen to be implemented as a system and then integrate with the others into one overall project system. The management disciplines are business continuity/ continuity of operations, crisis management and communications, critical environments, financial health & viability, human resource management, information & communication, incident response, information security, legal, audits, compliance, organizational behaviour, risk management, and supply chain management. In each of these areas, resilience is seen to be enhanced through managing change, building diversity, breaking down silos, managing risks, and adaptive capacity. This framework is supported by a model for increasing resilience: The organizational resilience model, based on ISO 22316. The model suggests organizational resilience principles and Attributes in (1) three dimensions (leadership & strategy, culture & behaviour, preparedness and managing risk), (2) nine strategies (shared vision, understanding context, effective leadership, available resources, managing risk, managing change, healthy culture, share information, continually improves), (3) six Behaviors of resilience (adaptive, flexible, resourceful, creative & innovative, inclusive & collaborative, Prepared, Robust & Redundant, Aware & Reflective, Diverse & Integrated). In both the framework and the model, explanations are provided but not within the framework but rather in separate capability assessments involving another 5 dimensions of resilience: leadership and strategy, culture and behaviour, infrastructure, preparedness and risk management, innovation and continual improvement. The presented content is very rich through all of these models and frameworks but that

Building resilience frameworks' comparison		
(© 2023 The ICOR)	Advantages	Covers a wide range of project management-related resilience dimensions (12 domains) which makes it inclusive in relation to project aspects, and aligned with practice.
	Disadvantages	Aspects provided are to a large extent abstracts, no further detailed elements or actions are assigned to resilience dimensions within the framework, which reduces its practicality. Also, all mentioned dimensions are related to organizations, but no explicit dimensions are included in the framework that relates to the resilience theory (e.g., Awareness, alertness, learning, absorptive capacity) which gives low flexibility to expand and adopt further resilience factors from other areas of resilience since
(Hollnagel, 2015)	Advantages	RAG offers coverage for resilience elements through the main phases of disruption (before, through and after), the elements explained through a question per each, which makes it clear and of a good level of detail to be applied in practice. It is also formulated flexibly to suit several types of systems (projects, organizations, and others), and examples of the way of application are provided and intended usage are clearly stated.
	Disadvantages	Elements are not combined in one overall framework. Hence the relationship between different elements among the four dimensions is not expressed. The elements are very process oriented so some soft essential resilience elements like collaboration or contractor-client relations are not elaborated among the elements.
(Rahi, 2019)	Adavntages	Items are all combined in one overall framework and the degree of detail the items reach makes the framework practicable to use. It combines theoretical and empirical bases and covers various project types. Suggestions for usage are stated
	Disadvantages	No practical example of the suggested usage is stated. Dimensions of resilience are not linked to possible related project management areas which may cause lower ownership by project team members to apply the suggested elements, as it is not clear whose responsibility it is. Also, the feature of multi-dimensional elements across dimensions is not highlighted, as these are more effective than others eleemnts in terms of participating towards several resilience dimensions at once.
(He et al., 2017)	Advantages	All elements are combined in one overall framework and a description is provided for each factor which offers practicability in applying the framework
	Disadvantages	The framework is very focused on the perturbation phase and reactive capacities needed, while aspects of before perturbation: proactiveness (e.g., awareness, alertness, anticipation), and after perturbation: (e.g., learning), are poorly elaborated in the framework.

Table 3.6: Resilience frameworks' comparison

also makes it too complex to grasp what are exactly the resilience dimensions and elements amongst all the presented different options and which framework or model would offer an overall view to be used in practice.

Hollnagel (2015) introduced the Resilience Analysis Grid (RAG) to build systems' resilience focusing on socio-technical systems. His approach qualitatively describes elements that enable resilience performance in four dimensions: the ability to respond, the ability to monitor, the ability to learn, and the ability to anticipate. Each ability is represented through a set of categories associated with questions, and each question can be answered by rating using six points Likert-type scale (Missing, deficient, unacceptable, acceptable, satisfactory, and excellent). The questions are detailed rather than abstract. However, it is stated that they may take different directions for different organisations and contexts, so they can be tailored and adjusted to suit a wide range of organizations. RAG doesn't intend to identify an absolute rating for resilience rather than provide a resilience profile of a system through these four dimensions represented by a radar chart for each. That can be used to manage the system and specifically to develop its potential for resilient performance. It is recommended to be used regularly through the life cycle of systems, as resilience elements are dynamic and change through time. However, still, no overall framework is introduced to combine elements of the four dimensions. Also, the resilience elements mentioned are very process oriented. Some soft organizational elements like collaboration or contractor-client relations are not elaborated among the elements.

Rahi et al. (2019) searched into the concept of project resilience from an organizational resilience perspective. He further developed a framework to assess and enhance project resilience. The framework combines theory and empirical studies of ten projects across several domains. It consists of two dimensions (awareness and adaptive capacity), 10 indicators, and 48 items are proposed to measure the two dimensions of project resilience. Indicators linked to the 'Awareness' dimension are clarity of roles and responsibilities, availability of risk management methods, alertness to scope and performance deviations, sensitivity to environmental changes, the efficiency of external resources, and leadership and involvement of stakeholders. While for the second dimension 'Adaptive capacity', the following indicators are set: engaging and empowering personnel, decentralising decision-making for qualified employees, resources mobilizing, partnerships and networks, personnel awareness of responsibilities, personnel innovative skills, strong decision-making and leadership, information availability and accessibility. Items are all combined in one overall framework and the degree of detail the items reach makes it clear and practicable to use. A 5-point Likert scale is suggested to be used for evaluating the indicators, by rating the items from ‘strongly disagree’ to ‘strongly agree’, with a neutral midpoint. However, no example is given of its application. The framework doesn’t specify explicitly which areas of the project management are involved to achieve the mentioned resilience items, rather than it is stated that project teams in general can use it. While this may not affect the framework used to evaluate resilience, it may lower the practicality of using the framework as a tool to build resilience. Some elements of the framework are located to participate in more than one indicator and dimension without explicit illustration of this feature of multi-dimensional resilience elements (e.g., partnerships are seen to participate in achieving efficiency of external resources as part of the awareness dimension, and also stated to enhance accessibility and mobilization of resources as part of the adaptive capacity dimension), which reflect an interesting finding that some elements have higher effectiveness towards resilience in its nature than others. However, this relation is not explicitly highlighted or explained.

Q. He et al. (2017) presents a qualitative framework of 15 critical factors to enhance resilience in construction projects from an organizational resilience perspective. The framework obtains three dimensions of absorptive, adaptive, and restorative capacity, 15 factors and three strategies to enhance resilience. The ’Absorptive capacity’ dimension consists of the following factors: slack resources, risk analysis, planning strategies, Insurance awareness, and Organizational learning. While for the second dimension ’Adaptive capacity’, the main contributing elements are stated to be: leadership, organizing capacity, communication, coordination, innovation, information and knowledge. The last dimension of restorative capacity is linked to the following aspects: external resources, loss assessment and insurance, re-planning abilities, and acceleration capacity. All elements are combined in one overall framework and a description is provided for each factor which offers practicability in applying the framework. However, the framework is very focused on the perturbation phase and reactive capacities needed, while aspects of before perturbation: proactiveness (e.g., awareness, alertness, anticipation), and after perturbation (e.g., learning), are poorly elaborated in the framework. Two elements are mentioned about these aspects: risk management and learning, which are considered part of the absorptive capacity dimension.

3.4. Conclusion

SQ1: What does construction project resilience mean, based on literature?

In the literature, there is little consensus on construction project resilience definition. Across all reviewed perceptions, a construction project resilience is introduced as the capacity, property, ability, or constant process of an entity (project, a system, or an organization) to perform certain functions (maintain positive adjustments, understand, respond, absorb, recover) in face of triggers (inherent challenging characteristics, critical events, variations, disruptions, disturbances) under certain constraints(timely effective, cost-effective) to achieve a desired outcome (same original performance state, or more desirable improved stronger state). In defining resilience, literature tends to build the definition on main areas to be thought of and distinguished. These are: specify the resilience of what, against what, for what, and through what.

The literature shows that resilience is needed not only in response to unknown-unknowns or unpredicted events, but rather for all types of disruptions such as known-unknowns, and unknown-knowns. Few works of literature have mentioned resilience needs in terms of positive affect events (opportunities) and these claim that resilience would enable projects to exploit opportunities. Construction projects’ inherent characteristics of complexity (dynamic and time-dependent) and uncertainty, make predicting disruptive events not always applicable and accurate. Hence, a risk management process that essentially depends on identifying the possible risks as a first step, would always hold uncertainties and sometimes totally miss anticipating some crucial disruptions. Literature acknowledges approaches claimed to help manage through the unknowns, like vulnerability management and agility. However, both of them were found to have a proactive focus mainly on tackling the probability of disruption events, without much effect on the ability to react and cope with the impact of disruptions. Hence, researchers state a need for an overall proactive and reactive approach.

Resilience functions in a project emerge to be more visible once a disruptive event occurs. It is mainly noticed through the project performance curves, named also the resilience curves. These curves delineate system performance as a function of time, showing how project performance (represented by a chosen KPI) diverges through time once a disruptive event occurs, based on multiple aspects (most used are financial and schedule performance curves). Resilience functions vary through the phases of before, through, and after a disruption, where the related project performance curve is noticed to take the bathtub shape that illustrates performance stability before disruption, decrease through disruption, and increase again after disruption to reach the previous stability level again, or a higher level.

SQ2: What elements contribute towards construction project resilience, based on literature?

Most literature works introduce resilience elements categorized into main dimensions that together constitute resilience. Even though there is low consensus on these dimension's choices (e.g., include vulnerability or not, include learning or not), there is consensus found on the main resilience elements. Research works define resilience dimensions based on their conception of the gradual emergence of resilience through the perturbation phases. That starts from the phase before perturbation by understanding the cause of disruptions which is expressed through several alike terms as follows: vulnerability analysis, anticipation, awareness, perception and prediction ability. Then resilience dimensions are centred around acting upon anticipated disruptions sources (e.g., prevent or mitigate) using the following terms: effective planning, preparation, risk management, and prevention. Then, dimensions are set to monitor these sources. These dimensions focus on enabling proactive behaviour of the project system through the phase before a perturbation. While, once a perturbation occurs resilience dimensions are expressed as responding, adapting capacity, absorptive and recovery capacities. Then afterwards, after concluding a perturbation, resilience dimensions are expressed as recovery capacity, and learning. Across these visions it was concluded that there are resilience aspects related to the level of preparation a system has to face disruptions in its normal status, that is proactiveness that includes awareness, anticipation and alertness. A second aspect that can be concluded is reactiveness, in terms of what capacities the project owns to perform in reaction to a perturbation, including absorption, adaption, and recovery capacities. Lastly, a third aspect is related to the project and the organization learning after a perturbation. As such, three dimensions can be concluded from the literature: proactiveness, reactive capacities, and learning.

The main resilience elements found in the literature are as follows. In relation to proactiveness aspects: nurturing awareness, monitoring changes, effective control and KPIs (Key Performance Indicators), effective risk management, and partnerships for the proactiveness dimensions. While main elements mentioned for Reactive capacities were in terms of three capacities of absorption, adaption, and recovery. Factors of team building, effective planning, early involvement, effective information sharing, mobilizing, buffer usage for duration and budget, decision making, and risk management, are stated as participating in the absorptive capacity. The adaptive capacity elements focused on information sharing, collaboration, team creativity, flexibility (technology and contracts), response plans, and risk management. The recovery capacity-related elements focused on re-planning, damage assessment, the project team (skills, experience, diversity, positive relations (team, client, stakeholders), flexibility (technology and contracts), team motivation, mutual goals and interests among client, stakeholders, and contractor. Learning aspects focused on having an efficient learning plan, and allocating sufficient resources, mentoring, team discussions, training and theoretical teaching, team discussions, learning by doing from daily activities, learning incentives and awareness, and informal conversations.

Searching into resilience contributing elements, four related frameworks were found in the literature. These frameworks do offer valuable insights regarding practices and factors that support building and enhancing resilience. However, only one framework is found focusing specifically on construction projects. The other three handle resilience from one chosen perspective, either from an organization or a system view. Advantages and disadvantages vary among these models. For example, one model offers a good level of detail and operationality. However, it focuses on systems thinking and processes and neglects soft important resilience aspects such as client collaboration and good relations. while looking at another framework, it does elaborate on the soft concepts but introduces elements on an abstract level. There is, yet, no framework found that combines (1) studying resilience from system, organizational, and project perspectives, (2) illustrating the link between project management theory with resilience science, and (3) obtaining an empirical application to be built on theory and practice.

4

Empirical Study: Interviews

After defining resilience constituents from the literature, interviews were performed to further discover elements and aspects that helped in practice to create a resilient performance for complex construction projects, namely infrastructure projects, and reveal resilience barriers found in practice. This chapter aims to answer the research question SQ3 and SQ4.

4.1. Interviews set up

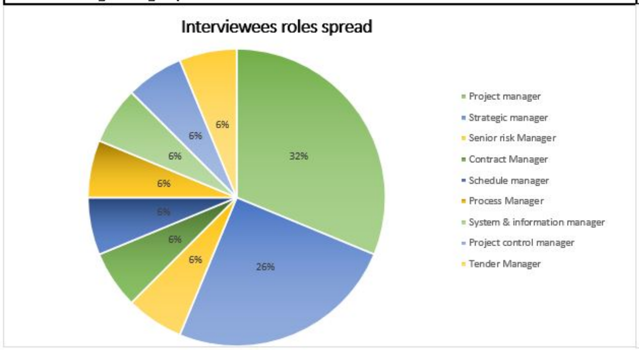
4.1.1. Study sample and interviewees selection

The study sample was chosen amongst complex infrastructure projects executed by Bam with the following criteria: a recent project (finished during the last 10 years;>2012, a complex project type A or B (Bam infra classifies projects in the tender phase based on its complexity into four levels from A (Highest complexity) to D (lowest)). This complexity classification is based on the following complexity elements ranked from the top-weighted element. First comes contract value. Followed by contract type, client record/ previous relationship, and technology needed. Finally, project location, project risk, and organizational complexity in terms of partners and previous relationships with them. Project budget ranges through these categories from 5M to more than 100M euros. More criteria are used to select projects sample as follows: success diversity to cover successful and non-successful projects related to meeting client requirements, intended duration, and planned budget. Also, the interviewees' availability was taken into consideration.

Interviewees were selected based on the selected projects, while amongst a large number of personnel per project, it was targeted to interview roles in the project management areas which were found related to construction projects resilience, based on the literature study. Therefore interviews included roles on three managerial levels as follows: The mother organization management level (strategic management roles from the mother organization), project management top level(project manager), project management middle level (process manager, project control, Schedule manager, contract manager, procurement manager, tender manager, risk manager, information and systems engineer). A project manager owns a comprehensive overview of the project, its encountered risks, success factors, and lessons learned. He plays a critical role in project success (team leadership, decision-making, client communication, ..., etc). For these reasons, and since the aim of the interviews is to discover the factors that enabled or not projects to perform in a resilient manner in face of disruptions, more interviews were conducted with project managers than the other roles where a project manager is seen to be able to give a rich overview of resilient factors. Other participants than project managers play also an essential role to provide more in detail resilient practices related to their role (e.g, planning techniques, contract management practices,....etc,).

Overall, 16 interviews were carried out (5 project managers, 3 strategic management roles, one strategic and project management role, 7 interviewees across middle management roles: a contract manager, a risk manager, a schedule manager, an information manager, a process manager, a project control manager, a tender manager). The process stopped at that number of interviews due to (nearly) data saturation and time limits, where for the last four interviews relatively very few new resilience elements were further introduced. Participants had various backgrounds: Civil engineering, Environmental engineering, Structural engineering, Business administration, Accountancy, and Real estate development. Fifty per cent of the interviewees (8 out of 16) had a civil engineering educational background. The experience of the experts in large infrastructure projects spread as follows: 13 participants Between (14 to 38) years of experience, one participant with 2 years of work experience, and two participants between (6 to 7) years of experience. Figure 4.1 illustrates an overview of the interviewee's background, roles, and years of experience.

Num	Position	Educational Background	Works experience (years)
1	Project manager	Environmental engineering	22
2	Project manager	Civil Engineer	38
3	Head of risk management in Bam NL	Engineering, real estate management, public adminstration	15
4	Manager of bam foundations techniques division	Technical degree: road and water constructions	22
5	Project manager	HTS Civil construction	6
6	Senior risk manager	Industrial engineering	30
7	Project manager	Civil engineer	30
8	Managing director in the management group for the	Civil engineer	20
9	Contract Manager	Civil Engineer	14
10	Project manager	Civil Engineering and business adminstration	30
11	Schedule management (Integral Planner)	Civil Engineering	20
12	Manager Business Unit (Integrated projects)	Business administration and management	26
13	Process Manager	Civil Engineer	6,5
14	Information system developer and system	Mechanical engineering, transport engineering, and logistics	2
15	Manager project control	Accountancy and project control	20
16	Tender Manager	Art & ntercultural communication	7



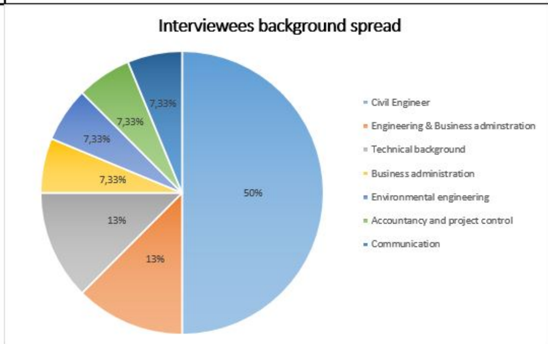


Figure 4.1: Interviewees analysis

4.1.2. Interview guide

Semi-structured interviews with an interview guide of 10 questions (Appendix .1) were prepared to fulfill the intended related objectives. The planned time for one interview is 60- 75 minutes. Interviews took place via the Microsoft teams online meeting tool due to its recording and transcription options, and time constraints. The link between interview questions, their targeted objectives, and research questions are explained in the following. The goal of the interviews is to help answer the following research sub-questions:

SQ3: What elements contribute to building construction project resilience, in practice?

SQ4: What are the limitations of building resilience in construction projects?

To help answer these sub-questions, interviews questions were designed with the support of the literature review findings with the objective of identifying construction project resilience dimensions and elements based not only on Professionals' expertise and views but also based on facts coming from specific solid incidents from real projects that participants were involved in. After the interviewer and the interviewee introduce themselves, the interview had 10 questions, grouped up into 5 main themes and one section to introduce the research topic. On purpose, the resilience concept was not introduced to interviewees in the first two questions groups (group A and B) to not direct their answers in a specific direction, and make a space for new resilience dimensions to emerge. The main research question, resilience definition, and resilience general dimension (proactiveness, reactive capacities, and learning) were only introduced after the empirical discussion regarding challenging issues, remedies, results, and lessons learned these experts faced in a complex infrastructure project. That helped them to acknowledge the research problem on their own before being introduced in the next interview phase (Phase D-Introduce the topic) by the interviewer. Then, interview questions go specifically into the three main dimensions of resilience found in the literature. However, to reinforce the empirical evidence (Avis, 2003), the general dimensions were revealed at a very general level without uncovering the resilience elements found in the literature study. The ten interview questions assembled in five main groups are further explained as follows:

A-Profile questions: helps understand the effect of interviewees' years of experience and academic and professional background on their vision of resilience concept. Also, it supports exploring participants' diversity which helps formulate a more comprehensive view of the research topic.

B-Resilience in expert views: This theme aimed to discover experts' free vision regarding resilience dimensions based on their experience in practice. Question 1, aimed to search the thresholds that project managers and teams aim to protect, as (Nogal et al., 2016) referred that it is essential that these thresholds are defined and clear in an adequate resilience definition, to serve ultimately design the resilience functions. Successful project were used instead of resilient project to not reveal the topic directions yet as (Rahi et al., 2019) refers that participants in practice has limited recognition of the word resilience usage in the construction management and the concept behind it. So, mentioning the word would lead to explanatory questions by interviewees to reveal the research topic which is planned to be introduced in phase D of the interview, to support the empirical evidence. The second question of group B: aimed to freely discover dimensions and elements contributing to face disruptive events in construction projects and hence towards its resilience.

C- Resilience in empirical case: This theme aims to discover resilience dimensions and elements based on an empirical case that experts were involved. The items are more tangible and linked to reality rather than only expert opinion which is also important and was considered in theme B. The studied projects and incidents were left to the expert to choose based on the projects they learned from the best. However, the criteria to direct their choice were explained. These are Infrastructure projects, project complexity (high: A or B), and successful or not (here successful definition is based on the agreed thresholds to safeguard which they already defined in the previous question 1). Half of the participants were asked about successful projects and the others were directed to less-successful ones. However, these percentages differed through the interviews' execution based on the interviewee's past experiences. The next Question 4, aimed to discover unexpected disruptive events they faced in the mentioned projects. Also, the notion of success was linked to their previous definition of success, and aligned with the success status of the project (successful or less-successful). For example, less successful projects may not have very successful incidents to focus on, rather than challenging ones. The interview was dynamic in that area and steered based on the interviewee's past experience. Elements of resilience were raised from the ways project teams could (or could not) successfully face the discussed event. Furthermore, question 5, aims to discover more about the managerial aspects and practices to face disruptive events.

D-Introduce the topic: this part holds no questions. It aims to introduce the research topic in preparation for the next interview phase(phase E). This section then started by explaining the research problem summarized in infrastructure projects' poor performance under high uncertainty and complexity. Then, the solution approach was introduced at a general level, represented in the resilience concept definition and the main general dimensions as defined in the literature review results without mentioning the elements which were resulted from the literature study.

E- Resilience elements and barriers in the specific resilience theory dimensions This section aims to uncover what elements contribute in practice to create each of the three main resilience dimensions (Proactiveness, adaptive capacities, and learning) as well as the barriers that hinder these aspects based on professionals' experience.

F- Closure This part views the participants as partners in this research, and let the chance for them to participate in any further views, literature, or advice they find related, important, and helpful to this research topic.

4.2. Data analysis method

The chosen method for the analysis is the Quantitative Content Analysis (check 2.2) using ATLAS. ti software. This method is used usually to capture and build a frame or model to describe a phenomenon.

It is systematic and consists of three main phases of preparation, organizing, and reporting (Vaismoradi et al., 2013). These stages include the following steps for inductive research: select the unit of analysis, open coding, grouping, categorizing, reporting, and conceptual system developing (Elo & Kyngäs, 2008). These phases are applied in the analysis of the empirical interviews as illustrated in Figure (4.2)

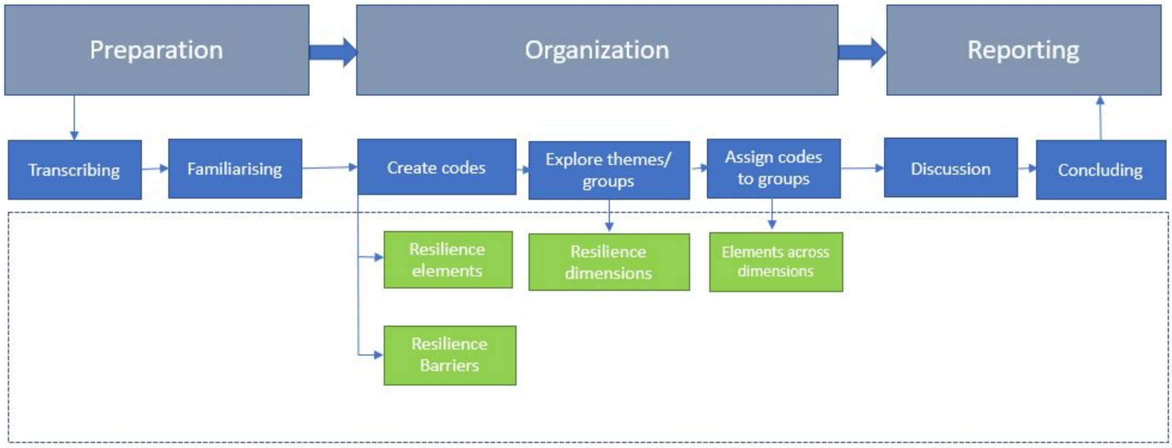


Figure 4.2: Data analysis process

1-Preparation phase: the recorded interviews were transcribed and documented. After that, a familiarising process started with re-listening to the interviews and highlighting the main ideas related to the intended interviews' objectives. These are quotations in the language of Atlas. ti tool.

2- Organizing phase: this phase included coding the highlighted data (the quotations). Coding means summarizing in a brief way related to research objectives. The reason behind coding is that row data is large and dense and takes a long time to go through and analyze. Coding helps represent the main idea of the data aligned with the research perspective (Elliott, 2018). For this research, codes represent resilient elements discovered in the interviews. Coding was held through a subsumption strategy to create codes that represent the data, this strategy implies reviewing quotations one after the other to either assign related pre-created code or to create a new code that suits the quotation (Friese & Ringmayr, 2013). Simultaneously, data related to the empirical incidents mentioned by interviewees (disruptive events, causes, solutions, results) were extracted and filled into an excel sheet to be analyzed and represented in the data analysis results. After that, an open detection of what the data wanted to say was carried out. In other words, defining emergent mutual themes or patterns across all the data (not across codes, to exclude the effect of researcher interpretations). That was done by using Atlas. ti Concept Clouds across all analyzed interviews' transcripts. This revealed a dimension for categorizing the data, emerging from the data itself, i.e., grouping based on project management fields (client, contract, schedule, risk management, ..., etc.). This dimension was used to further group the codes (resilience elements) in the final research outcome (not in the interviews' results, as another dimension of grouping was found also essential to be used based on the literature study and the research objectives, e.i, resilience-related dimensions (proactiveness, reactive capacity, and learning), and he software Atlas. it doesn't facilitate creating two-dimensional grouping (matrix) for elements). Following that stage, three groups were created in a concept-driven way (Schreier & Flick, 2013), and based on the research objectives and the main resilience dimensions concluded in the literature study (proactiveness elements, Adaptive capacity elements, Learning elements, and Resilience Barriers). Codes were assigned to related groups.

3- Reporting phase: This is done based on reports generated by Atlas. ti (concept clouds, list of codes, list of groups), then these codes were further organized into Excel files to be further compared, analyzed, and presented as findings. Overall, 16 interviews were analyzed. Within these 16 interviews, 349 quotations are made, and 87 codes were created. Codes were assigned to four groups based on the research interviews' objectives (proactiveness elements, Adaptive capacity elements, Learning elements, and Resilience Barriers), while another classification dimension emerged from the data and is used in the final resilience framework creation as a Matrix.

4.3. Results reporting

The approach focused on building up a gradual story-line with the interviewees starting with the interviewees' empirical perspective and then moving into a more specific literature-based resilience perspective. The empirical study of this research was reasoned as follows: define the resilience target, then uncover general resilience practices, main sources of disruptions, main disruption areas, and practices for withstanding disruptions through empirical focus cases. Then it was time to introduce the topic, and to make sure that the research is still building upon the successor's knowledge, the specific dimension of resilience(proactiveness, adaptive capacity, and learning) were investigated in practice. The results are presented based on the semi-structured systematic approach used in the interviews.

4.3.1. Resilience elements emergence

Elements of resilience emerged gradually through the interviews. As we can notice in Figure (4.3), interviewees who are in the role of a project manager (PM3, PM4, PM6, PM7, PM8) provided an average of 20 elements per interview. While experts in higher organizational strategic management roles provided an average of 22 elements (SM1, SM2, SM3). While middle management roles provided an average of 10 elements. This may support the initial reasoning of choosing participants in project management and strategic management roles, more than the other roles, as they own more overview and they could introduce more resilience-related elements. No new elements were introduced by interviewees in the last four interviews, and the overall number of resilience elements mentioned by participants decreased dramatically after the 12th interview (the reason may be that these interviews were with middle management of specific project management areas). Figure (4.3), introduces the empirical resilience elements that emerged through interviews. Each column represents the overall resilience elements mentioned in one interview.

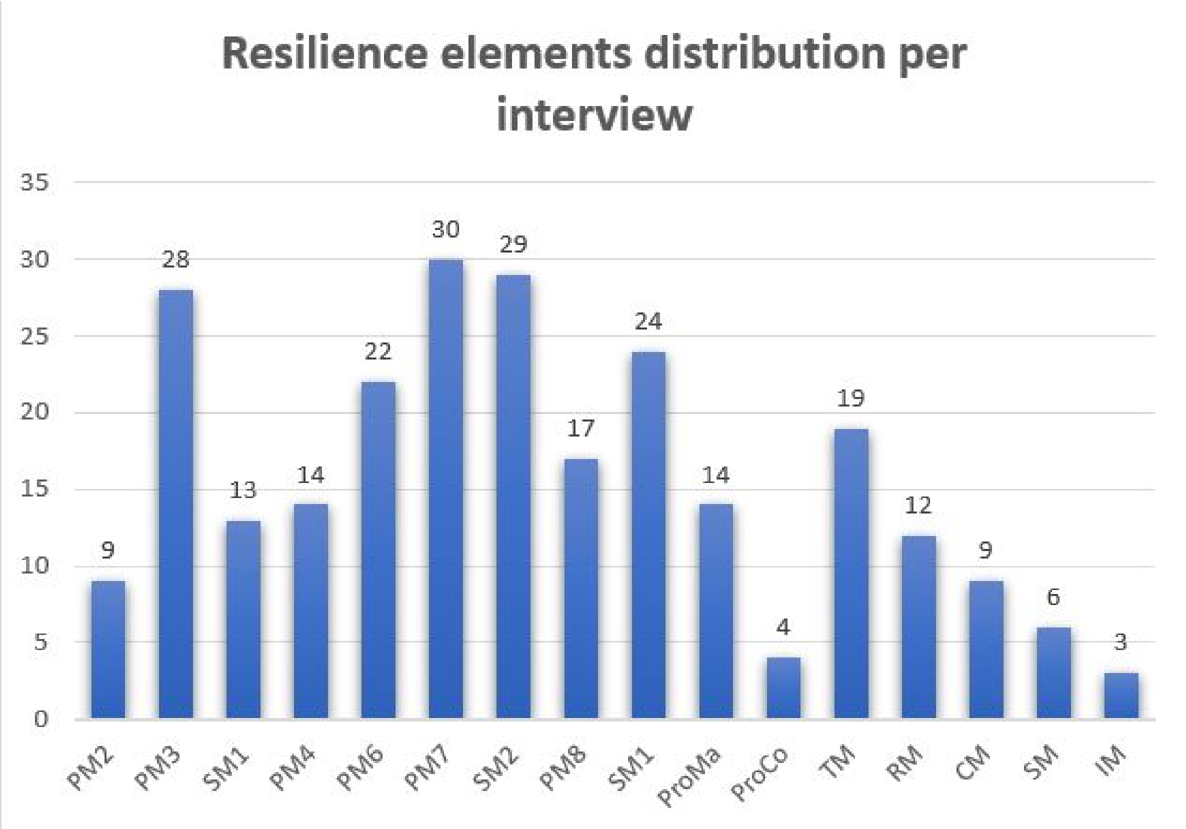


Figure 4.3: Empirical elements emergence through interviews

4.3.2. Resilience goals & thresholds

The resilience concept is highly connected in literature to the notion of success. If you are resilient, it is most likely that you are successful since resilience enables withstanding disruptions that threaten success criteria (Cooper et al., 2013). For construction projects, resilience focuses essentially on the continuity of success and keeping the normal planned level of functioning. Like a person succeeds continuously doing a task, or a system functions keep flowing the normally needed way (Doorn, 2020). Crosby (2012) revealed in his study of success in complex mega projects across Chile, Australia, and Europe, that success needs to be positioned in the front-end design of projects through embedded resilience strategies. This success concept needs to be specifically explained as it may vary from one organization or project to another based on their objectives and values (Chan & Chan, 2004). Resilience then, in a construction project, is also subjective to the definition of success for the project organization, since it focuses on the continuity of project success. That affects the resilience concept and its contributing factors. Therefore, Interviewees were asked first to define what is a successful project, and what thresholds they strive to protect once disruption occurs in construction projects, where a successful resilience function's response should be aligned with the defined success criteria of the project.

Resilience Goals

In defining what is a successful construction project, the interviewees had a large consensus (11 out of 16) viewing a successful project as a project that results in making the intended planned profit. The second element, in terms of participants' consensus, that makes a construction project a success is client satisfaction (8 out of 16), while project team satisfaction and on-time project delivery had the same level of consensus (6 out of 16). Other success criteria are stakeholders' satisfaction (mentioned by 4 out of 16 experts), safety (mentioned by 4 out of 16 experts), and quality (mentioned by 3 out of 16 experts). While some unique visions of a successful project were also found as follows: fulfilling project intended goals in the organization portfolio, resulting in a functional end-deliverable, Add value to the world (e.g., sustainability).

However, not all of these aspect has equal importance for all projects. The importance depends on the project position in the organization's portfolio and also on the related client and stakeholders. Nevertheless. From a contractor perspective, making a profit is stated as a highly important success criterion by most interviewees across all projects, as it is linked to the organization's continuity in the market :

"Everybody says we want to have the right quality and things, which are important, but I say we are a company that has to make money to keep existing. So in the first place, if you don't make money, you don't want this project in your portfolio" SM1.

The majority of the interviewed professionals referred explicitly and implicitly to the iron triangle of project management as an essential success characteristic: Time, cost, quality(Leong et al., 2014). However, not the scope.

"The triangle cost, time, and quality. That's the most important part" (ProM).

On the other hand, few experts did not consider being on time or within budget as factors that are always needed to achieve a successful project. They consider the importance of these elements subjective to the client and stakeholder's priorities of project objectives. They further referred then to the importance of client satisfaction, and stakeholder satisfaction.

"When my client is satisfied when my shareholders are satisfied, and when my team members are satisfied. Sometimes my client will have different priorities in the project objectives. I do not mention delivering on time or within budget because it depends on the project's objectives. So for example, in this project, now schedule and timely delivery is the lowest priority. The highest priority is compliance with regulations and requirements and stakeholder management. So that's why I don't put here that I'm successful when I meet the schedule or the budget. That is related to the project objectives" (PM4)

Safety was mentioned four times as a project success criteria. However, when it was mentioned it was considered of high priority, either as the first characteristic of project success, or considered one of the basic requirements rather than a project success criteria:

"That's the most important part, and safety is more than success criteria, it is a must, a requirement" (ProCo)

Two unique views on success were mentioned by interviewees in strategic management roles, both express a perspective wider than a project level. They set light on how this project participates to the organization's success and the balance of its portfolio, and also on how the project adds value to the world to make it a better place.

"Third, and this is a bit new now, but I'm also changing that, I think the approach is successful if we can make a positive impact on this world, to do something, that we don't harm the world, that we create sustainable solutions" (SM2)

"My success is more in the tender phase because I think that risk management, especially de-risking of your portfolio on a business level starts with the right projects in the tender phase with the right conditions" (SM1)

Since resilience aims to achieve the continuity of project success then a resilience response shall have then more than a fast response, and financial feasibility, where all the mentioned project success criteria are needed to be taken into consideration. As mentioned by the RM:

"Most times we do solve problems, it may take a long time, and cost more money, but eventually we solve them. The thing is how these solutions affect project goals" (RM).

Resilience thresholds

Since resilience is mainly about protecting the desired performance thresholds and evolving successfully in face of disruptions, interviewees were asked to specify if they have a specific acceptable percentage of performance deviations that they accept as a threshold to not exceed. Experts explained that there is no acceptable deviation level, and any variation of the planned duration, budget, or quality is not acceptable, but of course, it is almost inevitable. Once a perturbation occurs, project management always pursues going back to the same previous planning with as fewer changes as possible, even if the changes may seem to lead to a less duration or budget (opportunity), the actual problem is in the interdependencies. Project interdependencies are known to a certain extent in the original planning, projects then are more predictable and the project team has more knowledge about project component relations. while a change in the planning, in project components, or the used technologies may lead to creating new and unknown interdependencies and consequently to unexpected perturbations. The experts further explained that the thresholds are the planned duration, i.e., the critical path activities in planning, the intermediate milestones and moments of partial delivery of work (if contractually applicable), and desired quality. Also, the ability to keep performing the daily regular activity and keep the course of the project running is considered a threshold.

"We go to work day and night at the weekend to solve the problem, then we are again on track to the plan of the total project planning. Otherwise, with new planning, it is hard to oversee what cascading effect any problem will have on the whole project. That's because, for the main planning, we had months of work to plan things with each other in a way enabling us to anticipate the interrelations dependencies between activities. So, we had to get on track for this delaying part so that we are again, back to the planning that we thought about in the past." (PM4)

"Response is depending on the critical path and on the schedule that we should protect. If it's not necessary for that part of the work, then we don't need to speed. But if it's critical, we have to make our deadlines, then we have to speed up or add an extra crew."(MP7)

"I think the first thing is that if we fail to perform that's a breaking point. If you cannot do what we have to do. If you're not delivering quality, if you're not being on time, then the foundation of things start to crumble down." (SM2)

"Contract milestones are important to keep. It is not always the end milestone. Sometimes the individual ones you have to deliver something." (SM)

"If we have a loss, it's not a success. We need to earn money. So, we always think of an expected profit in advance and the profit could be a bit less, but if we have that, it is a loss then, it's not success. The client also has milestones from the contract in which he wants things to be finished, and most of the time they don't just think only of a date. But the date has a reason, because they have to hand it over to another company or the trains need to run at a certain moment." (RM)

4.3.3. Disruptions examples and resilience elements

To gain insights supported not only by interviewees' expertise but also with empirical examples, participants were asked to provide disruptive events cases from infrastructure projects that they have participated in during the last 10 years. Since resilience functions essentially aim to enable projects to withstand adversities, these real cases are valuable to provide empirical resilience elements. Table (4.1) introduces the resilience elements found through the empirical cases, ranked in descending order based on their repetitiveness among the different cases and projects.

Empirical residence elements from study cases

Element	Frequency	Element	Frequency
Client collaboration/ trust	8	External mobilizing	2
Team flexibility (eg., re-design, replanning, changing tasks)	6	Verification system for design against client requirements	2
Internal mobilizing (Within the mother organization)	5	Creativity	1
Client covers extra costs	4	Informing the client continuousely about project changes and status	1
Partnerships/ joint venture collaboration	3	Open and safe culture to share and solve mistakes	1
Effective communication (team, client, partners)	3	Suppliers' collaboration and good relations	1
Network relations	3	Effective risk management	1
Schedule Buffer	2	Crashing resources	1
Contract flexibility	2	Mother organization support	1
Changing work techniques	2	Team building	1
Change the project's team and management personnel	2	Managers positive mentality	1

Table 4.1: Empirical resilience elements- study cases

The empirical cases revealed that intangible aspects of Collaboration, trust, and flexibility, are essential elements that helped to overcome disruptive events. The two main components mentioned related to these aspects are the project team and the client. The study shows that they both played an essential role in solving multiple disruptions of various types and sources amongst 14 different projects, where client collaboration enabled overcoming eight various disruptions that each belong to a different project. Team flexibility also enabled overcoming the six mentioned disruptions. The elements found illustrate the three aspects of reactive capacities (absorptive, adaptive, and recover) that were found in the literature (check Section 3.3. Based on the definition of the absorptive capacity of being able to withstand disruptions without changing the system structures, the following elements were found to contribute to this capacity: Schedule buffer (absorb time), Internal and external mobilizing (absorb need for resources), mother organization support, partnerships. While other elements represent the ability to respond to disruptions by changing the system components or relations participating towards the adaptive capacity dimension, such as Changing work techniques and change in team personnel and management, contract flexibility, team flexibility to change their tasks, re-planning capacity, and re-designing. On the other hand, some elements were found related to the recovery capacity which means restoring resources and the ability to perform the desired level of functioning. For example, the client covering of cost overruns is a direct restoration of the financial loss that a contractor faces, compared to the planned budget, where this restoration will help in financing the rest of the project and continue carrying out the desired works.

The studied cases of disruption events are demonstrated in Table (4.2)

Disruptive event form empirical cases			
Interviewee code	Disruptive event	Interviewee code	Disruptive event
PM3	Sand storms that was more than we expected delayed the work	PM6	Authorities delays issuing a permit
PM7	Underground explosives not declared by the client in the tender phase, the authorities then did not give th epermission to start the work that led to dispute		Critical resource supplier (special glass) got bankrupt
	Covid effect on communication and staff availability	SM3	A large variation order from the client led to a change in the design, leading to a change in planning, and procurement. The client did not collaborate and cover the extra costs.
SM2	Specially built tunnel boring machiene mal function while execution	ProM	Delays in permits, due to the need to change the design, which goes back to contradicting requirements from the client (very detailed design requirements from the client that contradicts needed specifications).
	Design method not aligned with the ocntract client expectations which led to discussions and delay		The opportunity came up with corona virus , that the roads were less crowded compared to the normal situation in this construction area (city centre)
PM8	Opportunity : Client changed his needs after contract awarding , the new scope came up with a lot of negotations with client but also with better prices that led to make profit	ProCo	Delay in design, due multiple interpretations of design norms going back to that the project is unique, and international with a lack of international design norms
	Delay in the project design due to lack of needed technical knowledge to create solution design while doing in parallel design and construct		Contractual changes with a new set of standards for the technical installation, after one year project, had to stop and start over again.
SM1	Unexpected coronavirus that affected the collaboration and creativity of the project team in a negative way, and caused inefficiency at the working site due to needed health measures	RM	An error in the tender design was discovered in the construction phase, due to limited tendering time and the largeness of the scope which led to changes related to design, execution method and planning.
PM2	Two movable bridges were not functional to open and close properly due to over-designed safety indicators and wrong translation of client needs , which led to hindering cars and ships traffic and resulted in un-safe circularity	SCH	Planning in efficiency led to that installation started before finalising the engineering (design), then execution stopped because the design was not ready. Personnel changed or left from the design before finishing the design, the client change his requirements, and the design was not open in terms of having multiple
PM5	Through the execution of the building pit, the design had to be redone due to un buildability of the tender design, also under-qualified subcontractor partner responsible for the building pit, and team conflicts		

Table 4.2: Disruptive events from empirical cases

4.3.4. Disruption sources & occurrence timing

In total 19 disruptions were studied. Almost 50% of the studied disruptions appeared in the construction phase (8 of 19). While four appeared in the design phase, two in the planning, and another two appeared as stresses all over the projects. While for the commencement phase, tender phase, operation, and maintenance, only one disruption appeared per phase. Occurrences per phase are demonstrated in descending order in Table (4.3).

Disruption occurance phase	
Construction Phase	8
Design	4
Planning: permits	2
Stress: all phases	2
Commencement	1
Operation and Maintenance	1
Tender phase	1

Table 4.3: Disruptions occurrence per project phase

Disruption sources

While disruption's main sources were mainly found in the design (7 out of 19), Client related which is mainly found scope changes he requests that mostly imply changing the design, project planning, and procurement. Another area is tender: tender design, tender Inaccurate information handed by the client, and tender verification with client needs. Lack of technical knowledge by the main project team or subcontractors, environmental sources like weather or disease(e.g., Corona Virus). Novelty may be a source of disruptions as well. For example: in one of the project a boring machine was developed specifically for that project by a specific supplier, which makes the project in depend on the related supplier, and also the newness of the technology produce uncertainty. Furthermore, the lack of verification of project output, mainly design, against contract and client requirements. Moreover, team building if it is not efficient may be a source of disruptions like conflicts. Also, the change in the continuous changing of the team members weakens the learning curve and the team building, and lead sometimes to loss of information. other sources of disruptions were found to be: Parallel planning strategies for execution and design, authority low capacity issuing permits, critical suppliers going bankrupt, and unsafe project culture to be open or share mistakes. Table (4.4) shows these disruptions sources areas in descending order.

Disruption source areas			
Frequency	**Disruption area**	**Disruption sub-area**	**Saub area frequency**
7	Design		7
4	Client	Client changing orders	3
		Contradicted client requirements	1
3	Tender	Design	1
		Information	1
		Verification	1
3	Technical knowledge	Lack of technical Knowledge	2
		Under qualified sub-contractors	1
2	Environmental events	Nature conditions/ weather	1
		Nature / Covid desease	
2	Novelty	Technology	1
		Collaboration form/ lack norms	1
2	Verificatin	Wrong translation of client needs (Over-design, different design methods)	2
2	Team building	Team conflicts	1
		Team's personnel changes	1
2	Planning strategy	Planning strategy: parallel (design and execu	2
1	Authorities	Authorities (issuing permits capacity)	1
1	Suppliers	Critical supplier went bakrapt	2
1	Project Culture	Un-safe culture to share mistakes	1

Table 4.4: Disruption sources

What we can notice from the above tables, is that despite the fact that most disruptions are rooted back to the design area, almost half of the disruptions were not discovered till the execution phase, in several cases, a design was discovered to be unbuildable or contradicting with the client's requirements in the start of the construction phase, where mostly this will lead to re-design or design adjustment and delay the project.

4.3.5. Successful and less-successful projects resilience analysis

To have a better overview of the resilience contributing elements, half interviewees were asked about a disruptive event they faced in a successful project, and the other half were asked about less successful projects. Since resilience evolves and becomes visible in response to disruptive events (Check resilience curve notion in section 3.2), it was chosen to study and discuss in deep one disruptive event per project rather than the whole project as a specific example would results in more operational and specific resilience elements based on real disruptive events. To that matter, eight perturbations were studied in successfully delivered projects, while another eight incidents were studied in eight less-successful finished projects. Since all of the discussed projects are completed, we may say then that both types the successful and less successful were able to overcome disruptive events and reach their projects to the delivery point. However, in successful projects, the effect of these events is managed to not affect the project's main objectives (based on final financial and schedule results and also interviewees' answers). Since resilience focuses on the continuity of project success (Doorn, 2020), we may conclude that projects that were able to continuously respond to disruptions in a resilient way (as fast as possible and without harming the project's most valuable objectives), and hence protect projects' final results and objectives, own higher resilience level. Studying one disruptive event per project won't reveal then whether the project is resilient or not. Rather, it will help conclude what elements enable projects to overcome perturbations without harming projects' objectives (successful projects) or without harming projects' objectives (less-successful projects). Table (4.5) and Table (4.6) illustrate disruptions mentioned in successful and less-successful projects showing the events, the phase where the disruption was discovered (related project phase), the cause area, the solution area, lessons learned (was associated by the interviewees with the less-successful projects), project budget, project duration, and contract type, respectively.

Disruptive events in uccessful projects

Interviewee	Disruptive event	Related project phase	Cause area	Solution area	Budget (Million euros)	Duration (years)	Contract type
PM3	Sand storms that was more than we expected delayed the work	Execution	External: Nature conditions/ weather	Shcedule buffer	250	4	Design and Build
PM7	Underground explosives not declared by the client in the tender phase, the authorities then did not give th epermission to start the work that led to dispute	Tender phase	Tender information	Client covers extra costs, contract			
TM	Covid effect on communication and staff availability	Stress: all phases	External: Nature / Covid desease	Adapt the work and communication technique			
SM2	Specially built tunnel boring machiene mal function while execution	Execution	New technology	Critical supplier trust, joint venture collaboration,team flexibility , risk management			
IM	Design method not aligned with the ocntract client expectations which led to discussions and delay	Design	Design methods, alignment with requirements	communication	200	4,5	DBM
PM8	Opportunity : Client changed his needs after contract awarding , the new scope came up with a lot of negotations with client but also with better prices that led to make	Commencement	Client: Scope change	Team flexibility, client covers extra cost	220	5	Aliance contract
CM	Delay in the project design due to lack of needed technical knowledge to create solution design while doing in parallel design and construct.	Design	Design: Team technical knowledge planning: Parallel	Planning ,network, client covers extra budget, internal mobilizing, collaboration	220	5	Aliance contract
SM1	Unexpected coronavirus that affected the collaboration and creativity of the project team in a negative way, and caused inefficiency at the working site due to needed health measures	Stress: all phases	External: Nature / Covid desease	Client trust relation, contract manager positive mentality, creativity	65	2	Design and build

Table 4.5: Disruptions in successful projects

Disruptive events in less-successful projects

Interviewee	Disruptive event	Related project phase	Cause area	Solution area	Lessons learned	Budget (Million euros)	Duration (years)	Contract type
PM2	Two movable bridges were not functional to open and close properly due to over-designed safety indicators and wrong translation of client needs , which led to hindering cars and ships traffic and resulted in un-safe circularity	Operation and Maintenance	Tender verification, information, personnel, procurement	Client involvement , organization involvement, outsourcing	1- Not participating in projects beyond the organization's current specialty and knowledge. 2- Preserve team stability and continuity through the whole project			DBFM
PM5	Through the execution of the building pit, the design had to be redone due to un buildability of the tender design, also under-qualified subcontractor partner responsible for the building pit, and team conflicts	Execution	Tender design, un qualified sub-contractors, team conflicts	Change team personnel	1- Make sure to choose qualified subcontractors partners especially for executing critical parts 2- Change the project team once it is not able to function together			
PM6	Authorities delays issuing a permit	Planning: permits	External: Authorities	Client good relation , schedule buffer for critical activities		115	4	Design and Build
SM3	Critical resource supplier (special glass) got bankrupt A large variation order from the client led to a change in the design, leading to a change in planning, and procurement. The client did not collaborate and cover the extra costs.	Execution Construction	External: supplier Changing orders	Organization network Internal mobilizing, partners collaboration	Diversity in suppliers for critical resources			
ProM	Delays in permits, due to the need to change the design, which goes back to contradicting requirements from the client (very detailed design requirements from the client that contradicts needed specifications).	Planning: permits	Design , permits, contradicting requirements	Internal mobilization, verification system	1- Avoid investing large critical budgets internationally if we own low knowledge about their work culture 2- Communicate with the client before the design starts about the contractual value of his delivered design, and specifications. Ask him to explain the level of verification for the designs he provides.	300	6	DBFM
	The opportunity came up with corona virus , that the roads were less crowded compared to the normal situation in this construction area (city center)	Execution	External: Nature / Covid disease	_				
ProCo	Delay in design, due multiple interpretations of design norms going back to that the project is unique, and international with a lack of international design norms	Design	New collaboration form: lack of policies and norms	Communication and collaboration				Design and Build
	Contractual changes with a new set of standards for the technical installation, after one year project, had to stop and start over again.	Design	Changing orders	Mobilizing and client covers the extra budget				
RM	An error in the tender design was discovered in the construction phase, due to limited tendering time and the largeness of the scope which led to changes related to design, execution method and planning.	Execution	Tender design	Team changes, partnerships	The knowledge of people in the team is important and open culture is important. Speak up and discuss things., and share your knowledge and, and share information	500	6	DBFM
SCH	Planning in efficiency led to that installation started before finalizing the engineering (design), then execution stopped because the design was not ready. Personnel changed or left from the design before finishing the design, the client change his requirements, and the design was not open in terms of having multiple choices of suppliers	Execution	Planning: parallel	Re-planning, re-design, communication (client and team), verification		500	5	

Table 4.6: Disruptions in less-successful projects

In comparing both project types, several points were noticed. In the successful projects, they could discover the issues mostly in the early phases as we can see in Table (4.5) four out of eight disruptions were discovered in the commencement, tender, and design phases and only two in the execution phase. While in the less-successful projects, these were discovered mostly in the later project phases: six in the execution phase, and one in the operation and maintenance phase as shown in Table (4.6). In terms of the solution areas, the successful projects showed mentioning of factors not mentioned in the less-successful projects of adaptation abilities, team flexibility (two times mentioned), creativity, positive mentality, team communication, and collaboration, risk management. These elements were already found in the literature study as Figure (5.1) illustrates. The client support element was the most repetitive (four examples). For the less-successful projects, client support was mentioned three times, while new elements that were not mentioned in the successful projects emerged, like changing the team members (mentioned twice). The internal mobilizing element was mentioned three times to help with these projects. What we can notice as well is that the project duration and budget were higher for the less-successful projects rather than the successful ones. Furthermore, the contract type for the successful projects involved mostly collaborative features (alliance contract), and design and build contract type as well, without involving any financing to be done by the contractor side. On the other hand, the less-successful projects involved the finance part for three different projects (DBFM contract type).

4.3.6. Empirical elements of proactiveness, reactive capacities, and learning

Elements that contribute to resilience in construction projects are revealed in two ways: based on professional experience in complex projects and empirical case examples. Elements from the empirical case were illustrated in the previous section. While this section introduces professionals' elements of resilience based on professionals' expertise.

Elements of resilience based on professionals expertise

In total 75 elements that contribute to construction projects' resilience are found based on experts' views, distributed amongst resilience's main three dimensions as follows: 30 elements for Proactiveness, 23 elements for reactive capacities, 9 elements for learning, and 13 elements contribute to more than one dimension. Elements are organized in ascending order based on their frequency of occurrence in Appendix (.2).

Top 10 resilience empirical elements

The table below (4.7), shows the top 10 resilience elements with their associated dimensions based on the frequency of mentioning by interviewees.

The table illustrates that 10 out of 18 interviewees mentioned schedule time buffers as an element that offers the capacity to adapt to disruptions. The second most mentioned element was the effect of repeating the same scope of work by the same team members where they can learn and move their lessons learned to the next project. Participants link this aspect to all three resilience dimensions. The other items repetitively mentioned included aspects of the contract that offer flexibility, the Mother organization having a strong network and relationships with suppliers, sub-contractors and with clients, the Project management approach, efficient formal and informal communication across the project, the more soft aspects of project team competences of collaboration, motivation, and ownership were also considered important. Client management and change management were also seen as important aspects connected to each other through the expressed need to timely inform the client about project changes, as well as informing the project team. As we can notice, each element belongs to two aspects: project management area (e.g., contract, client, Project team, schedule...), and resilience-related aspect of collaboration, buffer, partnerships, diversity, flexibility, motivation, and effective communication.

elements were allocated to each dimension depending on the interviewees' answers, these are presented per dimension in the following sections.

Elements contributing to all dimensions

Across interviews, some elements were found contributing towards all main three resilience dimensions of pro-activeness, reactive capacities, and learning.

The First element indicated by 10 of 18 experts, is having **effective risk management**. Risk management is seen as essential in terms of facing disruptive events. The process of risk assessment through risk sessions throughout the different project life cycle creates awareness within

Ref	Resilience element/ Code	Frequency/ Grounded	Resilience dimension/ Code
I1	Schedule buffer	10	Adaptive Capacities
I2	Repetitive projects with repetitive team's member	7	Awareness and alertness, adaptive capacities, and
I3	Collaborative contract features (e.g., two stage contracts)	5	Adaptive Capacities
I4	Organization network of suppliers ,specialists , and clients	5	Adaptive Capacities
I5	Partnerships with subcontractor and suppliers (formal and informal partnerships)	5	Awareness and alertness, adaptive capacities
I6	Suitable team combination (experienced, starters, males , females,...,etc.)	5	Awareness and alertness, adaptive capacities
I7	Team motivation and ownership	5	Adaptive Capacities
I8	Team work and collaboration	5	Awareness and alertness, adaptive
I9	Timely communicate changes to client and within the project team	5	Awareness and alertness
I10	Ability to pause the project for short period once needed for re-adjustments	4	Adaptive Capacities

Table 4.7: Top 10 resilience elements

the project team and stimulate them to anticipate more possible adversities and promote thinking about lessons learned from previous projects to put into affect. While risk planned responses participate towards creating more capacity in place (e.g., buffers, technical experience) and a plan to solve disruptions when they occur. Risk management in the tender phase is considered of high importance by interviewees, as it affects all the following stages. Good risk management is seen to be tailored to project uncertainties and reach beyond probability impact assessment to include more aspects like an affected object, the timing of risk occurrence, and available time o respond. Also, having an expert and sufficient combination the team personnel is essential to get the right insights ad input for the risk managers. Another essential aspect mentioned is contractual risks and risk liabilities where a mutual understanding of contractual risks enables better responses without conflicts in face of perturbations. Experts stated the following:

It does help if you already thought of some kinds of measurements. Once something occurs and you already have a response in place as a plan B, then you're already prepared and you only need to perform your plan that you've already thought of in advance. That helps. This is risk management. (RM)

There's a lot of uncertainty during the tender phase and you have a lot more certainty during the project phases. So when you have that in mind, then you can take a look at what's a good risk budget for this project? Or what is a good control mechanism for this project? Or where do we have to have focus on supply chain management.(ProMa)

Risk managers can also identify risk, but they're also dependent on the input they get from the team. So you need a balanced team in order to have a good risk management.(TM)

When I think some adversities like that can happen, they also come in the risk register and we put a value for it, and measures to get the risk down.(PM7)

But the most problems we have is in the risks which are in between the employer and the contractor where you have sometimes a difference of opinion about who is the owner of the risk. And even if it's written down in the contract, black and white, if the amounts are getting very big, then people also change their opinion.(PM8)

So I always interview team members and ask them the right questions so that they identify, analyze, and treat risks in a proper way.(RM)

The second element, mentioned by 7 interviewees was: repeating the same type of projects, with the same client, same contract type, and same key personnel, as much as possible. Repeating the same type of projects will help anticipate possible disruptions, and enable better responses for unanticipated events, as dependencies and cascading effects possibilities are then better known, so enabling better and faster assessment and responses. They stressed that having the same key personnel involved in repetitive projects or asking for advice from someone who did, will help to transfer and apply the lessons learned. While having personnel who worked before with the same client helps to have already positive relations ad good knowledge about the client, participants stated :

"If you have enough time to talk with an experienced team who've done those things already more times, then you get also anticipate the risks that will come. You can already talk about them, and you can already take your measurements. You can always do the solutions in front." (PM4)

"But what makes it a special project is that we learn from other projects. So we learn from our mistakes and we make sure that we don't make them in the next one. We make sure that personnel: the key members who were involved in the previous similar project, are involved in this project to transfer and apply lessons learned. And then you can say we are learning."(SM1)

"I think then you have a few people in your project team with the experience with this kind of contracts, and you see something happens, he says then: oh, that happened before to me, then I could not handle it well, this time I do it differently." (PM3)

Other aspects considered contributing toward resilience of all three dimensions listed in descending frequency order as (1) having sufficient team combination form several aspects like experienced and starters, males and f-males, team oriented and goal oriented,...,etc, (2) Team motivation and ownership (e.g., tasks ownership, risks ownership), (3) Good relation with client from the start of the project (buffer in client relation), (4) Project culture: safety , transparency and openness, effective communication among the project team.

Also, some elements were stated by interviewees to effect both proactiveness and reactive capacities as follows: Partnerships with subcontractors and suppliers (formal and informal partnerships) as they can transfer the state of art and market changes related to their specialities creating awareness and alertness, while also such partnerships will increase the capacity to react in face of disruptions, for example, expert advises or mobilizing. other important aspects of similar effect are: Teamwork and collaboration, Qualified sub-contractors and suppliers, of proven record (not the cheapest option), Project manager's ability to manage client and contract in an efficient and aligned way (facilitated by an efficient team that give him the time to do so), Effective communication between contractor, client and stakeholders, Update standards in alignment with latest knowledge.

4.3.7. Proactivness contributing elements

Experts associated the proactiveness with the following concepts emerged from their answers that we can see in the concept cloud shown in Figure 4.8. Most repetitive concepts mentioned are related to the following aspects: People, team, client, risk management, manager, planning, meetings, expertise, subcontractor, partner, and culture. With stress on two phases: tender and design. In the centre, we see people, mentioned 36 times by interviewees when they were asked about proactiveness. Several participants stressed that people in the project are the most essential source of both problems and solutions. People were mentioned in terms of having experienced team members, knowing the people and experts across the mother organization to be aware of its potential or vulnerability, team work, and team transparency. Another emerged project area for proactivity is the Client, in terms of being informed proactively and timely with project status or possible issues, building continuous good relations with the client that helps understating his goals and interests and anticipate

Table 4.8: Empirical proactiveness concepts cloud

any related changes. Effective risk management is essential for proactiveness as was explained in the previous paragraph. On the other hand, the project manager plays an essential role towards proactiveness since he is a key starter in creating an open and safe culture where team members can timely share and communicate any mistakes or notes in a formal or informal way. Also, it is essential for a project manager to be able to balance managing the project as well as the management of good client relations aligned with the contract, which helps timely avoiding of problems that root back to misalignment. Another key aspect is the manager's ability to be alerted to soft problematic indicators personnel show (e.g., going home early or being stressed). while two main phases were mentioned by interviewees as important to create proactive aspects, these are tender and design. In the tender phase, they stressed the involvement of the project manager and key project personnel like the procurement manager, to help set realistic tender planning. Also, risk management of the tender is crucial in expecting and preventing or mitigating possible future disruptions as well as setting a suitable risk budget and buffer. another aspect is the partnerships with sub-contractors and suppliers and the involvement of key ones in the tender phase to support design and planning, and also to create a sense of ownership of their scope and more protection for the project's success.

Overall Proactiveness elements are grouped, ranked in descending order, and presented in Table (4.9)

Interviewee statements were as follows:

”People are the biggest risks in your project. How they work together? Are they working for their own or working in a team. Do they help each other?” (PM6)

Empirical Proactivness elements	Frequency	Resilience dimension
Effective risk management	10	P, R, L
Repetitive projects with repetitive team's member	7	P, R, L
Partnerships with subcontractor and suppliers (formal and informal partnerships)	5	P, R, L
Suitable team combination (experienced, starters, males , females,…,etc.)	5	P, R, L
Team motivation and ownership (e.g., tasks ownership, risks ownership)	5	P, R, L
Team work and collaboration	5	P, R, L
Timely communicate changes to client and within the project team	5	P
Good relation with client from the start of the project (buffer in client relation)	4	P, R, L
Assure sufficient interpretation of client demands (communication, meeting, verification,…,etc.)	4	P
Qualified sub-contractors and suppliers, of proven record (not the cheapest option)	4	P,R
Preserve system relations (original project planning) that enable being aware and alerted to interdependencies	4	P
Project culture: safety , transparency and openness	4	P, R, L
Requirement management , verification and validation through open shared platform with standards and forms (e.g., verify design against client requirements)	4	P, L
Monitor internal vulnerabilities	3	P
Continuous team key personnel meetings, discussing and reporting (Schedule , finance, percentage of completion) monthly or weekly	3	P
Cross disciplines work understanding sessions (design, risk, work preparation, ...,etc.) for ependencies and interfaces awareness	3	P
Having knowledge about the client (through meetings and collect information)	3	P
Informal collaboration and conversations at all levels	3	P
Project manager ability to manage client and contract in an efficient and aligned way (facilitated by efficient team that give him the time to do so)	3	P,R
Project manager ability to sense soft indicators of performance problems within the team	3	P
Using internal and external audits (check compliance with the management system processes, quality requirements, ...etc.)	3	P
Alertness through mother organization sending notifications of common problems	2	P

Table 4.9: Empirical proactiveness elements

”You need an experienced staff, people who have done it before” (PM3)

”It’s not only the database, I think you need more than only data. You also have that the people can find the expertise within Bam in a quick way. Nowadays, I only phone the people I know, maybe there is a colleague Bam organization who can answer my question better than the people I know” (PM6)

” Usually I know the majority of the problems before people tell me. That’s through the communication, like you are always there with the team, you hear a small thing or a big thing, or that people are a little bit busy with a certain meeting, which is a little bit extraordinary.I’ve learned that there are soft indicators that things are not going well. I think if we are not capable of sensing these soft indicators that people are going home early or if you feel that they’re not telling the whole truth then it’s time to then think about you may be reaching a breaking point.” (SM2)

” Talking and having meetings that everybody feels comfortable, that the barriers are low. My door is always open from my room, so people can walk in and say how are you doing? and I’m saying, how are you doing? And how was your day yesterday? And you had a very important meeting with the client. Did it went well or something happened on the site? Why did this happen? Yeah. How you gonna solve it? Do you know how to solve it or do you need any help to solve it?" (PM8)

"The main problem is that I was not involved in the tender design. I had no influence anymore on the scope it was chosen, or the construction method" (PM3)

"We had a really good plan and we stick to it. So, the project manager was already involved in tender and responsible also in the tender phase, and he just made sure that the plan is realistic and wasn't changed." (TM)

"If the supply chain or subcontractors are involved from the very early beginning and works on this project in the tender phase and later on through the project, then you can say it's a subcontractor, but he's also responsible for the success of the project, for the success of the tender. Then it's more than a subcontractor, then you start talking about the partner.That is important" (SM2)

Contracts also were repetitively mentioned by interviewees as a possible factor to facilitate proactiveness. Contracts with cooperative features, namely mentioned Two stage contracts, offer collaboration between the client and contractor, to develop project design and planning together on two stages of adjusting, then the final design, planning and budgeting would be set. In this way, the most critical source of disruptions which is design-related problems would be minimized and more awareness and alignment with client requirements would be achieved, leading gt fewer changing orders in the future, as these last seen unfavourable by all interviewees as they disturb project planning.

"There are very severe risks in the design and construct contracts .What you see nowadays is that the client and contractor together come to a different approach to contracts, two-phase contracts, that means that the contractor and the client together make the design." (PM3)

"We promote two stage contracting. That in the first stage you develop the design completely, you conclude the planning and the price. And only then you agree with the client how to proceed. That helps to reduce changes in future and design errors" (SM1)

4.3.8. Reactive capacities contributing elements

Reactive capacities of ability to absorb disruptions and consequences without changing the system (project) elements or organization, an adaptive capacity which enables projects to face adversities through applying changes to the system, while the last capacity studied in this section comes into action to recover from the effect and losses encountered as a result of disruptive events. For the three capacities, the Client was repetitively mentioned by the majority on top of their answers. Once a disruptive event occurs it is important to inform the client timely and involve him in the solution, that needs of course to have client-contractor trust and good relations, and mutual settings of goals that will help to uniform the interests to solve the problem. The client may support with resources, expertise, extra time or budget, or even relaxing a few constraints.

"For example, if you talk about planning, you can say based on the mutual goals you already defined: it is in your interest that we finish in time. It is in our interest that we finish in time. What can we do to finish together in time? So maybe sometimes the client can relax certain requirements that don't hurt them. But on us,it could create an opportunity to maybe win some time." (SM1)

"And we also helped the client in the first stage of the project with a few problems they had. So, we build up some credit. So if then we faced some problems during the project we already had some credits, so he was more willing to help us. So there was a really good basis for a good collaboration." (TM)

Another important aspect that was repetitively mentioned by experts is having a buffer in time, money, resources, personnel, and client relations. that buffer should be aligned with project complexity and uncertainty. Mostly it was referred to that the buffer is built up in the planning phase through the risk analysis process aligned with the schedule and budget (e.g., Monte Carlo analysis). However, it was reported that in most projects buffers are not sufficiently allocated due to either optimism of the planning, or due to the time and budget constraints posed by the client, where more buffers could mean losing the whole tender.

Figure 4.4: Reactive capacities concepts cloud

> ”So the best projects I had, are when there was always some buffer, in money, some buffering risk budget, and also some buffer in the relationship. For example: I came back to the project because I had a good relationship with the client, then you can start a bit from there, but it’s only one aspect in this array of things that must be okay.” (SM2)

> ”Normally in projects the planning is really tight and we don’t have enough buffers to absorb some problems. We have a problem, I say always, the planning which we have is a happy flow and the unhappy flow from outside risk or inner risk will directly have an impact on the planning.”(PM6)

Furthermore, an important aspect seen contributing towards creating reactive capacities is the contract. Contracts can enable flexibility in response to disruption events. For example, if the contract allows pausing the project for a short period once a large disruptive event occurs, then cascading effects would be better understood resulting in better solutions in the long term.

> ”Flex ability is essential to withstand problems,if the contract gives you the possibility to be flexible” (TM)

> ”If there is a huge change, you need to pause and first understand it. But of course, some contracts don’t allow for this. And clients, they don’t like it, so they will do everything. to keep the contractor going and we need to also then explain why we can’t continue.” (SM1)

Moreover, having a trusted network of subcontractors is considered essential to help absorb and adapt in face of adversities. Once a disruptive event occurs, sub-contractors may help mobilise resources and expertise or offer connections to possible sources for solutions (e.g., technical knowledge advice, critical supplier)). If they developed a sense of ownership, partnership, and interest alignment towards the project then they would be enthusiastic and collaborative towards solving issues even if it was out of their scope. Therefore, when asked about reactive capacities repetitively interviewees mentioned having a trusted qualified network of sub-contractors and suppliers with long-term relations, especially for critical parts of the scope (e.g., construction pit), not necessarily written, but could be formulated informally, through repetitive collaborations in projects and maintain a good relationship. Also, it was referred to avoid choosing sub-contractors based on the lower price.

”We don’t set it on paper or in a strategy, but we that on the project.So nowadays, we have some subcontractors who they are more partners and when we have to order something. We ask first them if they have time, because we know when we have some problems after installation of something, they are there and they will help and fix the problem. (PM6)

”It is essential to work with someone that you trust and who has a proven expertise and proven quality record that is able to help you overcome surprising issues once it happens.” (Pm3)

”Those are the critical supplies and we have an early gentleman agreement with them since the tender phase, and based on that there is an allocation which parts of the bridge are in, in their scope and which is in our scopes. They are more like partners. we selected this partner because of their experience with steel bridges. They are already exist for many years. So there is a little risk that they would be bankrupt for example.” (ProMa)

Another three important aspects were mentioned in terms of having reactive capacities, most repetitive after the mentioned before which the concepts cloud also reflects in Figure(4.4), were: First, mother organization support through internal mobilizing for experts and resources, its connections with possible suppliers, stakeholders, authorities, and clients. As stated by interviewees sometimes the good relations and mutual interests of the mother organization with the client through other previous and current projects, help to solve and create larger capacity in face of disruption.

”The mother organization can also bring in people, bring in knowledge and facilitate conversation with the client because they can also have other relationship with the client or someone at a higher level than I do as a project manager.”(SM2)

”The organization provides help when extra resources once needed. And if the organization doesn’t provide directly then they have a flexible scale. They have people who can call, agencies and they start looking to help the project manager .” (PM8)

Second, team-related aspects of competencies, teamwork, ownership, creativity, positive mindset and collaboration. Repetitively experts stated that once a problem occurs it is essential to have the right experts with sufficient technical knowledge to solve it within the team, instead of going and searching or mobilising internally or externally. That creates the capacity to absorb the emergent needs for these human resources. Also, teamwork and collaboration with each other and continuous meetings help find a better solution in a faster manner and enhance team creativity to come up with fast efficient solutions. The choice of team members who are more probably to get aligned together plays an essential role to create a teamwork culture.

”That’s a project comes from a minus in money result to a positive result.

”The key was a really great team with a big ownership and responsibility.Team culture of cooperation is important.It’s a culture thing. However choosing the team is essential, if you put a lot of people together ,without think it over then of course at that level we have problems, but when you put the right people together and give them a space to work, they will collaborate, make a team ownership of the problem, and solve it.” (PM6)

”for personnel capacity, it’s very important to have a team that wants to work for each and another. So when someone is sick, it shouldn’t be a problem for the project. It’s not necessary to immediately to set another person in projects and their colleagues will for a few weeks do the other person work.” (PM7)

”In this case it was we didn’t expect this this risk . But the good thing was the contract manager as we call it the fire man works. He had very positive mentality in terms that: we have some problems, but we will be able to solve it. A lot of creativity was needed and performed been. It was really difficult to manage that, but we did. It's really strange. But if you put people in one room together, the creativity will be really high if you put them behind teams (online meetings platform). It's really difficult." (RM)

"You must have competent people to fix this design, to adjust the plan, to make a financial analysis through. It is essential in face of problems. However, if you have that all in place and the people are not willing to cooperate, not willing to perform together, the it you have a big problem." (SM2)

In total, 28 elements were mentioned contributing towards reactive capacities in face of disruptions. Table (4.10) presents these elements ranked in descending order based on their frequency.

Empirical reactive capacities elements	Frequency	Resilience dimension	Empirical reactive capacities elements	Frequency	Resilience dimension
Schedule buffer	10	R	Manager decision making (clear communicated, avoid dispute with client to save time, fast and efficient at crisis)	4	R
Effective risk management	10	P, R, L	Qualified sub-contractors and suppliers, of proven record (not the	4	P, R
Good and trust relation with client from the start of the project	8	P, R	Project culture: safety , transparency and openness	4	P, R, L
Repetitive projects with repetitive team's member	7	P, R, L	Informing the client proactively, continuous, and timely about project status and challenges (Suggested weekly)	3	P, R
Collaborative and flexible contract features (e.g., two stage contracts)	6	P, R	Project manager ability to manage client and contract in an efficient and aligned way (facilitated by efficient team that give him the time to do so)	3	P, R
Mother organization network and connections (e.g., specialists , authorities , and clients)	5	R	Agree on changes cost between contractor and client before start working on it (including the process disturbance costs)	1	R
Partnerships with subcontractor and suppliers (formal and informal partnerships)	5	P, R	Buffer in performance (to perform higher than expected if possible to compensate later on aspects of money loss or delays)	1	R
Suitable team combination (experienced, starters, males , females,…,etc.)	5	P, R, L	Effective communication between contractor , client and stakeholders	1	P, R
Team motivation, creativity and ownership (e.g., tasks ownership, risks ownership)	5	P, R, L	Effective communication	1	P, R, L
Team work and collaboration	5	P, R	Inform mother organization about project problems	1	R
Extra time and money from client to solve problems	5	R	Participates in construction industry field specific events (e.g., Bauma	1	P, R
Ability to pause the project for short period once needed for re-adjustments	4	R	Refuse changes orders that is out of core technical knowledge of the	1	R
Budget buffer	4	R	Shared platform for project KPIs	1	R
Client cooperation and understanding for project challenges	4	R	Update standards in alignment with latest knowledge	1	P, R

Table 4.10: Empirical reactive capacities elements

4.3.9. Empirical learning elements

According to interviewees, Learning is very important to build up resilience and capacities to face adversities. However, the challenge is in acquiring the right lessons from the right events and translating that into daily practice. In the concept cloud for learning, we see the team in the centre, which means it was the most repetitive project area with learning elements related to it. Other points seen are the client, organization, system, manager, meetings, tender, risk and gate referring to the stage gates process of reviewing project work, validation and verification. Learning started to be on the level of the organization as well as the project and they both affected each other. For example, periodic repetitive learning sessions per discipline across the organization (project managers, procurement, design, risk, ..., etc.) help share and draw lessons learned to improve each other projects and the organization's strategies. It is important to have a specific process for learning imposed by the mother organization as a requirement to be applied to all projects.

Experts' statements were as follows:

"We leave too much to the people themselves. I think some people are able to do that, but some people, they listen and they go on. So sometimes you have to, get the hands of the mother organization to implement a learning process." (MP4)

"We meet four times a year. We have a kind of meeting and after that, we go all the way to our own projects. So you are not working together, but you see each other four times a year, and then you talk about the things you've seen and learned. You learn what they are doing. So when you have kind of problem, you think that Now I can call this manager to help." (PM7)

The verification and validation process is suggested by interviewees to help with learning as well. It was referred to a current process used n the organization, that is the stage gates process, where there are specific moments in projects where specific submissions have to be delivered by the project team, reviewing the work done till this point, evaluating specific points, and prepare for the next phase.

"We have our stage gates by Bam. That's also a learning point. Are we doing the right things at the right moment on the project." (PM7)

Figure 4.5: Learning elements- Concept cloud

> ”We said you have stage gates 1, 2, 3, and four. In stage gate one, you need to deliver this, in stage gate two you need to deliver this. So we thought about what had to be delivered and when and that was fitting in the tender process. So we were not asking questions too early. That we were making sure that they were asked at the right time. When people were working with that info that then helped the team learn and also helped us to get a feel for how well did they understand the project.” (SM2)

Also, repetition was stated by interviewees as an effective active way of learning. Repeating the same types of projects and contracts, also repeating work with the same clients, and same personnel, is seen to lead to effective learning, transferring lessons learned through personnel, not through documents and large-size reports.

> ”Well, I say, you made a bridge, but let’s do it 10 times. Again, the same bridge with the same client. Then we can learn, then we can optimize, and then we can improve.” (PM2)

More elements mentioned by interviewees contributing towards learning are presented in table (4.11), in descending order based on their frequency. It is noted that some elements contribute to learning and other resilience dimensions at the same time. Dimensions are represented in the table through letters (L: Learning, P: Proactivness, R: Reactive capacities).

4.3.10. Resilience barriers

In searching for the barriers that may hinder resilience proactiveness, reactive capacities, and learning, explicit hindrances were stated and implicit barriers were noticed based on experts’ responses. The implicit barriers are seen to be related mainly to the following aspects: (1) Initial

Empirical resilience element- Learning			
Element	**Explanation**	**Frequency**	**Dimension**
Risk management	Effective risk management	10	P,R, L
Client trust relations	Good and trust relation with client from the start of the project	8	P,R, L
Repetition	Repetitive projects with repetitive team's member	7	P,R, L
Team combination	Suitable team combination (experienced, starters, males , females,…,etc.)	5	P,R, L
Specialization meetings	Periodic repetitive meeting per specialization across the organization (e.g., project managers quarterly meetings)	4	L
Project culture	Project culture: safety , transparency and openness	4	P,R, L
Information platforms	Having open shared platform to share information and changes	4	P, L
Mother organization	Mother organization embedding learning into its divisions and projects as a work requirement	3	L
Verification and validation	Set official reviewing ,validation and verification points through the project life cycle (e.g., stage gates review process) which are also learning points	3	P, L
Across desciplinary reviews	Across disciplinary work reviews for each other	1	P, L
Effective communication	Effective communication	1	P,R, L
Process learning	Process oriented learning instead of product oriented	1	L
Summarize lessons learned	Quarterly developed lessons learned in short summary form	1	L

Table 4.11: Empirical resilience elements- Learning

project choice and settings led by contractor conflicted interests (Business continuity VS Project success) stimulated by the construction market conditions and competitors, (2) Client (tender settings, collaboration), (3) Contractor Organization (Size and scope diversity), (4) Personnel (resilience awareness, motivation and time), (5) Management (culture, mentality), (6) Learning processes.

Across resilience dimensions, all interviewees stressed the importance of learning. However, they all stated that learning needs to be improved to be more effective. They further defined that the main learning barrier is the lack of a formal learning process which helps specify which project and incidents to learn from, what data are needed to learn from, and what the criteria of good lessons learned are. Also, the absence of accountability in terms of learning, where they stated that the mother organization should impose a learning process with people responsible for it, into all projects. The techniques used in learning should be different than the end project evaluation report, where these reports are overloaded with details and large size of reading which makes it hard for the personnel to find their way through and lower their motivation to use. Another element mentioned that hinders learning is personnel change.

While the main mentioned barrier that hinders creating the reactive capacities is the unrealistic project choice and settings from the beginning. Many factors may lead to the wrong choice of projects in terms of aligning with the organization's technical knowledge and performing capacities, mainly this is to keep the organization's existence and fulfil the commitment to its partners. While the unrealistic setting for the projects like setting tight schedules and budgets and overlooking known risks would root back to many reasons among them the hunger to win the tender which probably would lead to trying to set the lowest price and duration. The nature of the construction market and competitors (local & international) stimulate two contrasted interests for contractors of business continuity VS project success. For example, The construction market constraints contractor profit to (3 to 4 %) for large infrastructure projects which is not balanced with the level of risks the contractor should handle compared to other types of construction (e.g., residential). This will set pressure on the contractor which may lead to setting unrealistic or optimistic settings for the project and lower his ability to set any buffers in his planning and weaken his flexibility. Some resilience barriers were found to be related to the client. The client would probably set very ambitious requirements and constraints related to contract type, project size, project duration, budget, quality, ...and others. Where unrealistic requirements would push contractors to set unrealistic offers at the tender just to win, and then go into what we call project delays and overruns while the very same project, with more realistic project settings, would be just on time and within budget. The client also may hinder the possibility to build trust in cooperative relations due to negative assumptions built about contractors from previous projects. Also sometimes the client may choose low cooperative communication methods in the tender (e.g., few meetings or depending on written communication without direct connection), which would hinder contractor understanding and translation of client requirements.

Moreover, Organization’s large size and diversity are seen to hinder some resilience aspects. In large-size organizations, building one awareness culture and a learning process across the organization would be challenging, not only because of the large number of personnel but also due to the diversity of working scope and project complexity. For example, Infrastructure projects are more complex than residential projects and involve multiple changing stakeholders, where this difference implies differences in the management systems and approaches, functional divisions, contracts, organization forms and structure, and used tools and platforms.

Furthermore, experts stated that personnel awareness and motivation would affect project resilience. While the project is running, the main focus for the team members is to keep it that way, to do their tasks and perform well, where finding time to focus on risks anticipation or to read the long text of project evaluation or writing them seems to have non-direct benefits, boring process and no time for it. Project personnel are under pressure to balance their responsibility with these other indirect but also important tasks of learning or risk management.

Management and managers’ culture and mentality may also play a negative role towards their project resilience. As interviewees mentioned that the project manager mentality of openness, positivity, and flexibility plays an essential positive role to set the whole project culture into a more open and safe team culture. When the project manager is not willing to listen, discuss and support the team when they do mistakes, then they will start hiding and their ownership and teamwork level will drops which will hinder the project’s ability to timely anticipate problems, and react to solve them. Also, a project manager with long experience may have the ego to stop learning from other projects and only be closed to his own learning curve, which will promote less learning culture in the project as well.

4.3.11. Framework needs

In practice, there is a need for methods and tools to aid in managing projects through uncertainty. Building resilience in the project is a suggested solution. However, resilience is still a new concept in practice. The resilience concept needs to be introduced, explained, and aided with practical tools to be effectively applied. As found in the empirical study, practices to face uncertainty are scattered across projects and across each project’s dimensions and not built systematically and comprehensively. Practices differ per project and across the different divisions of the mother company, which makes it harder to compare and evaluates. A need for a systematic approach that aids organizational and project learning is also expressed through the interviews of almost all interviewees. While having one flexible framework will give a base for systematic comparison, quantifying, evaluation, and learning base.

4.4. Discussion

The main goal of the empirical search was to uncover what elements contribute towards construction projects’ resilience based on practical examples and experience. A second goal was to discover what factors hinder this resilience. While a third goal was developed in response to the results of the literature study to fill in the knowledge missing regarding resilience meaning in constriction projects. It was concluded in the literature study 3.2.1 that to define the resilience of any entity there are four main aspects that need to be adequately identified and built up as follows:(1) resilience of what? , (2) resilience against what?, (3) resilience for what?, (4) resilience through what?. While the entity is set to be the construction project define adequately in literature, answering that is the first question of this set. The other questions were also answered through the literature review, however, still offer general answers for some aspects. For question (2) resilience against what? still, need to know is, in construction projects, is resilience needed only for unknown-unknowns, or also for the known-unknowns and unknown-knowns? While for the third question (3), resilience for what, it was found in the literature that resilience aims to preserve the entity well functioning, and desired performance, and the continuity of the project success. But what is ”well”, ”desired”, and ”success” in construction projects? What does a resilience response look like? Few literature works to define it as fast responses and cost-effective. But is that it? or there are more aspects to take into consideration? what about quality? or stakeholders or environment? If the response came very fast and very cost efficient but it harms the quality or the stakeholder, is that considered then a resilience response? Finally, the literature study resulted in resilience contributing elements. However, still with low consensus and comprehensiveness. The empirical research went also looking for answers to these questions. The answers were presented in the above section and will be discussed in this section based on the same systematic approach the literature answered, and the interviews were built upon.

4.4.1. Resilience for What?

Since resilience is defined in construction projects as the project capacity to maintain positive adjustments when confronted with critical events (Geambasu, 2011), and the ability to recover timely and cost-effectively to the **original or desired state** (Mahmoudi & Javed, 2022). Also, defined to **preserve functions** to achieve **expected targets** despite being subjected to disruptive events in a complex and dynamic environment (Q. He et al., 2017). Resilience focuses essentially on the continuity of success and keeping the normal planned level of functioning.(Doorn, 2020). Based on that and to specify these aspects of positive adjustments, project functions, desired state, and expected targets, mean in a construction project. Interviewees were asked to specify what is a successful project, and once a perturbation occurs what goals they focus on through their responses, and what thresholds they try to protect. This idea of linking resilience to system stakeholders' objectives, beyond only the fast response or cost-effective criteria, was also supported in resilience-related research. Serulle et al. (2011) where they used amongst other elements to evaluate the resilience of transportation network, the elements of travellers' average speed reduction during perturbation and personal transport costs, also commercial and industrial related stakeholders were taken into consideration. They did not only consider the time needed to recover and the cost of actions needed to recover, rather they included the stakeholder's goals in the resilience function.

According to interviewees' answers, the main aims of responses in face of disturbance go in twofold, keeping the course of the project functioning, and protecting targeted goals.

Keeping the course of the project in function, which means being able to execute daily planned activity and work, and keep performing, is considered an essential goal in face of disruptions. While it is stated that the best option is to go back to the same planning they already had, with the same planned performance level. Even if new planning will promise better results due to the associated high level of unknown dependencies and its unknown effect on the project. This can be associated with what Geambasu (2011) and Pastor et al. (2015) referred to that the resilient system may aim to go back to the same pre-disruption equilibrium point or into a new desired one. However in practice. for a contraction project, the equilibrium is to keep the project course functioning according to the plan, it was referred that changing the components and relations of the previously planned equilibrium is not desired even if it may lead to a new equilibrium as it creates uncertainties and more possible future unforeseen disruptions. Targeted project success goals which resilience aim to protect, are related to three parties: contractor, client, and stakeholders, according to practitioners. For contractors, the most essential is to make the planned profit as it is related directly to their business continuity and existence. This profit is included already in the project contracted budget, which means protecting the budget is an essential success factor for the contractor and hence a resilience response goal. This can be associated with what Mahmoudi and Javed (2022) and Priemus et al. (2013) referred to in their definition of resilience mentioning that resilience should be cost-effective and without risking stalemate in the process. That is the most important goal to protect from the contractor side. While other aspects suggested by participants are team satisfaction, and organization portfolio success. These are not found in resilience literature.

Then, it was argued by some practitioners that it is not necessary to always aim to protect the budget or the schedule. The focus of responses in face of disruption should focus on the most important goal of the project stated by the client and project characteristics. For some projects, stakeholders' management is the top priority, then even if the response was cost-effective and very fast if it does not involve good and timely stakeholder management and satisfaction then it is unsuccessful and will lead to further cascading issues. In that sense, we can argue that resilience responses should mainly take into consideration the project's main drivers. Mostly stakeholders' interests are illustrated through the client's interests. However, still some silent stakeholders like nature, still need to be taken in response consideration as claimed in interviews that the project shouldn't harm the surrounding nature, and helps add value to the world.

On the other hand, practitioners set great importance on safety which is the non-negotiableproject's base for the project, and all responses should take that into consideration.

In the found resilience literature no further points were mentioned to define resilience goals, rather the time, money, and keeping the flow of the work going. while we can clearly see that in practice more aspects are essential to be taken into consideration depending on project most essential driver(S).

4.4.2. Resilience through what?

1- Proactiveness (Awareness, Anticipation, Alertness)

According to practitioners, 22 elements were found contributing to project proactiveness. 11 elements of them participates also in other dimensions on top of them: (1) effective risk management which was always the first answer when asking about productiveness, (2) work repetitiveness. In literature Rahi et al. (2019) and Tengblad and Oudhuis (2018) consider risk culture and de-centralising risk management participating to project awareness also where Geambasu (2011) considers it an essential part of disruption anticipation. This refers to the traditional predict and control culture which Pich et al. (2002) referred to as its un-efficiency in face of uncertainties.

In literature, Francis and Bekera (2014) and Geambasu (2011) consider risk management contributing towards the adaptive capacity through enabling already planned responses (fast). In that sense, literature does reflect implicitly on the fact that some elements do participate in more than one resilience dimension. While work repetitiveness was not mentioned to this matter in the found literature.

Furthermore, an essential aspect claimed by the interviewed professionals is that partnerships with sub-contractors don't only help enable absorptive capacity for the project but also enable awareness and alertness towards changes in the related market and industry which serves to anticipate possible disruptions. Rahi et al. (2019) referred to this element as part of project awareness.

Other elements were only associated with Proactiveness. Top mentioned elements were timely informing the client and also the project team about any changes in the project, which would help get their input in terms of the effect of these changes, so anticipating cascading effects as well as conflicts. Client again appears in the second most repetitive element stated by interviewees, they stressed that the continuous process of validating the work, especially the design against client requirements is essential to anticipate and prevent any future perturbations, and the sooner this process is applied the better. Furthermore, the third repetitive aspect was to preserve the same initial project planning as much as possible, as the team spent already time and diverse human resources thinking and discover its dependencies, which helps predict the cascading effects of changes. Another element mentioned is effective monitoring through using KPIs or audits, which helps be alerted towards adversities.

Both literature and practitioners were found to be aligned in specifying three main aspects of proactiveness: awareness in terms of being aware of changes, anticipation in terms of predicting and responding to adversities, and alertness in terms of monitoring and controlling. Despite that interviews were open for the first part of it for practitioners to specify their own dimensions no further aspects were added to the three sub-dimensions related to proactiveness. What was, however, noticed is that most of the anticipation elements mentioned by interviewed experts are focused on externally generated disruptions and their sources, despite the fact that one practitioner(The head of risk management in the mother organization) referred to the high importance of being internal focused on anticipating project ad personnel own vulnerabilities based on project complexity and characteristic. On the other hand, several works of literature refer to the importance of defining of internal vulnerability and factors affecting it, as a first step of building resilience (Cerè et al., 2017; J. Zhu, 2016). Another key aspect that can be noticed is that literature describes elements more as abstracts like collaboration or sensitivity to changes without further defining what that actually means or may be applied in the project, while practitioners provide more level of operational features for the elements. Another essential note is that some elements mentioned in the literature were not mentioned by practitioners, like personnel self-awareness of their own skills and performance and others, and vice versa. So, building a comprehensive view of resilience would need both literature and empirical views.

As has been demonstrated, proactiveness elements need to be combined both from literature and empirical cases. Proactiveness involves awareness, anticipation and alertness. Across these, practitioners still by intuition chose the traditional predict and control approach which needs to be balanced with accept and react approach. Where it is important to focus more on assessing the internal changes and vulnerabilities as sources of disruptions not only the external changes.

2- Reactive capacities (Absorptive, Adaptive, Recovery)

In total, 28 elements were mentioned by practitioners. 16 of them were found participating in other resilience dimensions as well, and 12 related only to adaptive capacity according to professionals. Risk management is considered participating in reactive capacities which makes sense since risk responses include an already thought plan for expected disruption with related risk budget. This is associated with Francis and Bekera (2014) that preparedness increases adaptive capacity.

What was noticed while asking about reactive capacities, all practitioners stated first: inform and involve the client, some of them extended it to inform the mother organization as well. This also aligned with the main first two objectives defined by practitioners about project success which are contractor profit, and client satisfaction. Literature acknowledges these two goals as important elements in a project goal, as well as the fact that resilience aims for to continuity of project success. However, no related elements were found in the literature. Some close element found is collaboration.

Some elements were mentioned in both literature and by experts like: creativity, partnerships, collaboration, buffers in time and money, decision-making, decision making, and creativity.

The directions of the elements, in both literature sources and according to practitioners, are more towards soft behavioural and managerial aspects. Practitioners claim the importance of collaboration (especially with clients and partners), communication, timely informing, understanding, decision making and project manager behaviour. Some strategic aspects, like repetitive project choices in the organization portfolio, partnerships, and field-related networking. While technical aspects had high consensus, fewer elements were mentioned like buffers in time and money, performance control platforms and tools.

On the other hand, some ideas were not explicitly mentioned by interviewees, compared to the literature. Essentially it is information-related elements, motioned by J. Zhu (2016) of having proper information sharing, or using BIM (building information modelling) stated by Vugrin et al. (2011). However, participants referred implicitly to these elements by mentioning the timely communication changes and continuous meetings.

An important aspect was mentioned related to recovery capacity mentioned by the experts. This is the costs' liabilities of project changes before putting them into effect, as well as, client coverage for the effect of some perturbations in terms of money loss or time delays. These could be associated with the factor mentioned by Francis and Bekera (2014) of having a conflict of interests amongst project stakeholders towards recovery costs' liability, which may prolong or hinder reaching the desired level of recovery.

One contradicting concept was found comparing literature to empirical views. That is parallel planning techniques. This is seen in literature as an element participating in building restorative capacity where if for example dividing projects into zones can offer the possibility to continue working on one area if the other areas had disruption, allowing by that more time space and effort focus to recover. However, it was found in the empirical cases that parallel planning of design and execution was eventually a source of disruptions where any design mistake, miss interpretation or change will lead to not only change in the design but the executed work and interrupt the process with high failure costs. However, no examples are mentioned about parallel planning in terms of zones which may indeed offer more capacity to recover as the literature suggests.

Regarding the level of practicality of elements, (again)like the proactive elements, practitioners had more tangible elements than literature. However, in some aspects, the literature does mention specific details like the importance of flexibility enabled by technology-based flexibility and operational procedures flex-abilities.

As such, elements found in literature and based on experts both fall into the three subcategories composing reactive capacities of absorptive, adaptive, and recovery capacities. Soft organizational and behavioural aspects are the most important based on literature and empirical evidence. While to put resilience into effect less abstract view should be searched, while combining empirical and theoretical offers this feature as well as provide a comprehensive view.

3- Learning

The importance of learning is highly appreciated by all of the interviewees and they have a high awareness of it. However, it is stated that yet no specific process for learning apart from the project evaluation final report and the stage gates procedure which is essentially intended for verification and validation objectives, while it is seen to also serves to learn across projects and in the same project. Indeed any type of evaluation would form the first base for learning. however, still what projects should be reviewed, when and how to conclude effectively lessons learned. For example, some practitioners concluded that certain types of complex projects, especially DBFM type, should never get involved again and stop tendering for it. While others concluded that with repetition and good learning from previous projects, these projects may be accomplished successfully.

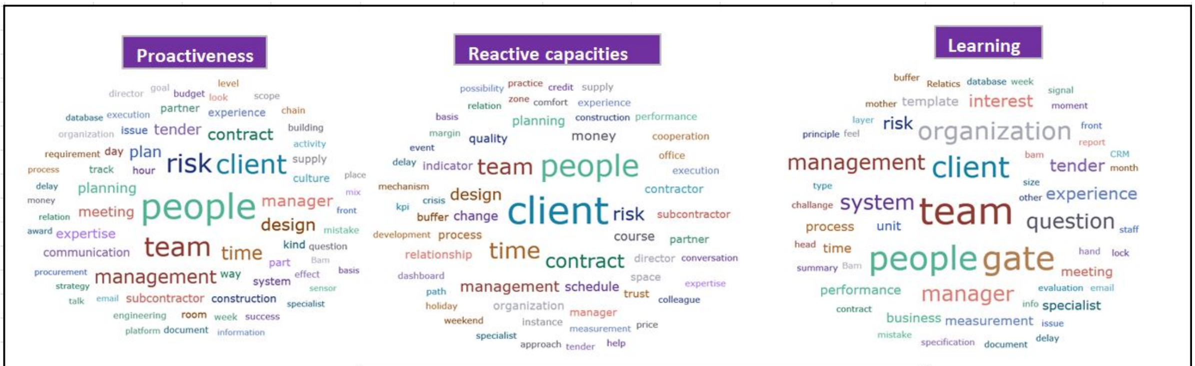
Only 13 elements were found based on professionals participating in the learning dimension. 9 of these are associated with other dimensions as well, while only 4 elements are linked exclusively to learning. That is aligned with the challenges explained by professionals of not having a learning process in place, and not imposing learning processes by the mother organization. Where this challenge is also referred to by Hollnagel (2015), where he refers that it is not enough to know how often something happens but also to learn why it did or did not happen, and most importantly specify the criteria of which events/ projects we should learn from and how to generalize or not. Where it is suggested by interviewees that process-oriented learning would enable better generalising across different construction projects scope options.

Both literature and practice refer to two types of learning: passive and active. There is high consensus among interviewees about the idea of repeating the same project scope, with the same team members as much as possible to build up continuous learning about specific aspects before jumping into a new scope. This can be associated with the learning by doing elements referred to by Tengblad and Oudhuis (2018). While passive learning is learning through documentation or training indicated by Madni and Jackson (2009) which is also referred to by practitioners suggesting that shared information platforms, and small sizes evaluation reports would be helpful to learn if project personnel had enough motivation and time to do so. Practitioners prefer active learning by repetition or informal meetings.

some elements were mentioned in both theory and practice. These were a related mix of soft organizational aspects of communication, collaboration, open and safe project culture, informal learning-oriented meetings, and also technical and strategic aspects Like platforms technique, documents techniques, specific processes, repetitive choice of projects, and team structure diversity. However, the literature provided some new aspects not mentioned by interviewees. These are: allocating specific learning resources, and proactive learning which suggests not only learning reactively from incidents happening in projects but also learning proactively about changes in the surrounding environment and construction market and keeping updated with the latest knowledge. Another element mentioned is learning incentives which could be associated with the element of personnel motivation suggested by interviewees.

As such, Learning elements are a mix of technical, strategic and soft elements. It mostly comes in response to learning current shortcomings where the most essential is to have a process for learning and to pose this process by the mother organization. Two essential points should be taken into consideration while designing a learning process: (1) active learning is seen as more effective according to practitioners, (2) personnel motivation for learning.

Across dimensions



Concept cloud comparisosn					
Proactiveness		Reactive capacities		Learning	
Peopole	36	Client	35	Team	8
team	25	People	26	people	7
client	25	time	18	stage gates	7
risk	24	team	17	client	6
Manageme	15	contract	14	organization	5

Figure 4.6: Resilience elements concept cloud comparison

Across all interviews, repetitive project management areas emerged which professionals found related to construction project resilience. These found mainly related to the project system components: Client, project team/ people, contract, risk management, project manager, project management and manager, contract, and mother organization. Specific phases that interviewees found crucial affecting resilience emerged as well, namely: the tender and design phases. A comparison of these aspects are

Figure (4.6) illustrates how these aspects are stated by practitioners to contribute towards resilience dimensions of Proactiveness, reactive capacities, and learning. The found resilience elements are in relation to the emerged project management areas. Despite that, we see some components of the client, project team /people, contract, risk management, manager, contract, and planning contribute towards all of these dimensions, but still, it differs in the level of participation. Where for Proactiveness elements most concepts mentioned were related to project people/ team, which is seen logical as most of the soft aspects found essential for proactiveness are performed and related to personnel. For example meetings, risk sessions, client management, team collaboration, and risk awareness culture. While client, risk management and project management approach stand after. For reactive capacity, the client is the centre of the mentioned elements, which can be explained by the client satisfaction goal stated as important by practitioners where a successful reaction would fulfil this goal. After that, more elements were found related to time in terms of buffers, or to the project team in terms of collaboration and creativity and other related concepts, and contracts in terms of flexibility and clarity. On the other hand, learning elements were centred around the project team while new concepts arise related to learning are the stage gates verification and validation process, and the mother organization's role in the learning process.

There is dependency noticed between the different elements: for example, informing client timely about project change is mainly related to the project manager's availability to devote time for that and keep it aligned with contract management, which also depends on the project team's effectiveness and competencies to perform the desired level and create by that the needed time for a project manager to manage client relations.

Furthermore, there are elements shared across the three resilience dimensions related to effective risk management, client-contractor good relation, repeating projects scope, sufficiently diverse team combination, open and safe project culture, and effective communication. These may be considered essential elements to build resilience as it builds up in all resilience aspects at once.

Essentially elements from the three dimensions were mostly related to soft, organizational, and strategy aspects. For example collaboration with clients, teams and stakeholders, communicating, creativity, partnerships, and creativity, project safe open culture. While technical aspects were found more in the learning-related elements where aspects like learning processes, platforms and tools are needed.

In terms of the number of elements. It was seen that most elements professionals mentioned are related to reactive capacities. And the lowest for learning. Where it may be explained that awareness towards creating capabilities to face disruptions has a more tangible effect and is more familiar in the current construction practices. While learning effects are not direct and take time to see its results, also current learning is mostly passive that needs reading large-size reports and takes time.

4.5. Conclusion

SQ3: What elements contribute towards large construction project resilience, in practice?

In practice, 62 elements are found contributing towards resilience. Based on experts' views most repetitively mentioned elements were: schedule buffers, effective risk management, Good and trust relation with the client from the start of the project, Collaborative and flexible contract features (e.g., two-stage contracts), Mother organization network and connections (e.g., specialists, authorities, and clients), Team motivation, creativity and ownership (e.g., tasks ownership, risks ownership), Extra time and money from the client to solve problems, Partnerships with subcontractor and suppliers (formal and informal partnerships), Teamwork and collaboration, Timely and proactively communicate changes within the project team. Furthermore, and based on studying empirical cases of disruptive events, the elements that actually helped overcome disruptions were: client collaboration and trust, team flexibility (e.g., re-design, re-planning, changing tasks), internal mobilization, the client covering extra costs, partnerships, and collaboration. Several elements were revealed to affect more than one resilience dimension. In general, most elements were mentioned in relation to the reactive capacities and the lowest amount was found for learning elements. Also, the majority of the elements were found related to organizational soft aspects rather than technical. Resilience dimensions were the same as revealed in the reviewed literature: proactiveness, reactive capacities, and learning, where these were found to cover all detected elements. Several project management-related domains emerged from interviews as participating towards resilience as follows: client, project team/people, contract, risk management, project manager, project management and manager, contract, and mother organization. Tender and design phases were found crucial to build resilience in a construction project as the various resilience elements need to be embedded in the project management plans which are developed in the early stages of the project. For example, building good relations with the client, goals alignment, team building, schedule and budget buffers, and contract flexibility. All of these elements are built at these early phases of a project.

SQ4: What are the barriers to building resilience in large construction projects? Barriers that hinder construction project resilience were found mainly related to six areas: (1) Initial project choice and settings led by contractor conflicted interests (Business continuity VS Project success) affected by the construction market conditions and competitors, (2) Client tender settings and collaboration, (3) Contractor Organization (Size and scope diversity), (4) Personnel (resilience awareness, motivation and time), (5) Management (culture, mentality), (6) Learning processes. Amongst all, the importance of finding a solution for the learning barriers was stressed by practitioners.

Additional findings Practitioners' views helped to understand that resilience response is not only about being fast, or cost-effective in responding as found in the literature. It is more about how to respond, as fast as possible, but without harming the project's most valuable objectives. Where these objectives are not static but rather dynamic and could change through project phases. Therefore, construction project resilience can be understood as:

The ability of a construction project to overcome disruptive events (preserve its well-functioning and ability to perform to achieve expected targets) fast and without

bypassing the current most valuable project objectives thresholds, enabled by proactiveness (Awareness, anticipation, alertness), reactive capacities (absorptive, adaptive, recovery), and learning.

5

Resilience framework for construction projects

After searching into the concept of resilience, its dimensions, and the elements contributing toward resilience. It is time to combine this knowledge into an effective presentation to assist its understanding and usage in theory and practice instead of having it only as a narrative description. Available building resilience frameworks are reviewed in the literature study (check 3.6) to point out what advantages the framework can obtain, and what disadvantages to try to avoid. Building on the research-defined gaps (1.2), literature study results (3.6), and framework needs resulting from the interviews (4.3.11), the framework needs and criteria are identified. Then the framework and its design are presented. This chapter concludes with a discussion of the developed framework and its intended usage.

5.1. Framework needs and criteria

The framework design and objectives evolve from unfulfilled needs in both theory and practice. In theory, as defined in section 1.2 resilience understanding and recognition at the level of a whole construction project, and Operationalising resilience in construction projects are both underdeveloped. Also, the need for further empirical evidence related to resilience contributing elements and practices was expressed by several researchers (Geambasu, 2011; Q. He et al., 2017; Rahi et al., 2019; J. Zhu, 2016). Furthermore, in the few found frameworks which introduce elements to build resilience, the frameworks found are not comprehensive and contain at some point abstracts more than practical elements.

In practice, there is a need for methods and tools to aid in managing projects through uncertainty. Building resilience in the project is a suggested solution. However, resilience is still a new concept in practice. The resilience concept needs to be introduced, explained, and aided with practical tools to be effectively applied. As found in the empirical study, practices to face uncertainty are scattered across projects and across each project's dimensions and not built systematically and comprehensively. Practices differ per project and across the different divisions of the mother company, which makes it harder to compare and evaluates. A need for a systematic approach that aids organizational and project learning is also expressed through the interviews of almost all interviewees. While having one flexible framework will give a base for systematic comparison, quantifying, evaluation, and learning support base.

It may be then more efficient to gather resilience factors from theory and practice in one framework that facilitates practitioners' understanding, assessing, and designing for resilience at the early phases (e.g., tender) of projects and through the project life-cycle. However, currently, there is no such comprehensive framework to the knowledge of the author of this paper, as most resilience-related frameworks describe the resilience process Burnard et al., 2018; Francis and Bekera, 2014; Madni and Jackson, 2009 or resilience conceptual frameworks to support better resilience understanding Cerè et al., 2017; Tengblad and Oudhuis, 2018 rather than grasping resilience elements. Moreover, even the few frameworks that do handle resilient contributing elements introduce resilience from one perspective of systems resilience or organizational resilience with different choices of resilience dimensions to focus on. Based on these mentioned elements, the framework needs are concluded in theory and practice.

Needs from practice:

1. Building resilience in the early stages of the project
2. Assessing and enhancing resilience through the project's different phases
3. Form a base to evaluate, discuss, and understand project performance behind the used Key performance indicators numbers
4. Aids project and organizational learning across multiple disciplines

Theoretical needs:

1. Comprehensive framework that unified the scattered resilience knowledge
2. Framework obtain all views: system, organizational, and project view in studying resilience
3. Construction project resilience specific
4. explain the link between project management theory with resilience science
5. Empirical evidence-based resilience elements, to align theory and practice

Framework Criteria

Framework criteria and specifications are defined in response to the concluded needs. The framework then has to be in alignment with the following criteria:(1) comprehensive, (2) operational, (3) based on theory and practice, and (4) facilitate resilience responsibilities' ownership by the different project disciplines (5) qualitative and quantitative. While criteria defined by Kolfschoten(2007) for the effective framework will be included as follows: (6) usefulness, (7) Clearness, (8) ease of use,(9) Open to further improvements and completeness which is reflected already in the comprehensiveness criteria.

5.2. Resilience framework for construction

The framework is designed to meet the specified needs and criteria based on the following process: Conclude and design framework dimensions, including and excluding resilience elements, assign resilience elements into dimensions, design the evaluation function and related illustrations, and conclude the intended use of the framework.

1. Conclude and design framework dimensions:

Previously, in Section 3.3.1, the main resilience dimensions were concluded from the literature study as follows: proactiveness, reactive capacities, and learning. The resulting resilience elements from the literature study as well as from the empirical study are found to be all covered within these three dimensions, and no new resilience dimensions emerged from the empirical research. However specific projects' components and areas appeared in theory, and more repetitively in practice, as focal points that resilience elements revolve around. In theory, it was referred to human agents/ personnel, resources (material technology, techniques, substance, energy), information, project management, organization, risk management, stakeholders management, and systems engineering. At the same time, the empirical studies recurrently revealed aspects of client, project team, contract, partners (sub-contractors, suppliers, and joint venture partners), mother organization, project manager, risk management, project management, schedule, and change management. Also, the empirical evidence discloses a large consensus on two specific project phases (tender, and design) which are considered more important than other phases to build project resilience. Therefore, resilience elements emerged also in relation to these specific phases. Another essential finding in both theory and practice was that a large amount of resilience elements participate in building more than one resilience dimension.

As a result, to cover all resilience aspects related to construction projects in theory and practice, the framework was designed as a matrix of two directions. The first direction consists of the three concluded main dimensions (proactiveness, reactive capacities, and learning). The second comprises 15 aspects (13 project management-related aspects of Client management, stakeholder management, monitoring and control, partners, mother organization, risk management, project manager, project team, schedule management, change management, contract management, project management approach, information management, and two critical phases: tender management and design management). Each resilience element is then assigned to one project management-related area, and one or more resilience dimensions depending on its contribution.

2. Including and excluding resilience elements:

The resilience elements were chosen based on the following include rule: an item is included in the framework if it was mentioned in two reference sources of literature and empirical interviews. That results in three scenarios of inclusion: an element mentioned in two different literature sources, by two interviewees, or in one literature and by one interviewee. The sum of the included elements was then 87 elements. These categories are presented in the framework as Letters of B, Li, and I, respectively.

3. Assigning resilience elements into dimensions:

To assign resilience-included elements to the framework dimensions, two bases were used; literature classification, and empirical classification by interviewees.

The first base is classifications found in the literature study (check section 3.3.1), where previous research work has already assigned specific elements to contribute to specific fields summarized in Figure (5.1) and explained in detail in Section (3.3.1)

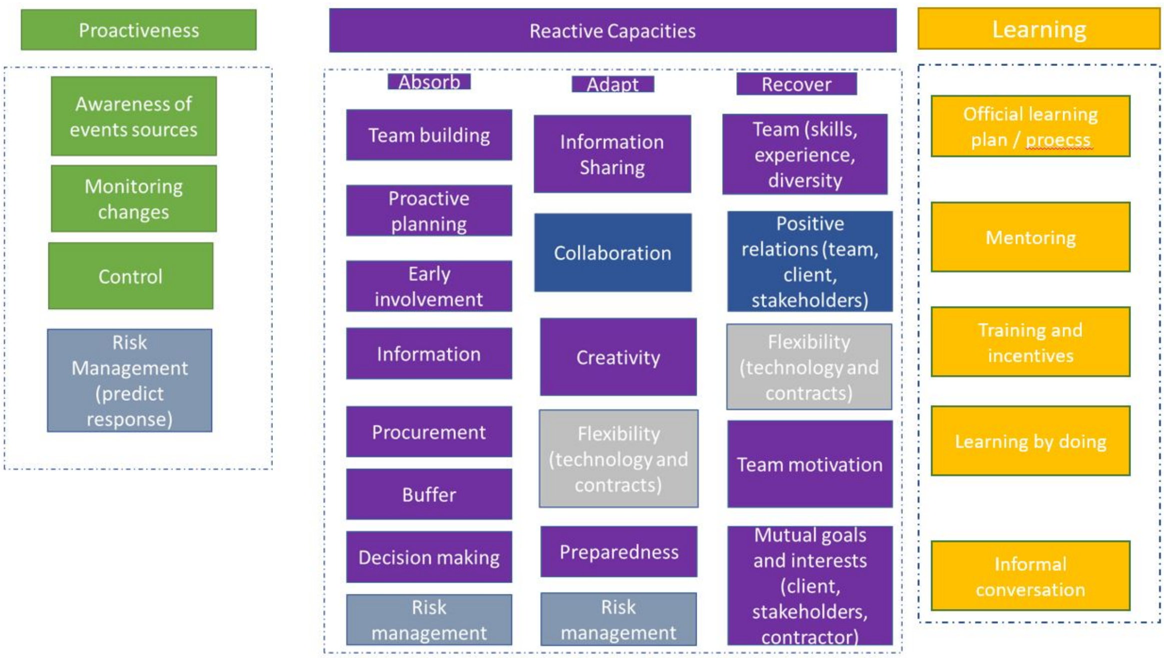


Figure 5.1: Assigning resilience elements in literature

The second base to assign resilience elements to the framework dimensions is Interviewee's classification. In the interviews, participants were asked to specify elements that participate towards the three main resilience dimensions of proactiveness, reactive capacities, and learning (check interview guide Appendix (.1), and the interviews' design (4.1.2). That helped to get experts' views on resilience elements already categorized into the three main resilience dimensions as explained in Section (4.3.6). The empirical resilience elements were accordingly then assigned to the resilience main dimensions as it is shown in Appendix (.2), in column "Resilience dimension", where reactive capacity elements are referred to with the R letter, proactiveness with P, and learning with L. While the elements collected in the other interview sections that did not direct participants' answers toward specific dimensions, were assigned based on the literature views.

It is important to mention that further sub-categorizing of the resilience dimensions into sub-dimensions and lower grouping levels (e.g., flexibility, resourcefulness, improvisation, robustness,..., etc.) is acknowledged but chosen to not be included in the framework to avoid over-complexity and keep framework practicability. The chosen dimensions are used to categorize resilience elements for two reasons. First, it represents what emerged from the study, so reflecting the empirical and theoretical evidence. Second, it helps to further analyze the overall resilience function into packages related to project management domains which are already existed in practice, so then It can be further assigned and analyzed by the related specialist. This is seen to help assign resilience-building tasks to the project's various departments. Hence, to develop a comprehensive construction project resilience framework, the elements lists resulting from the literature and the empirical studies, are combined, compared, assigned, and re-arranged into one overall framework.

4. Design evaluation function and related illustrations

To aid in assessing resilience profiles for projects, the framework is designed in a way to facilitate that need. An input space (column) is created where the users can rate the efficiency of the application for each resilience element in their project. This is the only input the user needs to set. The framework will transfer then each rate into the affected resilience dimension (Reactiveness, proactive capacities, and learning) multiplied by its weight. The need for Weights usage is acknowledged in the framework design (to reflect the different levels of importance of each element towards resilience), and decided for this research to be used as the values of (1) for all elements. More research is needed to formulate a solid weight distribution across all resilience elements. Instead, equal weight with a value of one is used for all elements, and this need for weights is mentioned in future work suggestions (7). The framework suggested being used to uncover the resilience print of each project not only about the main resilience dimensions of (proactiveness, reactive capacities, and learning) but also across the different management disciplines of the project. This was through rating the effective application for each resilience element in the studied project through the Likert scale which is advised by Hollnagel (2015), Patriarca et al. (2018), and Rahi et al. (2019) to be suitable for resilience evaluation. The applied Likert scale in the study cases is already used in Hollnagel (2015) paper as follows:

1. Rate (5): Excellent – the system exceeds the required efficiency of the resilience element application
2. Rate (4): Satisfactory – the system fully meets the required efficiency of the resilience element application
3. Rate (3): Acceptable – the system meets the nominal efficiency of the resilience element application
4. Rate (2): Unacceptable – the system does not meet the nominal efficiency of the resilience element application
5. Rate (1): Deficient – there is insufficient resilience element application
6. Rate (0): Missing – there is no application of the resilience element

After rating the resilience items, the framework will generate five radar charts. The first is the project resilience print, to illustrate the project resilience abilities across the three main resilience dimensions. Where it shows which dimension is not reaching the acceptable level (level 3), to apply enhancements. To further identify these enhancements, it is possible to zoom in on each of these dimensions through three radar charts illustrating the resilience print for each of the three dimensions across the project's different resilience-related disciplines. These prints are the Proactiveness print, Reactive capacity print, and learning prints. The fourth outcome of the framework is the Management areas' resilience print, which is generated to illustrate how well each discipline of the project is contributing towards the overall project resilience showing which areas need to be further improved (e.g., project management approach), and by filtering this specific area in the framework it is possible to identify which resilience element exactly needs to be more efficiently applied (e.g., emergency action plan). It is essential to mention that each element may affect one or more dimension which is depicted in the framework. The elements rate from each dimension aggregates to reflect the total dimension value. Also, the elements from each project management discipline aggregate to represent the contribution value of each Figure 5.2, presents the designed framework which is further illustrated in Appendix (E).

The PRL resilience Framework - for Construction projects

Category	Element	Discription	Source	Proactiveness	Reactive capacities (absorb,	Learning
Client management	Implicit objectives understanding	Understand the client's objectives priorities, implicit interests, and worries	I	P		
	Mutual goals	Client- contractor mutual goals establishment and continuity (via continuous dialogue)	B	P		
	Client support	Client support with covering the extra time and money to solve problems, or facilitating solutions by relaxing constraints if possible.	I		R	
	Trust relation	Client -contractor trust and good relation	B		R	
Stakeholders managem	Timely Informing	Timely inform stakeholders about related changes and problems	I	P	R	
	Interests alignment	Interests alignment amongst client, stakeholders, and contractor	I	P		
	Effective Communication	Continuous dialogue and communication with stakeholders and client to keep alerted with their changes and interests. That is through transparency and wisely chosing moments and the content of communication (e.g., after the contract award everyone is happy, so a good moment to	B	P		
Monitor and control	Lag KPIs	Lag KPIs usage for after performance evaluation (output measurement)	B	P		L
	Lead Kpls	Lead KPIs usage as an early warning system before possible disruptions (predictive measurement)	B	P		L
	Soft KPIs	Alertness and observation of soft unwritten KPIs (e.g., team stress, working hours, ...,etc.)	I	P		
	Monitor Changes (internal and external)	Timely monitoring, informing and aligning with internal and external changes (stakeholders, market, client, mother organization)	B	P		
	Processes focused monitoring	Monitor processes quality and compliance with processes	I	P		
	Audits and colleagues reviews	External and internal audits, and colleague review for work	B	P		L
Partners (Suppliers, sub-contractors, joint	long term relations	long term relations	B	P	R	L
	Ownership	Nurture Sub-contractors sense of ownership (e.g., early involvement in tender)	I	P	R	
	Qualified	Have trusted network with good quality and proven record (e.g.,not the lowest price option)	B	P	R	
	Diversity	Suppliers diversity for critical items	I		R	
	Mutual goals	Partners shared vision and goals	B	P	R	
	Mobiliazing	Ability of external mobilizing for experts from partners	B		R	
Mother organization	Culture	Culture of safety to communicate mistakes and support to solve	I	P	R	L
	Network	Mother organization network and connections (specialists, authorities, and clients) and good relations (e.g., help solve problems with clients, provide resources)	B	P	R	
	Timely support	Timely support with needed interventions and mobilising to solve problems	B		R	
	Standardization	Standardization for processes and forms, where having standards enable learning across the organization and projects. Also, it facilitates faster responses and is better based on the well-defined and known process and sources of information	I	P	R	L
	Participation in industry-related events	Participating in construction field-specific events (e.g., The Bauma construction machinery display event).to keep updated, aware and alerted with the latest changes and technology, market resources availability, and reinforcing and expanding the organization network.	B	P	R	
	Impose learning process	Organizational set and impose specific process for learning	B	P		L
	Mother organization alertness	Mother organization sending alerting notifications of common problems and changes across the organization	I			
Risk management	Opportunity management	Opportunities awarness and management	I	P	R	L
	Effective risk management	Effective risk management (e.g., assessment beyond (probability * impact) assessment, including other factors of the available time of response, activities criticality, ..etc)	B	P	R	L
	Project-specific	Design risk management plan based on project specific characteristics, complexity and uncertainty	Li	P	R	
	Risk culture	Nurture risk culture of awareness and ownership	B	P	R	
Project manager	Positive mindset	The positive mindset of the project manager	I		R	
	Temporal project pause	Ability to pause the work course when it is needed (large change order, disruption) till understanding its cascading effect. (e.g., contract facilitates this need)	I	P	R	
	Network	Project manager network to provide experts or resources once needed	I	P	R	
	Team oriented	Un-formal meetings and daily connections with the team	I	P		
	Experience	Project manager experience	I	P	R	L
	timely exclude personnel	Timely exclude team memebers once needed	I		R	
	Efficient decision making	Manager decision making (clear communicated, avoid dispute with client to save time, fast and efficient at crisis)	B	P	R	
Project team	Motivation	Nurture team motivation and ownership (through positive comments, celebrate small successes, and incentives)	B	P	R	L
	Training	Project team training (processes, field coaching, cooperation, problems solving)	B	P	R	L
	Resilience	Positive mindset and resilience of team members	B		R	
	Role awareness and ownership	Project team awareness and ownership of their own role responsibilities and their risk management role	B	P		
	Team competency and combination	Competent team (technical knowledge, soft aspects,, etc.) , with a suitable combination (Communicators, solvers, women, men, new, experienced) based on the project features of complexity, uncertainty and on the client	B	P	R	L
	Collaboration and compassion	Project team collaboration and compassion	B	P	R	L
	Creativity	Creativity	B		R	
	Goals alignment	Team members align their role goals with project goals and thresholds (budget, time,..etc) based on contract understanding	I	P		
	OBS completness	Project roles completeness in an early stag	Li	P	R	
Schedule Management	Preserve system relations	Preserve system relations (original project planning) that enable being aware and alerted to interdependencies which are already thought of and to a better extent discovered in the original planning	I	P	R	
	Buffer	Have risk and complexity based time buffer	B		R	
Change management	Inform client	Timely and continuously inform the client about project changes and possible problems	B	P	R	
	Liability agreement	Mutual liability agreement (time & money) before execute scope change orders	I	P		
	Boundaries	Set fixed period for client to change scope (e.g., design baselines)	I	P		
	Timely Sharing	Timely show and share project changes within the team	B	P	R	
Contract management	Alert the team	The contract manager continuously alerts the project team to possible contractual concerns	I	P		
	Felxible cooperative contracts	Collaborative and flexible contract features (e.g., two-stage contracts, allow work pauses once needed, possible by passing certain clauses in the contract to facilitate solutions once needed)	B		R	
	Contractual risks	Realistic contractual risk responsibility distribution (e.g., underground conditions)	I		R	
Project management approach	Project-specific	Project-specific management methods based on project characteristics and complexity understanding	Li	P	R	
	Meetings	Weekly progress meetings for key project personnel (project manager, procurement manager, design lead, work preparation, construction lead, risk manager)	B	P		L
	Informal collaboration	Informal collaboration and conversations for project team and involved parties	B			
	Inter-disciplinary organization	Personnel understanding of each other roles and dependencies (e.g., quarterly meetings across specialisation to explain and evaluate each other roles)	I	P	R	
	Operational balance	Balance tasks between disruptive events related tasks and original tasks	I	P	R	
	Celebrate successes	Celebrate small successes as a team (e.g., schedule fixed, milestones accomplished)	B		R	L
	Learning techniques	Small size evaluation summaries for learning, and setting timely learning moments through the project (e.g., every 3 months)	I			L
	Work repetition	Repetitive projects with possible repetitive team members	I	P	R	L
	Personnel continuous training	Continuous training, theoretical teaching and improving knowledge level of personnel	Li	P		L
	Learning culture	Nurture a culture of learning among the project team (meetings, informal converstaions, trainings)	I			L
	Learning resources	Allocated learning resources (personnel responsible, budget, ...etc.))	I			L
	Financial Buffer	buffer in the project budget and emergency budget from the mother organization if needed	B		R	
	Plan for resilience	Planning for project resilience and commitment to it	Li			
	Operational flexibility	Operational procedures flexibility and alternative work techniques availability	Li		R	
	Escalation plan	Having specific escalation criteria and plan for all project's specialisations throughthe project life cycle	Li		R	
	Emergency response plan	Emergency response plans and guidelines to specify who does what and when, once a perturbation occurs, for different types of perturbations.	Li		R	
	Validatio and verification process	Set official reviewing, validation and verification points through the project life cycle (e.g., stage gates review process) which are also learning points. This help keep aligned with client and contractual requirmenets , discover current deviations and anticipate future events	I	P		L
Information management	Information platforms	Having open shared platform to share information and changes	B	P	R	L
Tender management	Tender selection	Chose projects that fits company abilities (technical, organizational,...etc)	I	P	R	
	Project team involvement	Involvement of work preparation, control, procurement and execution	B	P		
	Project manager involvement	Involve project manager in the tender (scope and construction method)	B	P		
	Knowing the client	Collect information and learning about the client	I	P		
	Critical suppliers agreements	Critical suppliers analysis and early agreement (un formal agreement)	I	P	R	
	Project information completence	Sufficient project information in the tender phase (given by the client and/or self-investigated)	B	P		
	Tender design	Verify the tender design to be: realistic, applicable, constructable	I	P		
	Client's demands interpretations	Efficient interpretation of client demands: written verification matrix and discussion with client	I	P		
Design management	Sub-contractor involvement	Early involvement of key sub-contractors in the design phase	I	P	R	
	Verification	Design verification system against client requirements	I	P		
	Design consciousness	Design consciousness to be aligned with the project thresholds(time, budget ..etc)	I	P		

Figure 5.2: The PRL resilience Framework for Construction projects

5. The intended use of the framework

Based on the pre-discussed needs, the framework is intended to be used as a tool to (1) Aid resilience design and embed resilience elements into construction projects, most importantly in the tender phase and in creating the project management plans. (2) Aids evaluating and enhancing construction projects from a resilience perspective, through running the PRL resilience evaluation periodically (suggested quarterly). (3) Aids comparing projects across the organization in a systematic way, and forming a base for learning. (4)Aids project and process control monitoring and understanding the Key performance indicators results from a project-level perspective. The framework can be used by the tender team in the tender phase, the project manager, and the project management team (key personnel meetings) in creating project management plans and in their progress meetings, process, and project control. The framework is also seen to help evaluate projects and hence may be used in the internal audits process across the organization.

5.3. Discussion

Design to fulfill design criteria

Overall the framework was designed to fulfill the intended usage, needs, and design criteria. The framework element was built based on Literature study and empirical interviews involving empirical cases to fulfill the criteria (3) based on theory and practice. All project management areas (contract, schedule, team, client,..., etc) were taken into consideration in the study scope and also all resilience found dimensions, including learning and proactiveness not only the adaptive capacities, that were to fulfil the criteria(1) comprehensiveness. Elements took an operational level of details as much as possible, rather than wide abstract elements (e.g., having statements in the contracts that enable pausing the project once needed, instead of an abstract such as contract-based flexibility), that is to fulfil criteria (2) operational ability. While to fulfil the criteria(4) facilitate resilience responsibilities' ownership by the different project disciplines, the framework subcategories were chosen to be grouped in a way that aligned with the project management different areas which are also recognizable in practice. For example risk management, contract management,.., etc. Where resilience elements could be assigned as a package to the related area to further apply or enhance.

Project management common practice VS resilience based project management practice

It is noticeable in the framework's resulted elements that some can be already recognized as good project management practice elements and would be distinguished in related literature, while other elements would seem more resilience specific like; having an emergency response plan, buffers, work insurance, alternative operation methods, and routes, or mobilizing abilities. However, does that means that the other more commonly known practices are not resilience specific as well, or do not contribute to creating project resilience? for example: building a trustful collaborative client-contractor relationship, is a common successful construction management practice. However, let's further ask, why? why have we always heard that good project management will build good client-contractor relations? When this question was asked through the interviews executed in Chapter 4 mostly as a follow-up question, and the answers were that it helps stay aligned and connected with the client to timely be informed and anticipate any changes in his requirements, conditions, or others. Also, it helps with client understanding and support to overcome disruptions and issues and create a happy, safe, and open culture among the team. These mentioned reasons are directly leading to two essential dimensions of resilience: proactiveness and reactive capacities. Therefore, although this element would be considered a common project management practice, in creating a comprehensive framework of resilience-contributing elements, it can not be ignored or excluded. That was one example, and discussing all the framework elements would lead to another 80 pages of research. However, in the framework, it is indicated which element affects which dimensions which initiates a justification line of thinking for considering each element a resilience element rather than project management common practice.

The relationship between project management and resilience may seem complicated. which one is the larger concept? and how these two intersect. Such concept interaction is expected since project management practices aim to achieve a successful project based on defined objectives (Lindahl & Ryd, 2007), and also resilience in principle aims to accomplish the success of the project (Cooper et al., 2013). However, project resilience is more essentially focused on the continuity of success through all disruptive events, and keeping the normal planned level of functioning (Doorn, 2020) through being reactive, proactive, and learning (Rahi et al., 2019). Creating a resilient project then aims for the same overall purpose of project management with focusing on continuity not only on the final results, and also through focusing on specific abilities. As such every resilient project it is expected to be successful, while not every successful project is expected to be resilient. A project could be successful because it was faced with very few disruptive events, for example. Another point is that all attempts and practices to build (more) resilient projects will be through actions taken by project management, it won't just happen by itself Z. Zhu et al. (2020), and these resilience elements will be the under the project management practice, as the framework also revealed. For example: having a buffer in the schedule will aid in creating absorption capacity and hence a more resilient project. However, to be embedded in a project it needs the project management and schedule management to think of this element and set it in their management plan then execute it. In such socio-technical systems like a constriction project, where even the project concept itself is sometimes mixed with the project management concept Munns and Bjeirmi (1996), it is expected to have mixed views for resilient project and resilience-based project management.J. Zhu and Mostafavi (2015) suggest a study of managing safety in a resilient was, and also Geambasu, 2011 introduce the management of construction project in a resilience-based approach. The difference between a resilience-based framework like the PRL framework, and other good project management frameworks is that a resilience-based framework is systematically directed to aid in building the three main resilience capabilities of protectiveness, reactive capacities, and learning which enable projects to perform in a resilient was in face of disruptive events and hence achieve project success as an end results and through project phases.

The resilience concept is very wide, and as we saw in the research scope 2.1, it is affected by larger systems (other projects in the same portfolio, mother organization resilience), or by smaller components (E.G, personnel own resilience). all of these aspects, even a human being own resilience can not be built/ enhanced without conscious management of his life and decision, based on resilience perspectives of proactiveness, reactiveness, and learning.

Therefore, what this paper suggests and what is actually found through the theoretical and empirical studies, is that a project as a system is desired to be resilient, and this resilience would display in its performance. To achieve that on the level of a project, resilience-based project management needs to be in place which adds practices related to dimensions of proactiveness, reactive capacity, and learning instead of having overall traditional project management practices that aim to create successful projects mostly without setting a further detailed structure of what functions a successful project should have, why, and how they may work together. While the resilience-based approach offers a more systematic tangible approach that not only aims to achieve project success but also set the focus on success continuity throughout project phases and perturbations. Hence, resilience-contributing elements will involve aspects of the common good practice of project management, and add more elements based on the resilience concept and dimensions.

6

PRL Framework Evaluation: case studies

In the previous chapter (5) the framework needs were concluded based on the literature study and the empirical study. Criteria then were designed to meet these needs and steer the framework design. As in every new artefact coming to light, it is not completed before evaluating the specified criteria against the defined needs and the artefact against the specified requirements. The framework content and structure are evaluated then accordingly and introduced in this section through the empirical application of the framework on three study cases.

6.1. Content evaluation against needs

Content evaluation is mainly oriented to test how well the artefact addresses stakeholders' needs, it is to answer the question 'Are we doing the right thing? In that sense, it has the same orientation as the validation process' Ryan and Wheatcraft (2017). However, for qualitative research, to use the terminology validation in terms of proving the total validity of the research outcomes, more than three study cases are needed (Dworkin, 2012). However, the empirical application in these three cases is valuable as it will help to evaluate the alignment of the outcomes (created framework) with the theoretical and empirical needs and set the way for further improvements. To that matter, the framework is going to be tested through its application in three case studies. The case studies are chosen to be infrastructure projects, recently finished, having various complexity levels and sources, and of available data, documentation, and personnel to interview. Six interviews were performed, two per each project. The interviewees were a project manager and a process manager from each project. These roles were chosen because they own a more comprehensive overview of the various project's aspects. The framework is used to uncover the resilience print of each project not only in relation to the main resilience dimensions of (proactiveness, reactive capacities, and learning) but also across the different disciplines of project management. This was through rating the effective application for each resilience element in the studied project through the Likert scale which is advised by Hollnagel (2015), Patriarca et al. (2018), and Rahi et al. (2019) to be suitable for resilience evaluation. The applied Likert scale in the study cases developed based on the scale used in Hollnagel (2015) paper as follows:

1. Rate (5): Excellent – the system exceeds the required efficiency of the resilience element application
2. Rate (4): Satisfactory – the system meets the required efficiency of the resilience element application
3. Rate (3): Acceptable – the system meets the nominal efficiency of the resilience element application
4. Rate (2): Unacceptable – the system does not meet the nominal efficiency of the resilience

element application

5. Rate (1): Deficient – there is insufficient resilience element application
6. Rate (0): Missing – there is no application of the resilience element

In the application of this scale, it could be that the required resilience element application efficiency is the nominal level, In this case, it is suggested in this research to evaluate the element as satisfactory since its minimal satisfies the desired level.

After rating the resilience items, the framework will generate five radar charts. The first is the project resilience print, to illustrate the project resilience abilities across the three main resilience dimensions. Where it shows which dimension is not reaching an acceptable level (level 3), to apply further enhancements. To further identify these enhancements, it is possible to zoom in on each of these dimensions through three radar charts illustrating the resilience print for each of the three dimensions across the project's different resilience-related disciplines. These prints are the Proactiveness print, Reactive capacity print, and learning print. The fourth outcome of the framework is the Management areas' resilience print, which is generated to illustrate how well each discipline of the project is contributing towards the overall project resilience showing which areas need to be further improved (e.g., project management approach), and by filtering this specific area in the framework it is possible to identify which resilience element exactly needs to be more efficiently applied (e.g., emergency action plan). It is essential to mention that each element may affect one or more dimension which is depicted in the framework, and the elements rate from each dimension aggregates to reflect the total dimension value.

Resilience elements weights

	Project management area	Weight .Avg
1	Information management	4,3
2	Client management	4
3	Planning & Schedule Management	3,9
4	Project manager	3,8
5	Project team	3,7
6	Partners	3,7
7	Contract management	3,7
8	Project management approach	3,6
9	Risk management	3,3
10	Change management	3,3
11	Mother organization	3,2
12	Monitor and control	3,1
13	Stakeholders management	1,7
14	Design management	1,3
15	Tender management	1,3

Table 6.1: Weighted resilience management areas

The need for using weights to reflect each element's importance towards resilience is acknowledged. The six interviewees were asked to specify the importance of each element from their experience. The weights are presented in Appendix (D). However, it was decided to not use the found weights in the current framework as more participants are needed to formulate solid weight-related findings (qualitative studies would demand a minimum sample size of at least 12 to reach data saturation (Clarke & Braun, 2013; Fugard & Potts, 2014; Guest, Bunce, & Johnson, 2006). Therefore, for the PRL framework, equal weights with a value of one are used for all resilience elements. While the weights are investigated through the six interviews to support future research in formulating more concrete views regarding resilience elements' weights. Table (6.1) introduces the weighted resilience management areas in descending order, where the top five weighted areas are: information management, client management, planning, and schedule management, the project manager, and the project team. The Likert scale was used for the evaluation of the weight, explained through the following:

1. Rate (5): Must have: Necessary element for a resilient performance of the project
2. Rate (4): Should have: Important element for a resilient performance of the project
3. Rate (3): Would have: Have a small impact on the project resilience if it was left out
4. Rate (2): Could have: Have a very small impact on the project resilience if it was left out
5. Rate (1): won't have: not a priority for this project
6. Rate (0): Not relevant

Evaluation logic and data

The study cases are investigated in terms of project characteristics, project perturbations, project performance, and project resilience. That is carried out by reviewing projects' management plans, available progress and evaluation reports, and the database of the infrastructure projects' financial performance. For the financial performance, the acquired data shows the gradual progress (one update per quarter) of the project's financial performance, extracted into Excel sheets format to be further studied and visualized for the selected study cases. Data regarding other performance areas like time and quality was also searched for. Still, there is a low focus in the organization on these aspects compared to the monetary aspects. Hence, data is not available in a database across the organization, so low data availability. Detailed data related to the progress of schedule performance (Primavera or MS project files format) are available at the schedule manager and were possible to be obtained for one project (P2).

The study cases aim to view projects' performance over time and compare it to the resilience print created using the framework. The financial performance is represented by the deviations from the desired financial results (zero: means the project performing as desired, negative values mean a loss, and positive means higher profit than expected). Similarly, the variation orders are calculated in comparison to the original contractual work amount (contract value), where positive means more work and changes, and negative means less work. It is further discussed in the cases below why these indicators were chosen. The logic behind the chosen validation is based on what was discussed earlier in section 3.1, that is project resilience abilities will lead to positive results in terms of project performance. Therefore, studying if that applies in these three case studies, will further support (or not), whether the identified framework elements can be supported by empirical evaluation to be considered resilience elements. Also, comparing the management areas' resilience prints to the project's strengths and weaknesses found in its documentation and interviews would reflect if the framework is able to aid in depicting the project's strengths and weaknesses in terms of resilience abilities, and set the focus for further enhancements.

6.1.1. Study case (1)

Figure (6.1) represents the project studied in case 1, in financial numbers. Where we see the scope changing orders represented in the blue line and growing from the second quarter in the second year of the project, with a dramatic increase in the fourth quarter of the third year. A change in a project disturbs not only the changed area but also all known and unknown other disciplines that depend on it, leading to disturbance in the project planning as well. As we see, this project faced client changes' disturbances among other types of disruptive events which we can not all depict in terms of timing and intensity, therefore the project changes are chosen to be used to hint at a level of disturbance the project had through its phases. The financial performance of the project represented with the orange line started with a loss. Then, it shows stability till Q3 of the second year. However, with a needed major design change in Q3 of the second year, losses increased but got stabilized soon through the following year. Losses slightly increased again through the left period of the project even with the increase of changing orders. These were the financial figures for the first study case, i.e., a project with a final financial loss. However, a question may arise: is it enough to evaluate the project only based on its end financial results? and if so, what are the explicit and implicit reasons behind these

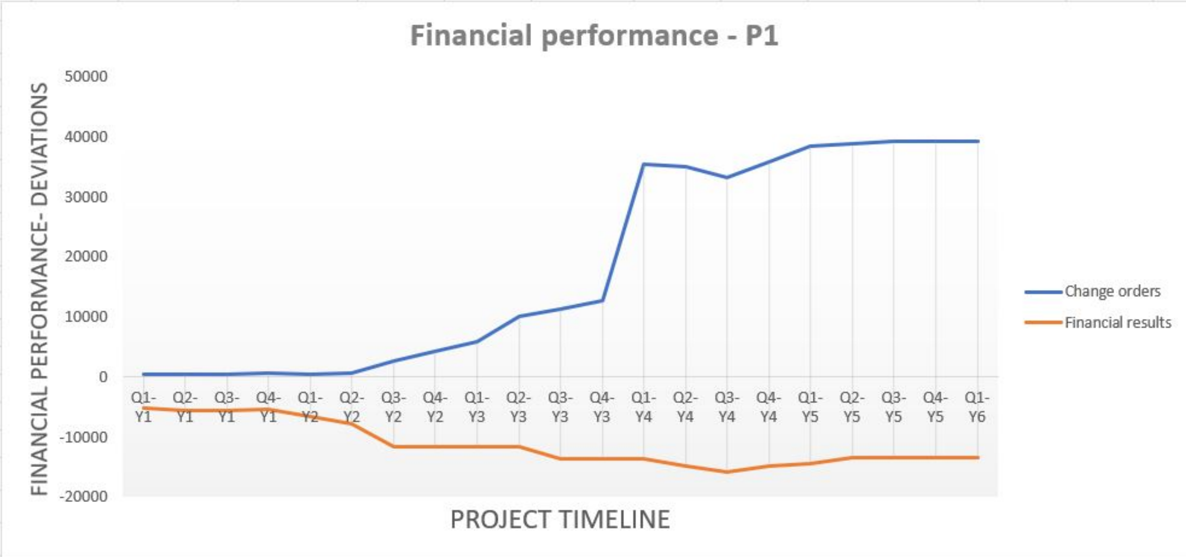


Figure 6.1: financial performance P1

results? and is it enough to recognize performance deviation reasons on the level of events/ issues, or are there underlying implicit attributes that represent the real problem? To answer these questions, it is needed to search into the project, its features, challenges, and the implicit storyline behind its financial performance figures.

Project 1 behind the figures
The project is a light train (tram) in a large city in the Netherlands. The project includes the design and realization of the tram Infrastructure, including tram rails, overhead lines, and stops. The route is eight kilometres long and has nine stops. The project consists of seven route sections. The related budget is €323 million in total, and around €70 million for the studied contractor which is the budget considered in this study based on the study scope and available related data. While the project duration is 5 years, for the following main four phases (Opstartfase; start-up, Ontwerpfase; design, Realisatiefase; realization, and Testfase; testing) The project included one external partner for the design part. While the implementation had the internal collaboration of two sub-divisions (companies) of the mother organization. The contract type is UAV-GC, Engineering, and Construction (E&C) contract and the client is the government represented by the executive board of the city region. The project was classified by the contractor as a top complex project (class A).

Project related views

The following points express some of the project's main challenges from the contractor's perspective and were obtained through interviews with the project manager and the process manager. (1)The Project manager changed the project management plan and the execution plan at the start-up phase(opstartfase), and the client was not aligned and happy with this change. He left the project shortly after in the third quarter of the first year, the project was then without a project manager for a short period where after several project managers were assigned during the next period to fill that role, with a different management perspective for each. After 4 months, an experienced project manager took over, apply an overview assessment of the current situation, and losses set verification of specifications against client requirements before starting to design, set a plan and focus on team building and continued with the project. (2)The project team from the contractor side had a high level of ownership, cooperation, efficient communication, and solidarity. (3) The client assigned freelancers from outside the client organization to carry out the management of the project from the client side. The decision-making main authority was still by the client part through the freelancers, which led to a long loop for decision-making throughout the project. The freelancers had each different management methods and styles to apply and also had implicit self-centred interests at some points which led to low cooperation in face of problems and prolonged the project. (4)Dialogue about client requirements, implicit interests, and goals alignment was missing due to the client's representative's reluctance. The client had implicit interests (e.g., aiming for a specific resource by a specific supplier which is usually not allowed to specify in the contract, so instead the client translated this specification that they thought would lead only to that supplier, but actually it was possible to lead to another option which the contractor choose for, as client interests were not explicit. The client accepted the contractor's choice at the start (the lowest price), then decide to ask explicitly for the technology that the supplier offers, which led to large changes in the design, planning, and procurement). (5) The client side lacks understanding of the contract. (6) The contract does not allow stopping when a change is needed. (7) The expected environment of the chosen city imposed public density more than what was planned for in the tender phase, which makes work realization more complex, and adjustments to the planning was needed.

From project documentations studies (progress reports and management plan):

(1) Roles were not fully assigned and responsibility boundaries were not clear. (2) The project size is large and of various aspects (rail, infra, facilities), which imposed challenges on the connectivity of these aspects by one execution manager. That creates the need for extra roles for reintegration management and multiple project directors. (3) Follow-up meetings (daily), and progress meetings (weekly) were indeed performed across the project's different teams. (4) Timely communication changes through daily stand-up meetings for the key personnel. (5) team based decisions through go/ no go decision points for the implementation discussed in the daily meetings, incorporated in the planning. Evaluate decisions, learn and adjust through the daily meetings. (6) Based on an interview with the project manager (unrelated to this specific study case but rather related to section 4, it was noticed that the project manager (who took over in the design phase) stress the open safe culture, very team-oriented, and when he was asked what is a successful project he emphasizes the success in the team building and having a happy team. (7) Lean planning approach is used.

Project resilience print

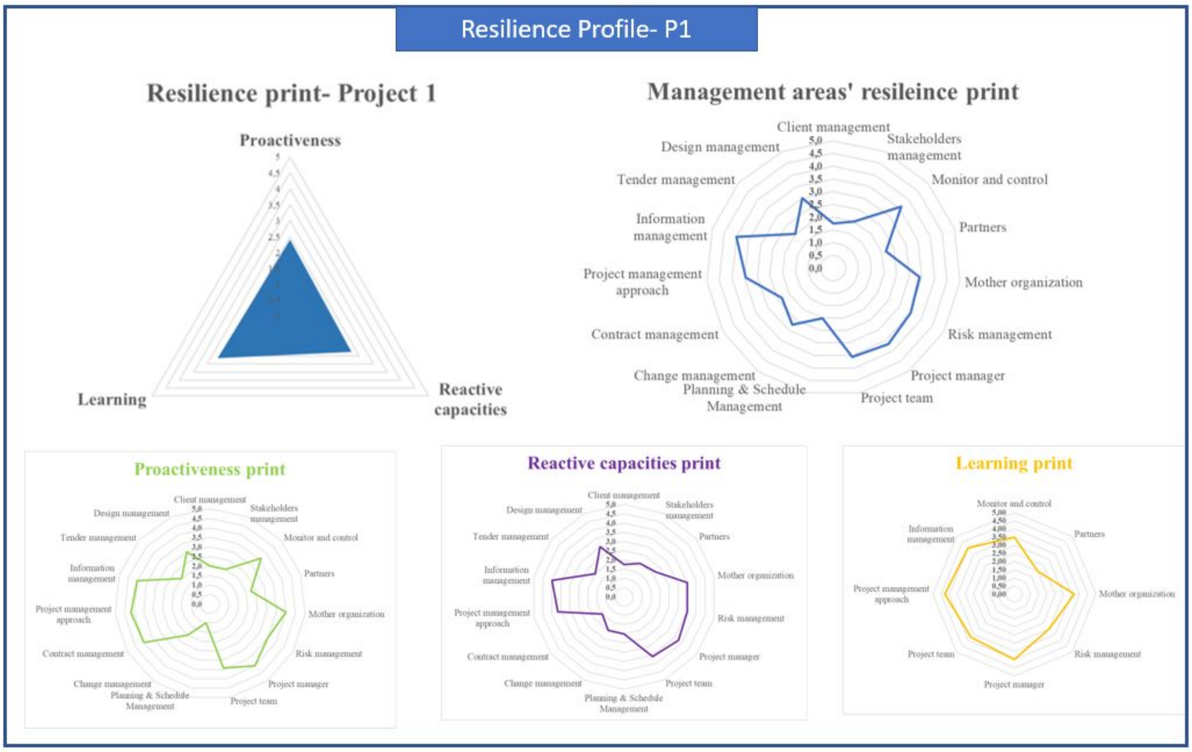


Figure 6.2: Resilience profile-P1

The resilience print for project 1, illustrated in figure 6.2 demonstrates a clear resilience signature of this system (project) that can perform more learning than proactiveness, and more proactiveness than reactive capacities. While the framework offers a view of explaining each of these abilities. In the reactive capacity print, we can identify that resilience elements related to the client management, contract, tender, and planning are in lower performance points, and by zooming on these areas in the framework, it is possible to further identify where exactly what resilience elements needs to be further improved. For example, the zooming in on the client management category, we see all related reactive capacity elements (Implicit objectives understanding, Mutual goals, Client support, Trust, and good relation, have scored poorly: 2, 2, 2, 1, 2 respectively, where 1 stand for deficient and 2 stands for Unacceptable. These results are actually aligned with the mentioned views in the previous paragraph 6.1.1, where we found that the client was reluctant to cooperate, had implicit unexpressed interests, and self-focused representative. Overall, looking at the management areas' resilience print, we can identify that resilience elements related to the project team, project manager, risk management, information management, and mother organization are performing on the level of 3.5 between acceptable (3) and satisfactory(4). where that can be indeed supported by the points found in the progress report and management plan of practices related to daily follow-up meetings, weekly progress reports discussed in weekly meetings, cooperative lessons learned and apply improvements, team-based decision-making gates, and the openness of the project manager. While to improve project resilience, some areas that are performing at an acceptable level need to be improved. These are client management, planning and scheduling, partners, contract, and stakeholders' management. The fact that these areas need further improvements aligns with the previously discussed points of the plan changing, and client reluctance, implicit interests that led to large changing orders the client requests that affected design, procurement, and planning. More specific improvements can be introduced by the framework by zooming towards each of these and checking which elements perform under the acceptable level. For example, in the partner's area, we can see that 'Nurture Sub-contractors' sense of ownership (e.g., early involvement in the tender)' is satisfactory, while, long-term relations Have trusted network with good quality and proven record (e.g., not the lowest price option), Suppliers diversity for critical items, Partners shared vision and goals, and Ability of external mobilizing for experts from partners are at unacceptable levels and enhancements need to be applied on these areas.

6.1.2. Study case 2

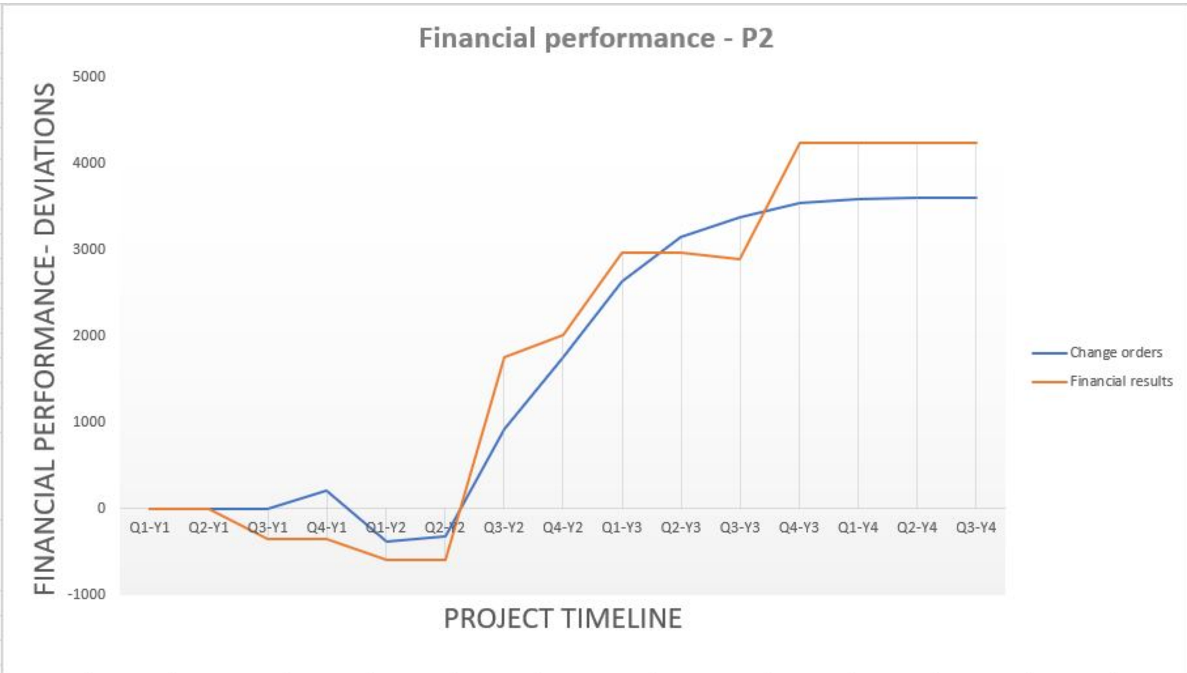


Figure 6.3: financial performance P2

Figure 6.3 illustrates the second case study in financial numbers. The figure depicts the progress of project scope changes requested by the client (blue line), and the project budget deviations (orange line), through the project timeline represented in time blocks (one block is 3 months; a quarter).

There were no scope changes through the first two quarters. while through the next three-quarters, changes started and fluctuated between increasing the scope and then decreasing it again to a point lower than the contractual scope which was shifted once more to a steep surge in the third quarter of year 2, to keep growing after till the delivery of the project in Q4-Y3. The last three quarters are the duration of handling documentation, arranging settlements, and closing out the project. On the other hand, project financial performance shows no deviations from the intended budget for the first quarter, then with the start of the fluctuating scope changes project started to show negative deviations (loss). However, the registered losses shifted dramatically into increasing profit with the increased scope till the delivery of the project and closing out with positive financial results (a profit).

Project 2 behind the figures
The project is an extension and renewal of a regional tram line in a large city in the Netherlands. The project consists of renewing ten kilometres of track and overhead wires, extending the tram rail network, adjusting the current line to make it suitable for a transport connection with the existing network, and 50 centimetres lower entry will be installed to achieve operation with low floor trams for 23 stops, and replacing part of the tram infrastructure to accommodate travellers in the coming years to have Safe transport for the next 30 years at the lowest possible life cycle costs. The project duration from commission to close out is 3 years and 9 months, and the related budget is 65.6 million euros. The contract is based on a two-stage tender approach and UAV-GC (De Uniforme Administratieve Voorwaarden voor Geïntegreerde Contractvormen; The Uniform Administrative Conditions for Integrated Forms of Contract) type of contracts, and the client is governmental; the related provenance represented by the executive board of the city region. The contractor classified the project as a second complexity (class B).

Project 2 related views

Interview-based views:
1. The project was partly repetitive (the studied project 1) with the same client, and the same hey personnel involved. 2. Lesson learned from a previous similar project (the studied project 1): Clear escalation plan involving the mother company network with the client (governmental side) to support and facilitate project mutual decision-making through a previously formulated good relation with this client. 3. Lesson learned: The client assigned freelancers from outside the client organization to carry out the management of the project from the client side. The decision-making main authority was still by the client part through the freelancers, which led to a long loop for decision-making throughout the project. The freelancers had each different management methods and styles to apply and also had implicit self-centred interests at some points which led to low cooperation in face of problems and prolonged the project. However lessons were learned from the previous project, and the contractor asked to appoint one official connection person with the client to communicate changes and decisions. 4. Lesson learned: Early involvement of the project manager and key personnel in the tender. 5. Lesson learned: stress and agree on the necessity of having mutual goals and vision, and create a culture of mutual objectives from the tender phase. 6. Two-stage tendering where the design was developed in a close view, alignment, and cooperation with the client then the contractor will fix a contractual project planning, schedule, and budget.

Documentations based views:
1. Using the innovative solution for work and surrounding safety monitoring through real-time app usage. One of the first construction companies to test the Safe Sight app. All communication about safety is centralized through this app. Employees can make reports that arrive at the project control room, to provide suitable responses and actions if needed. This offers an up-to-date and fast share of related information and decisions. 2. Stress, monitor, and measure the open, safe, and satisfactory culture: through a KPI (Satisfaction atmosphere, openness, proactive behaviour) that measures Colleague Satisfaction that scores the level of satisfaction with cooperation, Every 2 months is measured and a threshold of a minimum of 70% score for this KPI is set. 3. Set specific thresholds for the used KPIs, clearly communicated in the project management plan (e.g., 1% maximum of financial deviations). 4. Very clear structures and rules for meetings and follow-ups, authority, escalation plan, and decision making 5. Lean planning approach (LEAN planning sessions for the implementation.), and emphasize including stakeholders in these sessions. It is openly shared planning development sessions, adjusting planning based on objectives and immediate sharing of information. The results

of the LEAN sessions are shared by the integrated planner in the Master Planning and processed by the various disciplines in the detailed planning. A LEAN session means that there are stickers that can be pasted on sheets on the wall when information should be available to own a product or activity.

Project 2 resilience profile

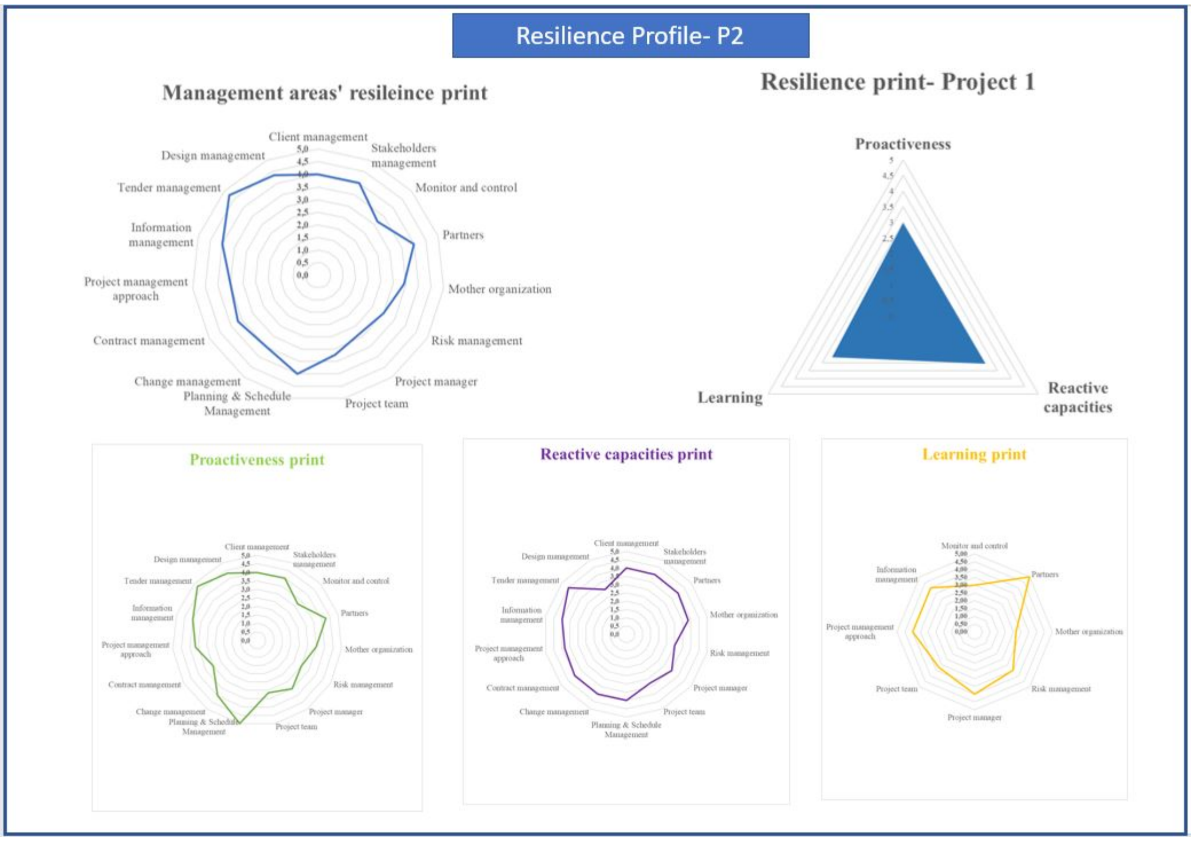


Figure 6.4: Resilience profile P2

This project, as the resilience print shows, performs best in terms of reactive capacities (3.1 score), then proactiveness(score 3), and learning (score 2.6). Where level 3 represents an acceptable level while level 4 represents a satisfactory level. Looking back at the elements that mainly participate to create reactive capacities identified in figure 4.10from section 4, the top third (a repetitive project with the repetitive client and team members), fourth (Collaborative and flexible contracts, e.g two-stage contract), and fifth (mother organization network and connections) reactive capacity elements strongly exist in this project as identified in the previous project's views. The main strong element this project had is the lessons learned from the previous similar project, especially since it deals with the same client. It is important to note that this learning led to creating acceptable levels of reactive and proactive capacities, while the learning capabilities of the project from its own challenges still need some improvements and also depend to a large extent on the needed improvements in the mother organization's learning approach.

While zooming in on the management areas' resilience print, the project had the most effective resilience elements in the domains of tender management (4.8) and design management (4.3), client management, stakeholders' management, and planning. We notice some similarities with the most problematic areas that appeared in the previous similar project of un sufficient tender cooperation and the lack of client-contractor collaborative relations. It makes sense then that the lessons learned will be around these areas, and be successfully transformed into a new similar project. Examples of lessons learned are to specify one contact point with the client instead of several freelancers, also focus on initiating a culture of mutual objectives in the early stages and involve the mother organization in good relations to facilitate this goal, participation of the project manager in the tender and avoiding changing key personnel and project management plan.

Overall, the resilience profile of Project 2, displays a tendency towards a circle resilience print shape, yet it is still not totally homogeneous and fluctuates mostly between levels 3 (acceptable) and 4 (satisfactory). All areas scores above the acceptable level but under satisfactory. Areas that can benefit from improvements are risk management, project team, and monitoring and control. While through zooming into the resilience elements related to each area, we can define more specifically what needs to be improved to build, for example, a better risk management resilience contribution, as follows: Risk culture and ownership among team members, Opportunity management, and Project-specific risk management approach based on project characteristic (e.g., complexity scan).

6.1.3. Study case 3

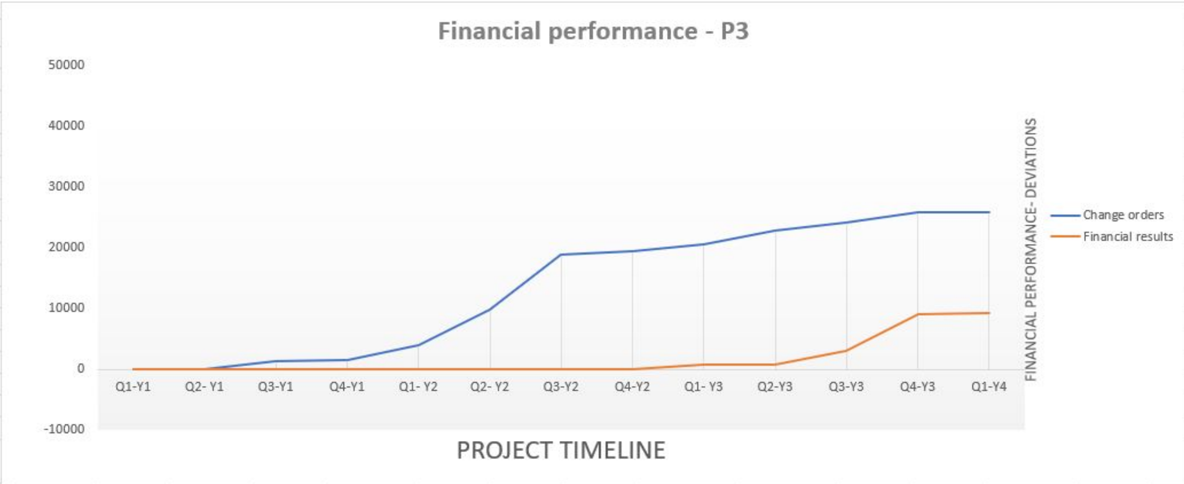


Figure 6.5: financial performance P3

Figure 6.5 illustrates the third study case in financial numbers. It shows that the work scope or amount changes were in terms of increasing not decreasing the work. Changes started in the second quarter of the project's first year and had upward growth till Q3-Y2 when it has a dramatic increase in this last quarter due to a large design change. After that, the contractual work scope/ amount kept mildly increasing till the end of the project.

The project financial performance represented by the financial deviations through the project timeline is showing stability (no loss or extra profit) despite the depicted work changing orders increase. It is until the last year of the project's lifetime, the financial results started to increase. Mainly we notice three profit-increasing moments in Q1-Y3, Q3-Y3, and the major one is in Q4-y3, is representing incentives of accomplishing milestones and final milestones slightly earlier than planned, risk budget saving due to efficient avoiding of expected risks, and change orders claims' compensation at the end of the project. The project close-out with profit more than planned.

Project 3 behind the figures
The project is part of an overall program of developing a new terminal building and pier as an expansion of an existing airport to meet the increasing number of passengers. The project scope included restructuring and relocating existing underground infrastructure, construction and integration of a new viaduct parallel to the existing viaduct, and the realignment of traffic routes in and around the area at both the ground and first (+1) levels. The client is a governmental party. The official Project language is English, since the tender was based on the international and a main sub-contractor is international as well. The project duration is three years and 3 months, from awarding to the close-out of the project. While the project budget is around 39 Million euros. The contract was FIDIC yellow (Fédération International des Ingénieurs-Conseils) Conditions of Contract for Works where Yellow Design & Build contracts, and used the NEN-ISO/IEC/IEEE 15288:2015 international standards for project management processes. the project is classified of a C level (The highest is A) of complexity based on the organization classifications

Project 3 related views

Interview-based views:
1. Stakeholders, especially governmental parties and companies (e.g., military and airline operators) from the surrounding environment, were the main source of complexity affecting the project's work planning and supply chain traffic. 2. Points of power: system and process thinking culture, very good tender estimations, manager and key personnel involvement in the tender with a collaborative approach with the client, very good contract management and control mechanisms, client management (inform and involve) were efficiently and timely done for all changes, an early formulation of the project team, very good performing team with creativity (e.g., execution team developed new construction methodology to produce in lower units rates than contracted which led to savings), Realistic risk budget and good performance in risk management and prevention which led to savings from this budget, Project manager experience, the mindset of system thinking, process-oriented, positivity, manoeuvre with the client and trustworthiness and control and anticipation the impact of the changes.

Documentations-based views:
1- Production acceleration capacity applied timely to fulfil milestones timely. 2- Internal mobilization capacity in the organization 3- Highly system and processes-oriented project management plans, very clear assigning and describing of roles and responsibilities, with clear comprehensive supporting sub-systems designed (e.g., stakeholder management system, project control system), with a focus on internal and external interfaces. 4- Applying an International Standard (NEN-ISO/IEC/IEEE 15288:2015) in alignment with the organization's strategic management approach, to provide a defined set of processes to facilitate communication among acquirers, suppliers, and other stakeholders in the life cycle of a project. The standards enable establishing business/working environments, e.g., methods, procedures, techniques, tools, and trained personnel. 5- Early involvement partners are explicitly planned for in the management plan. Sub-contractors and suppliers are considered partners, chosen based on previous good mutual work experience and long relations. 6- The Airside works around to make the work very technically and environmentally complex. Very large amounts of cables and pipes that have to be relocated, are all vital to the airport's current operations, such as the provision of gas, water and light, and sewage. All flights must remain operational without any interruptions as the flights are operated daily throughout the year.

Project 3 resilience profile

The project resilient print illustrates levels between acceptable (3) and satisfactory(4) for all three resilience main abilities. Where the reactive capacity was the most powerful capability for this project with 3.6 points, followed by proactiveness of a very close level of 3.5, and 3.1 for learning. This aligns with the project's views found in section 6.1.3, that referred to having good client relations and management from the start of the project, and the effective and creative performing team which both were found to play a key role in creating reactive capacities (check section 4). While for proactive capacity, the project had effective risk management which could achieve savings in the expected risk budget, and powerful project control through the focus on clear detailed project performance sub-systems and processes. While learning still needs some improvements especially from the part of the mother organization to set specific learning systems, processes, and resources in place.

To understand specifically which project management areas performed well and which ones need further improvement, the management areas' resilient print reflects how efficiently these performed in terms of creating resilient project performance. As we can see, resilience elements related to change management are the most powerful resilience area the project shows, aligning with the previously discussed high reactive capacity the project owns, where being reactive is essentially about efficient change management. As we can see the resilience print is almost taking the shape of a circle that varies between levels 4 and 5 (satisfactory and excellent), reflecting the efficient existence of resilience elements in areas of tender management, contract management, design management, project team, project manager, partners and stakeholders management, and risk management. While two areas of mother organization and monitoring and control show the need for slight further improvements to reach a satisfactory level. by filtering these areas in the framework, further elements of actions can be specified to improve. For the mother organizations, the following elements need to improve: standardization, imposing the learning process, mother organization alertness, and informing about changes. For monitoring and control, Lag KPIs usage after performance evaluation

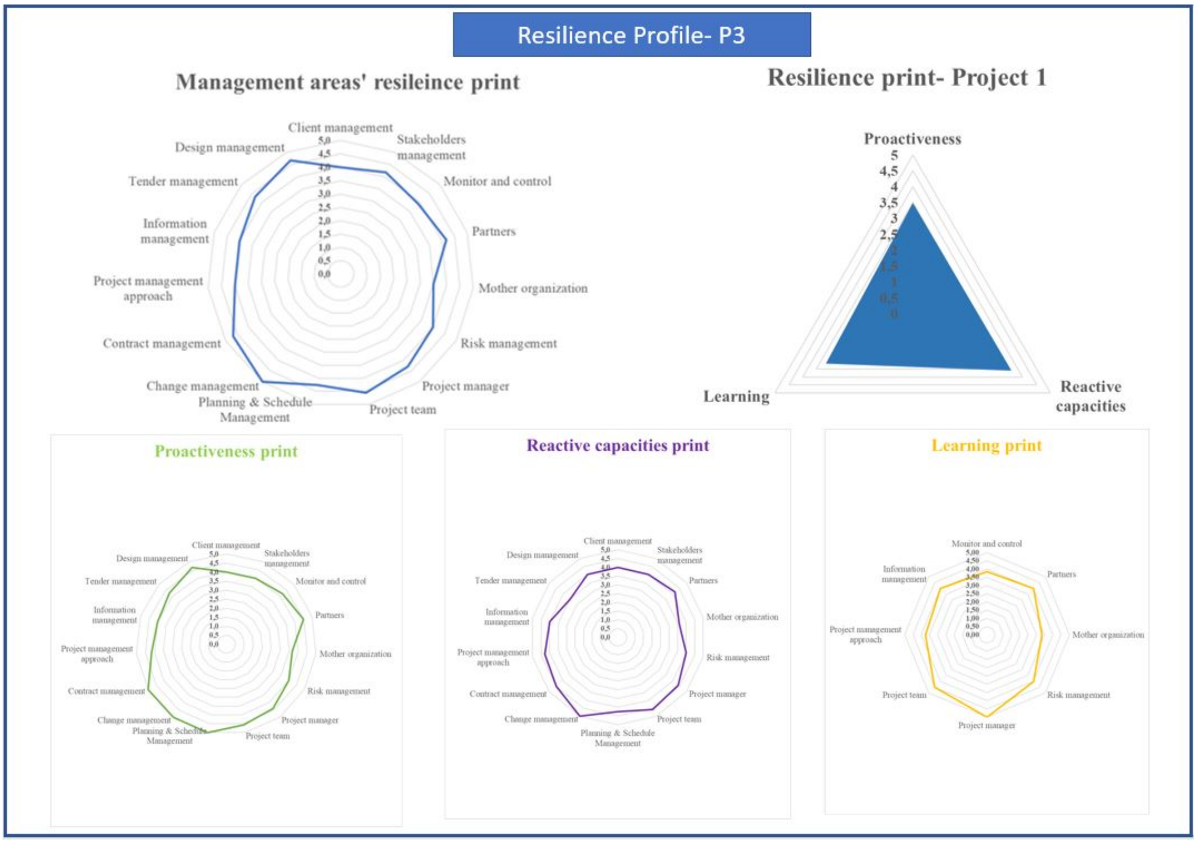


Figure 6.6: Resilience Profile- P3

(output measurement) needs to be improved.

6.1.4. Discussion: across cases analysis

Across all cases, we will look at three main aspects to compare: Project characteristics, changing orders and disruptive events, project performance, and project resilience. To that matter, A comparing summary is presented in the table below 6.2 handling the main aspects of project complexity characteristic (contract value, project duration, contract type, client, project language, location), also the project work changes (changing orders) compared to the original contract value, achieved financial result, and the desired financial results goal(from the contractor perspective). Also, a comparison figure of projects' financial performance progress through project phases and project resilience profiles is presented

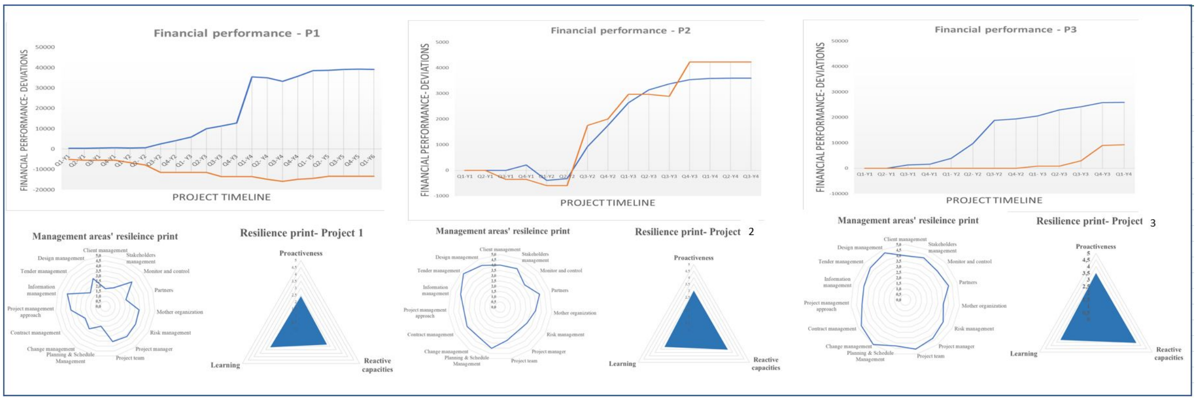


Figure 6.7: Across cases comparison

Project	Initial contract value	Contracted duration	Changes (compared to initial contract sum)	Profit	Intended profit	contract type	Client	language	Essential complexity factor	Main disruptive events
P1	70 M	3 years	57%	-12,4%	4,0%	Engineer and construct: UAV-GC	Govermental	National :Dutch	Location passing from a big city	Client implicit requiremnt led to large design change within the construction
P2	65,5 M	1year& 5 months	5%	6%	4,0%	Engineer and construct: UAV-GC	Govermental (same client of P1)	National :Dutch	Location passing from a big city	Client mis compliance with operating safety norms discovered in the testing phase, leading to a redesign and cnstruction
P3	39M	3 years & 3 months	66%	14,2%	3,8%	FIDIC yellow: design & build	Govermental	Internati onal: English	Stakeholders and surrounding environement :air port traffic, military and flights agncies stakeholders	Security requirements change at the start of the project & Problem with Piling work that led to large re-design

Table 6.2: Projects' characteristics

projects characteristics, changing orders, and disruptive events

As we can see in Table (6.2), all three projects have their own complexity and challenging factors. Also, the three projects were faced with disruptive events during their life cycles mainly large design changes and client changes the requirement. The contractual changes are considered in this study as an indicator of disruptive events as their source is either the client changing the work scope or quantities, which disturbs the original planning and creates new unknown dependencies or changes are requested by the contractor as a consequence and/or in response to (external & internal) disruptive events as interviewee mentioned and also in literature Keane et al. (2010) and Khalifa and Mahamid (2019). It is illustrated in the figure (6.7) that the first project had the most changing orders (57% increase compared to the original contract value) with a steep peak related to a client changing orders requested during the execution phase, which led to significant re-design, affecting procurement, work preparation, and execution as well. While in Project 2, the changes were fewer (5% increase of the original contract value) with a gradual increase till the delivery of the project. While the third project P3, had the largest changing orders (66%) mainly related to design changes and client requirements changes. In terms of complexity which is also a source of uncertainty and disruptive events (check section (3.2)), all three projects had main complexity sources related mainly to the location in a big city center for project P1, and also for project P2. Both projects had to be performed in a densely populated area where safety is an essential requisite. While for project P3, the location and the stakeholders were the main complexity drivers (airport traffic, military, and flight agencies stakeholders), also the type of work scope led to more complexity in the project, where a large amount of underground power lines had to be relocated without interrupting the airport operations and flights which in principle, has 24/7 operation time.

Projects' resilience print & performance

On the other hand, in terms of project performance and resilience, What we can directly notice from figure 6.7, is that a wider resilience print hints at better project performance. We see Project P2 and P3 which have a wider and more homogeneous resilience print compared to Project 1, closing with positive financial results of 6% and 14.2% respectively, while Project 1 was finalized with a loss of 12.4%. Where they could bounce forward to achieve higher financial results than targeted, despite being exposed to major disruptive events and changing orders of 5% and 66% respectively. What is noticeable in term of the resilience print is that in all three projects learning dimension require enhancements, mostly due to the lack of the organization's role in imposing learning processes and systems. what we can see is that the project which had positive end results had a similar pattern in terms of resilience print illustrating more reactive capacities than proactive, and more proactive than learning. Also, these illustrated more homogeneous shapes towards a circle shape, for the resilience print.

However, what we may argue is that the positive financial results may not reflect the whole picture of project performance. What we can see is that if the other performance aspects (e.g., quality, time, environmental permits,..., etc.) are not performing well, it is mostly that this will affect the monetary aspect with penalties and losses. However, the other way around is not always true. It could be the case that the project is going over the intended budget, but this extra money is used to mobilize and accelerate production to meet schedule deadlines or to further enhance the quality. Also, some aspects like team satisfaction can not be exactly reflected in the financial performance. On the other hand, it is highly noticed in practice (from the 24 executed interviews and 3 case studies) that aspects of being on time or within quality would be translated into monetary claims if it was not satisfactory or into incentives if it was. For example, project three displays an increase in the project profit in Q2-Y3 and Q3-y3, which are due to incentives received for the early accomplishment of three main intermediate milestones (check the milestones and schedule performance in Figure (6.8). Although it is important to look at the other performance indicators to have a full view of the project performance, still looking at the financial performance, especially the final results, would reflect a very essential part of the whole view which implicitly represents some other performance areas.

6.1.5. Insights into other performance areas- Time

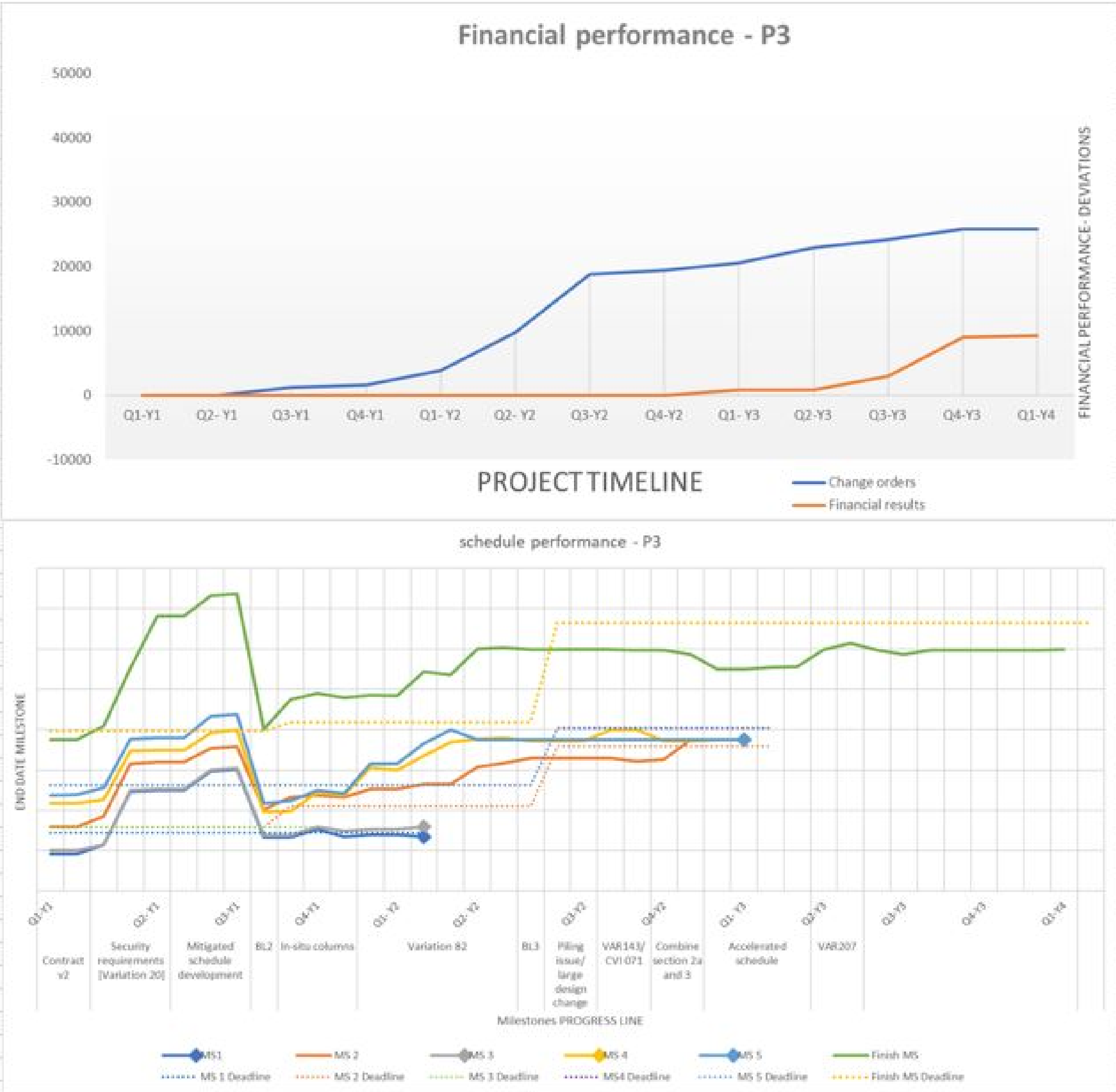


Figure 6.8: P3- Money VS time performance

For more insights into performance areas other than the monetary aspect, the schedule performance and the financial performance is presented for case study P3. Since it was already seen that project P3 has the wider resilience print, has the highest financial results, it is further investigated if the schedule performance for this project was also satisfactory, and were the P3 resilience large abilities (evaluated by the PRL framework), actually valid enabling project satisfactory performance.

In figure (6.8) we can notice three main ideas. The first is by looking at the period of Q2-Y1 and Q3-Y1, where the project faced variations in security requirements. We see the financial performance doesn't reflect this disturbance and how the project dealt with it, while the schedule depicted this event showing an increase (delay) in the expected finish milestone of the project as well as all intermediate milestones. However, it further shows the typical bathtub model (but in opposite direction) used in literature to represent the resilience function (check section 3.2), where it is clear that the project could bounce back toward the desired performance level (Initially planned baseline), using crashing resources and internal mobilizing to accelerate the production and return to the original plan. The mobilizing costs were not illustrated in that exact period in the financial graph, but rather in the final financial results Q1-Y4, as it was a topic of discussion with the client to cover related expenses which eventually happened.

The second main idea, we can notice from observing the period between Q1-Y2 and Q3-Y2, where a large change order related to design change due to problems in piling work, is noticed. the change is depicted through dramatic growth in the change orders line (blue line), while the financial effect is depicted in the final result of Q4-Y3, where the client covers these extra needed costs and no losses occurred. However, this issue did disturb the schedule with deviation from its baseline (BL2). The Project could also bounce back from this issue but not to the same previous equilibrium state (BL2) but rather to a new baseline (new equilibrium) which was created in agreement with the client. This reflects the team and project's capability and flexibility to cope with changes and adjust the plans, and the importance of timely informing, involving and cooperating with the client.

The final remark about schedule performance is that all milestones were meeting the agreed deadlines or earlier. The milestone Ms1 was delivered 14 days earlier, and MS3 delivered to meet the original planning dates, while MS2 (had 23 deals but did not affect the final finishing date), Ms4, and Ms5 meet the adjusted baseline BL3 with early delivery of 43, and 46 days respectively. The overall finish date was achieved and delivered 101 days earlier than agreed. This was awarded by the client as declared through the interviews and we see it reflected Q3-Y3 financial increase (profit).

Despite the fact that some may argue that creating baselines is a delay itself and the project eventually did not close out on the tender decided dates, we argue that the comparison should be between the actual delivery day and the planned delivery day agreed upon in the last baseline. The fact that a project team (team here includes the client, contractor, stakeholders, and partners) is able to cope with changes regardless if it is initiated by the client changing his needs or the contractor faces problems or mistakes, or unknown-unknowns. The fact that the project could reach an agreement that the client facilitates (maybe with more time or money) and the project team facilitates through their capability of re-planning, technical solution, and creativity to re-adjust the work, designs, procurement, plans..., etc, this ability to be flexible and adjusting as fast as possible and without harming project valuable objectives is the main ability of a resilient performance. Still, the fewer schedule and budget baselines are used the better, but the fact that it is used doesn't mean that the project performance is unsatisfactory, resilient, or successful.

Overall, what we can see is that Project P3 had large resilience capabilities based on the PRL framework assessment. The project was challenging with critical stakeholders and work conditions, international form of contract, international language, and changes of 66% compared to the contract value. However, it resulted in 14.2% profit (6.4 % higher than planned), and overall 101 days early delivery for the final finish date, and on time or early delivery for the intermediate milestones except for one.

6.2. Framework structure evaluation against criteria

The aim of this evaluation is to make sure that the basic structure of the system meets the identified criteria that were already set to fulfil stakeholders' needs. It is mainly to answer the question (Are we doing the thing right?) (Ryan & Wheatcraft, 2017). For the PRL framework, the stakeholders are in both areas of theory (body of knowledge), and practice (construction industry practitioners, specifically construction project management). The needs and criteria were already defined and used in the design stage in Section 5.1. While in this section, the framework is tested against these requirements as well as against research-specified gaps of (Gap1) Resilience vague definitions,

	Needs from practice	Framewrok features
PN1	Aids building resilience in the early stages of the project	Comprehensive resilence elements, especific elemts for tender and design
PN2	Aids assessing and enhancing resilience through the project's different phases	The rating system and generatedradar charts that can be compared over project
PN3	Form a base to evaluate, discuss, and understand project performance behind the used Key performance indicators numbers	The rating system, generatedradar charts, inclusivness of project management areas
PN4	Aids project and organizational learning across multiple disciplines	The rating system, generated radar charts, inclusivness of project management areas
	Theoretical needs	
TN1- Gap1	Comprehensive framework that unified the scattered resilience knowledge	All resilience dimensions and visions (organisation, system, and project) were included in the sope
TN2- Gap1	Framework obtain all views: system, organizational, and project view in studying resilience	Elements were included from literature related to all three visions
TN3- Gap 2	Construction project resilience specific	elemnts were included from construction related literature , and emperical interviews and case studies related to construction projects resielnce
TN4- Gap3	Explain the link between project management theory with resilience science	The freamewrok ncludes resilence dimensions as well as the project manageemnt areas iluustrating the ir contribution towards each other
TN5- Gap3	Empirical evidence-based resilience elements, to align theory and practice	Resilinec elements extracted from literature as well as emperical interviews and emperical cases

Table 6.3: Evaluation against needs

(Gap2) Resilience understanding and recognition at the level of a whole construction project is underdeveloped, (Gap3) Operationalising resilience in construction projects is underdeveloped.

The defined requirements/criteria were: Usefulness, Clarity, Ease of use, Comprehensiveness, Operation-ability / applicability, based on theory and practice, facilitating resilience responsibilities' ownership/linking project management to resilience theory, qualitative and quantitative, and Open to further improvements. The criteria were tested through the case studies, and also by sending the final frame design with an attached survey related to the specified criteria. These were sent to the 18 experts who participated in the empirical interviews illustrated in chapter 4. Also, the resilience definition concluded from the empirical interviews in the chapter 4 was included in the survey and practitioners agreed on an average of (4:satisfactory definition). The rating scale used for the surveys was using the six points Likert-type scale used to evaluate the resilience elements (Missing, deficient, unacceptable, acceptable, satisfactory, and excellent) The overall evaluation results are presented in table 6.3 and 6.4.

As we can see in the table 6.4, each theoretical need (TN) and need from practice (PN), was linked to specific criteria, and the framework feature that is intended to fulfil the need. While practitioner's views revealed that the framework is considered satisfactory to excellent in terms of its comprehensiveness and usefulness which is related more to the framework content. While areas of clearness, operation ability, and ease of use which are related to the framework structure are rated between acceptable to satisfactory.

Needs		Criterias	Rate
TN1, TN2	C1	Comprehensive	4,5
PN1, PN2, PN3	C2	Operational	3,5
TN5, TN3, TN5	C3	Based on theory and practice	Litreature & emperical study
PN2, PN3	C4	Facilitate resilience responsibilities' ownership	Grouping elements based on project management areas
PN2	C5	Qualitative and quantitative	Elemnts , scoring, and radar charts
PN1, PN2, PN3, PN4	C6	Usefulness	4,4
PN1, PN2, PN3, PN4	C7	Clearness	3,2
PN1, PN2, PN3, PN4	C8	Ease of use	3,5
TN1, TN2	C9	Open to further improvements	Resielince dimensions and project management areas to adapt new elements from both sides

Table 6.4: Evaluation against criteria

6.3. Conclusion

SQ5: how should these elements be included in one framework to aid in building and enhancing resilience in large construction projects?

To include the elements found in the literature and the empirical research in one solid framework, five main steps were needed: (1)design the framework dimensions to fulfil the defined needs, (2) include and exclude the found resilience elements based on a specified including rule, (3) assign resilience elements into the framework dimensions based on the literature and the empirical insights and classifications, (4) design the framework evaluation function and related illustrations (5) apply and test the framework. The resilience elements-including rule is as follows: an element is included if it has been mentioned at least by two sources, either two literature works, two interviews, or one literature and one interview. In terms of defining the needs and requirements, these were also defined based on theory and practice needs. An adequate framework has to fulfil the criteria of usefulness, clearness, ease of use, openness to further improvements, completeness, comprehensiveness, and operationality, based on theory and practice, and facilitate resilience responsibilities' ownership by the different project disciplines.

The framework then was designed to fulfil these criteria as much as possible. Where the elements from both the literature review and the empirical study were listed, compared, and organized into resilience dimensions, and project management areas based on their relevance. A scoring system with radar charts outcome was also designed within the framework. Assigning weights for the framework elements is important, however, further research is needed to identify these in a realistic way. Therefore all elements' weights are chosen equal to the value of one. Testing the framework against the defined needs is essential to identify its usability to practitioners where it was chosen to be tested through three study cases and evaluated through surveys. As a result, the concluded framework included three main dimensions (proactiveness, reactive capacities, and learning). 15 project management-related areas and 87 resilience elements, each assigned to one project management area and one or more dimensions.

7 Research limitations & conclusion & recommendations

7.1. Limitations

The research had limitations due to the time constraints, data availability, the newness of the topic that cost time but also led to the gradual excluding of unrelated directions and revealing research-related directions. The distinguished limitations are introduced as follows:

1. The research took into consideration the contractor perspective, which is the most important since it is the main performer of the project. However, including interviews with clients and stakeholders would enrich the research with their perspectives and their role in construction project resilience.
2. The research was executed focusing on one contractor company. Despite the fact that the chosen contractor company is international, large and includes several sub-companies in the Netherlands, still having multiple contractors participating in the research may further support and enrich the results.
3. Due to the topic's novelty, the literature study included all possible sources, with some of them building upon each other insights. Due to time constraints, this relationship of dependence or Independence between reviewed papers was not analysed in this research. Where such analysis would offer more insights regarding the theoretical evidence.
4. framework design acknowledged the importance of using weights in the aggregation of resilience elements into its categories and dimensions. Weights were explored through interviews with six experts. However, identifying these weights efficiently needs further research and interviews. Therefore equal weights with the value of 1, were used in the framework calculations.
5. The evaluation handled mainly financial performance and only one source for the schedule performance due to data availability constraints. while including more performance indicators (e.g., quality, team satisfaction,..., etc.) may further enrich the validation outcome.

7.2. conclusion

SQ1: What does construction project resilience mean, based on literature?

In the literature, there is little consensus on construction project resilience definition. Across all reviewed perceptions, a construction project resilience is introduced as the capacity, property, ability, or constant process of an entity (project, a system, or an organization) to perform certain functions (maintain positive adjustments, understand, respond, absorb, recover) in face of triggers (inherent challenging characteristics, critical events, variations, disruptions, disturbances) under certain constraints(timely effective, cost-effective) to achieve a desired outcome (same original performance state, or more desirable improved stronger state). In defining resilience, literature tends to build the definition on main areas to be thought of and distinguished. These are: specify the resilience of what, against what, for what, and through what.

The literature shows that resilience is needed not only in response to unknown-unknowns or unpredicted events, but rather for all types of disruptions such as known-unknowns, and unknown-knowns. Few works of literature have mentioned resilience needs in terms of positive affect events (opportunities) and these claim that resilience would enable projects to exploit opportunities. Construction projects' inherent characteristics of complexity (dynamic and time-dependent) and uncertainty, make predicting disruptive events not always applicable and accurate. Hence, a risk management process that essentially depends on identifying the possible risks as a first step, would always hold uncertainties and sometimes totally miss anticipating some crucial disruptions. Literature acknowledges approaches claimed to help manage through the unknowns, like vulnerability management and agility. However, both of them were found to have a proactive focus mainly on tackling the probability of disruption events, without much effect on the ability to react and cope with the impact of disruptions. Hence, researchers state a need for an overall proactive and reactive approach.

Resilience functions in a project emerge to be more visible once a disruptive event occurs. It is mainly noticed through the project performance curves, named also the resilience curves. These curves delineate system performance as a function of time, showing how project performance (represented by a chosen KPI) diverges through time once a disruptive event occurs, based on multiple aspects (most used are financial and schedule performance curves). Resilience functions vary through the phases of before, through, and after a disruption, where the related project performance curve is noticed to take the bathtub shape that illustrates performance stability before disruption, decrease through disruption, and increase again after disruption to reach the previous stability level again, or a higher level.

SQ2: What elements contribute towards construction project resilience, based on literature?

Most literature works introduce resilience elements categorized into main dimensions that together constitute resilience. Even though there is low consensus on these dimension's choices (e.g., include vulnerability or not, include learning or not), there is consensus found on the main resilience elements. Research works define resilience dimensions based on their conception of the gradual emergence of resilience through the perturbation phases. That starts from the phase before perturbation by understanding the cause of disruptions which is expressed through several alike terms as follows: vulnerability analysis, anticipation, awareness, perception and prediction ability. Then resilience dimensions are centred around acting upon anticipated disruptions sources (e.g., prevent or mitigate) using the following terms: effective planning, preparation, risk management, and prevention. Then, dimensions are set to monitor these sources. These dimensions focus on enabling proactive behaviour of the project system through the phase before a perturbation. While, once a perturbation occurs resilience dimensions are expressed as responding, adapting capacity, absorptive and recovery capacities. Then afterwards, after concluding a perturbation, resilience dimensions are expressed as recovery capacity, and learning. Across these visions it was concluded that there are resilience aspects related to the level of preparation a system has to face disruptions in its normal status, that is proactiveness that includes awareness, anticipation and alertness. A second aspect that can be concluded is reactiveness, in terms of what capacities the project owns to perform in reaction to a perturbation, including absorption, adaption, and recovery capacities. Lastly, a third aspect is related to the project and the organization learning after a perturbation. As such, three dimensions can be concluded from the literature: proactiveness, reactive capacities, and learning.

The main resilience elements found in the literature are as follows. In relation to proactiveness aspects: nurturing awareness, monitoring changes, effective control and KPIs (Key Performance Indicators), effective risk management, and partnerships for the proactiveness dimensions. While main elements mentioned for Reactive capacities were in terms of three capacities of absorption, adaption, and recovery. Factors of team building, effective planning, early involvement, effective information sharing, mobilizing, buffer usage for duration and budget, decision making, and risk management, are stated as participating in the absorptive capacity. The adaptive capacity elements focused on information sharing, collaboration, team creativity, flexibility (technology and contracts), response plans, and risk management. The recovery capacity-related elements focused on re-planning, damage assessment, the project team (skills, experience, diversity, positive relations (team, client, stakeholders), flexibility (technology and contracts), team motivation, mutual goals and interests among client, stakeholders, and contractor. Learning aspects focused on having an efficient learning plan, and allocating sufficient resources, mentoring, team discussions, training and theoretical teaching, team discussions, learning by doing from daily activities, learning incentives and awareness, and informal conversations.

Searching into resilience contributing elements, four related frameworks were found in the literature. These frameworks do offer valuable insights regarding practices and factors that support building and enhancing resilience. However, only one framework is found focusing specifically on construction projects. The other three handle resilience from one chosen perspective, either from an organization or a system view. Advantages and disadvantages vary among these models. For example, one model offers a good level of detail and operationality. However, it focuses on systems thinking and processes and neglects soft important resilience aspects such as client collaboration and good relations. while looking at another framework, it does elaborate on the soft concepts but introduces elements on an abstract level. There is, yet, no framework found that combines (1) studying resilience from system, organizational, and project perspectives, (2) illustrating the link between project management theory with resilience science, and (3) obtaining an empirical application to be built on theory and practice.

SQ3: What elements contribute towards large construction project resilience, in practice?

In practice, 62 elements are found contributing towards resilience. Based on experts' views most repetitively mentioned elements were: schedule buffers, effective risk management, Good and trust relation with the client from the start of the project, Collaborative and flexible contract features (e.g., two-stage contracts), Mother organization network and connections (e.g., specialists, authorities, and clients), Team motivation, creativity and ownership (e.g., tasks ownership, risks ownership), Extra time and money from the client to solve problems, Partnerships with subcontractor and suppliers (formal and informal partnerships), Teamwork and collaboration, Timely and proactively communicate changes within the project team. Furthermore, and based on studying empirical cases of disruptive events, the elements that actually helped overcome disruptions were: client collaboration and trust, team flexibility (e.g., re-design, re-planning, changing tasks), internal mobilization, the client covering extra costs, partnerships, and collaboration. Several elements were revealed to affect more than one resilience dimension. In general, most elements were mentioned in relation to the reactive capacities and the lowest amount was found for learning elements. Also, the majority of the elements were found related to organizational soft aspects rather than technical. Resilience dimensions were the same as revealed in the reviewed literature: proactiveness, reactive capacities, and learning, where these were found to cover all detected elements. Several project management-related domains emerged from interviews as participating towards resilience as follows: client, project team/people, contract, risk management, project manager, project management and manager, contract, and mother organization. Tender and design phases were found crucial to build resilience in a construction project as the various resilience elements need to be embedded in the project management plans which are developed in the early stages of the project. For example, building good relations with the client, goals alignment, team building, schedule and budget buffers, and contract flexibility. All of these elements are built at these early phases of a project.

SQ4: What are the barriers to building resilience in large construction projects?

Barriers that hinder construction project resilience were found mainly related to six areas: (1) Initial project choice and settings led by contractor-conflicted interests (Business continuity VS Project success) affected by the construction market conditions and competitors, (2) Client (tender settings, collaboration), (3) Contractor Organization (Size and scope diversity), (4) Personnel (resilience awareness, motivation and time availability), (5) project culture and management mentality, (6) underdeveloped learning processes. Across the three dimensions, the most barriers that were stressed by practitioners were related to the learning domain and it is found to be the most underdeveloped resilience dimension in practice, compared to proactiveness and adaptive capacity.

Additional findings

A more clear view of resilience definition could be formulated after analysing the empirical study outcomes. Mainly practitioners' views helped to understand that resilience response is not only about being fast, or cost-effective in responding as found in the literature. It is more about how to respond, as fast as possible, but without harming the project's most valuable objectives. Where these objectives are not static but rather dynamic and could change through project phases. Therefore, construction project resilience can be understood as: The ability of a construction project to overcome disruptive events (preserve its well-functioning and ability to perform to achieve expected targets) fast and without bypassing the current most valuable project objectives thresholds, enabled by proactiveness (Awareness, anticipation, alertness), reactive capacities (absorptive, adaptive, recovery), and learning.

SQ5: how should these elements be included in one framework to aid in building and enhancing resilience in large construction projects?

To include the elements found in the literature and the empirical research in one solid framework, five main steps were needed: (1)design the framework dimensions to fulfil the defined needs, (2) include and exclude the found resilience elements based on a specified including rule, (3) assign resilience elements into the framework dimensions based on the literature and the empirical insights and classifications, (4) design the framework evaluation function and related illustrations (5) apply and test the framework. The resilience elements-including rule is as follows: an element is included if it has been mentioned at least by two sources, either two literature works, two interviews, or one literature and one interview. In terms of defining the needs and requirements, these were also defined based on theory and practice needs. An adequate framework has to fulfil the criteria of usefulness, clearness, ease of use, openness to further improvements, completeness, comprehensiveness, and operationality, based on theory and practice, and facilitate resilience responsibilities' ownership by the different project disciplines.

The framework then was designed to fulfil these criteria as much as possible. Where the elements from both the literature review and the empirical study were listed, compared, and organized into resilience dimensions, and project management areas based on their relevance. A scoring system with radar charts outcome was also designed within the framework. Assigning weights for the framework elements is important, however, further research is needed to identify these in a realistic way. Therefore all elements' weights are chosen equal to the value of one. Testing the framework against the defined needs is essential to identify its usability to practitioners where it was chosen to be tested through three study cases and evaluated through surveys. As a result, the concluded framework included three main dimensions (proactiveness, reactive capacities, and learning). 15 project management-related areas and 87 resilience elements, each assigned to one project management area and one or more dimensions.

RQ: What elements contribute towards construction projects' resilience and how these can be combined in a framework to build (more) resilience in large construction projects?

Answering this question starts with understanding the resilience concept at the level of a construction project. In literature, resilience has many definitions from various perspectives: system resilience, organisational resilience, and project resilience, to arrive specifically at construction project resilience. Combining this theoretical knowledge with empirical experts' views, construction projects' resilience can be understood as The ability of a construction project to overcome disruptive events (preserve its well-functioning and ability to perform to achieve expected targets) fast and without bypassing the current most valuable project objectives thresholds, enabled by proactiveness (Awareness, anticipation, alertness), reactive capacities (absorptive, adaptive, recovery), and learning.

Resilience then has three main dimensions; proactiveness, adaptive capacities, and learning. In practice, 15 project management areas emerged to participate towards resilience: Client management, stakeholder management, monitoring and control, partners, mother organization, risk management, project manager, project team, schedule management, change management, contract management, project management approach, information management, tender management and design management. Each resilience element is found to belong to one project management area, and to one or more resilience dimensions, depending on its contribution. Some project management areas were found to contribute towards some resilience dimensions more than others. In terms of the proactiveness dimension, project people (internal and external teams, stakeholders, suppliers) were found the most effective, risk management and project management approach. Where for the Reactive capacities dimension, the client was the most effective element with a focus also on time management, and contracts. While for learning, the top effective area was mainly the project team, with a focus on stage gates validation and verification process, and the organizational learning

In the literature, 68 elements were found. Most repetitively mentioned are: network relations with sub-contractors, partners and suppliers, team member expertise and divers combination, complexity-based project and risk management methods, stakeholders alignment, emergency response plans, and timely communication.

In practice, 62 elements are found contributing towards resilience. Based on experts' views most repetitively mentioned elements were: schedule buffers, effective risk management, Good and trust relation with the client from the start of the project, Collaborative and flexible contract features (e.g., two-stage contracts), Mother organization network and connections (e.g., specialists, authorities, and clients), Team motivation, creativity and ownership (e.g., tasks ownership, risks ownership), Extra time and money from the client to solve problems, Partnerships with subcontractor and suppliers (formal and informal partnerships), Teamwork and collaboration, Timely and proactively communicate changes within the project team. Resilience elements found mostly related to soft, organizational, and strategy aspects (e.g., collaboration with clients and stakeholders, effective formal and informal communication, creativity, partnerships, and project safe open culture). Technical aspects found also needed to build resilience (e.g., schedule and financial buffers usage, techniques to crash resources, flexible technologies, flexible contracts, learning processes, information management platforms and tools).

To achieve resilience some barriers are needed to be tackled. These are mainly: (1) Initial project choice and settings led by contractor conflicted interests (Business continuity VS Project success) affected by the construction market conditions and competitors, (2) Client tender settings and collaboration, (3) Contractor Organization (Size and scope diversity), (4) Personnel (resilience awareness, motivation and time), (5) Management (culture, mentality), (6) Learning processes. Amongst all, the importance of finding a solution for the learning barriers was stressed by practitioners.

The most important to know is that in order to have a resilient project, resilience needs to be purposely planned, designed and embedded in the project management approach. A resilience framework, like the PRL framework, would aid in designing a resilience-based project management approach, as well as assessing and enhancing project resilience throughout its phases. An effective framework is seen to be based on both theory and practice, clear, comprehensive, qualitative and quantitative, and combines the resilience and project management theories. These were the criteria chosen and applied in the PRL framework design and resulted in a framework of three resilience dimensions, 15 project management areas contributing towards resilience and 87 resilience elements. The framework was further tested in three study cases where the results suggest that a wider resilience print hints at better project performance. Overall, the PRL framework is found to perform at an acceptable to a satisfactory level of performance as evaluated by the experts through surveys. As a first pilot, the framework is fulfilling the expected usage. Further improvements are suggested in the recommendations.

7.3. Recommendations

Recommendations for practice:

1- For the mother organization: Introduce and spread awareness regarding the concept of project resilience and the importance and benefits of resilience-based project management.

2- For the project tender team and project manager: the PRL framework can be used to guide the tender design into the resilience-based project by checking the introduced resilience elements and making sure they are taken into account in creating the project management design and the project management plans. Also, based on project-specific characteristics and complexity areas, the desired level needed of resilience for each element can be given to formulate a resilience baseline print to be checked and preserved through the project's progress.

3- For project key personnel: advised to use the framework in progress meetings every quarter, and link it to project performance progress charts. To help explain the performance, check the resilience print best and lowest areas, and apply needed enhancements.

4- For Internal audits: recommended to apply the framework with input from the project manager, process manager, and other two key personnel, supported with progress reports, to not fall into the effect of subjectivity.

Recommendation for further research

Future research work related to the resilience of construction projects is suggested as follows:

1. Further research towards identifying the weights and importance of each resilience element towards the overall resilience function and also towards the resilience dimensions.

2. The goal of the PRL framework was to introduce a comprehensive view of resilience contributing elements and draw the way to asses resilience. However, it doesn't introduce the exact resilience tailoring process for each project, since that depends on the resilience elements' weights (recommendation 1), and also on the complexity and vulnerability check of each project. Which is a topic for further research. It is suggested to link project complexity elements (suggested using TOE framework by Bosch-Rekveldt et al. (2011), referred to in section 3.1), to be used to design and tailor resilience elements from the PRL framework based on its specific complexity scan.

3. Further research is suggested towards applying the PRL framework to different types of projects (residential, industrial,..., etc.) and checking its variations and applicability.

4. One of the repetitively mentioned barriers facing resilience in construction projects, specifically in learning, is the low motivation of personnel to read and document evaluations, or lessons learned. It is suggested to study the effect of automation of these learning into more user-friendly and fast performing.

5. Investigating the concept of resilience on portfolio level and program levels, and searching the role of portfolio management in creating project resilience.

6. Investigate the relation between project resilience practices and project management best practices and how exactly these can be combined into practice.

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Appendices

Interview guide

Interviewee:

Date:

- Interviewer introduces him/herself, then Interviewee introduces him/ herself.

A- Profile questions

- What is your background, and current role? (if not mentioned in the interviewee self-introduction)
- For how many years were you involved in large construction projects?

B- Resilience in expert views

1. What is a “successful construction project”? What thresholds do you try to safeguard through the project?
2. How do you prepare a project to be able to face disruptions?

C- Resilience in empirical case

3. Through the last 10 years, would you recall a (un) successful A or B complex infrastructure project you participated in and learned from? Mention please project name, complexity class, start and finish year, Budget, Duration, Final result, and Contract type.

- Note C-1: (The used levels of complexity (e.g., A or B) are familiar across the organization and are based on the company tender categorization of projects complexity)
- Note C-2: (It is intended to ask 50% of the interviewees about a successful project, while the other 50 % about an un-successful example)

4. In the mentioned project, can you recall an unexpected disruptive event the project (un) successfully faced, and mention the following: The event, the causes, the solution, the duration till a solution was found, the final impact on the project, and the Lessons learned?

- Note C-3: (Depending on the answer provided for question three, interviewees with successful projects were asked to provide a successful coping example, while the rest were asked to provide the opposite)

5. What series of actions were taken once the project was faced with this disruptive event?

D- Introduce the topic

- Research problem and the main research question
- Research solution direction (resilience definition and general resilience dimensions in construction projects)

- Note D-1: The outcome of the literature review (resilience contributing elements) was unrevealed to the participants to support the empirical evidence

E- Resilience elements and barriers in the specific resilience theory dimensions

6. **Proactiveness:** What techniques do you use to be aware, alerted, and prepared for possible internal and external disruption sources? What are the barriers?
7. **Capacities:** What strategies do you use to help create the project’s needed capacities (absorb, adapt, recover) to face future disruptive events? What are the barriers?
8. **Learning:** Do you apply an explicit specific strategy to learn from previous successes and failures in the project? Are there such strategies in the organization? What are the barriers?
9. How does your specific field of work (role/division) helps overcome disruptive events in construction projects?

F- Closure

10. As a final question, do you have any comments, recommendations, or sources to share concerning construction project resilience to help this research?

Thank you

Emperical Resilience elements

Source	Empirical elements	Frequency	Resilience dimension
B	Schedule buffer	10	R
B	Effective risk management	10	P, R, L
I	Good and trust relation with client from the start of the project	8	P,R
B	Collaborative and flexible contract features (e.g., two stage contracts)	6	P,R
B	Mother organization network and connections (e.g., specialists , authorities , and clients)	5	R
B	Team motivation, creativity and ownership (e.g., tasks ownership, risks ownership)	5	P, R, L
I	Extra time and money from client to solve problems	5	R
B	Partnerships with subcontractor and suppliers (formal and informal partnerships)	5	P, R, L
B	Team work and collaboration	5	P, R, L
B	Timely and proactively communicate changes within the project team	5	P
I	Ability to pause the project for short period once needed for re-adjustments	4	R
B	Budget buffer	4	R
I	Client cooperation and understanding for project challenges	4	R
B	Manager decision making (clear communicated, avoid dispute with client to save time, fast and efficient at crisis)	4	R
B	Periodic repetitive meeting per specialization across the organization (e.g., project managers quarterly meetings)	4	L
B	Having open shared platform to share information and changes	4	P, L
I	Assure sufficient interpretation of client demands (communication, meeting, verification,…,etc.)	4	P
I	Qualified sub-contractors and suppliers, of proven record (not the lowest cost option)	4	P,R
I	Preserve system relations (original project planning) that enable being aware and alerted to interdependencies	4	P
B	Informing the client proactively, continuous, and timely about project status and challenges (Suggested weekly)	3	P,R
I	Mother organization embedding learning into its divisions and projects as a work requirement	3	L
I	Set official reviewing ,validation and verification points through the project life cycle (e.g., stage gates review process) which are also learning points	3	P, L
B	Monitor internal vulnerabilities and organization changes	3	P
I	Cross disciplines work understanding sessions (design, risk, work preparation, ...,etc.) for ependencies and interfaces awareness	3	P
I	Having knowledge about the client (through meetings and collect information)	3	P
B	Informal collaboration and conversations for project team and involved parties	3	P
I	Project manager ability to manage client and contract in an efficient and aligned way (facilitated by efficient team that give him the time to do so)	3	P,R
I	Project manager ability to sense soft indicators of performance problems within the team	3	P
B	Using internal and external audits (check compliance with the management system processes, quality requirements, ...,etc.)	3	P
I	Alertness through mother organization sending notifications of common problems	2	P
I	Mother organisation support and commitment to the project	2	
I	Verify the tender design to be: realistic, applicable, constructable	2	P
I	Efficient interpretation of client demands: written verification matrix and discussion with c	2	P
I	Early involvement of key sub-contractors in the design phase	2	P, R
I	Design verification system against client requirements	2	P
I	Design consciousness to be aligned with the project thresholds(time, budget …etc)	2	P
I	Small size evaluation summaries for learning, and setting timely learning moments througl	2	L
I	Repetitive projects with possible repetitive team members	2	
I	Balance tasks between disruptive events related tasks and original tasks	2	P, R
I	Team members align their role goals with project goals and thresholds (budget, time,..etc)	2	P
I	Project manager network to provide experts or resources once needed	2	P, R
I	Un-formal meetings and daily connections with the team	2	P
I	Project manager experience	2	
I	Timely exclude team memebers once needed	2	R
I	Understand the client's objectives priorities, implicit interests, and worries	2	P

I	Monitor processes quality and compliance with processes	2	P
I	Nurture Sub-contractors sense of ownership (e.g., early involvement in tender)	2	P, R
I	Suppliers diversity for critical items	2	R
I	Standardization for processes and forms	2	P, R
I	Opportunities awarness and management	2	P, R ,L
I	The positive mindset of the project manager	2	R
I	Agree on changes cost between contractor and client before start working on it (including the process disturbance costs)	1	R
I	Buffer in performance (to perform higher than expected if possible to compensate later on aspects of money loss or delays)	1	R
B	Effective communication between contractor , client and stakeholders	1	P,R
B	Timely inform mother organization about project problems	1	R
B	Participates in construction industry field specific events (e.g., Bauma for machinery display)	1	P,R
I	Refuse changes orders that is out of core technical knowledge of the contractor	1	R
B	KPIs usage and having shared platform for project KPIs	1	R
I	Update standards in alignment with the latest field-specific knowledge and regulatory	1	P,R
I	Across disciplinary work reviews	1	P, L
I	Process oriented learning instead of product/end result oriented	1	L
I	Quarterly developed lessons learned in a short summary form	1	L

Resilience elements from literature

Element	Element from literature	Source	Occ
Network-based mobilising	Network and partnerships to mobilize resources once needed	Petit et al., 2013; Rahi, 2019; Sapeciay et al. , 2017; He et al.,	4
Team members diversity / expertise	Qualified, inclusive and diverse team member to rely upon in anticipation and reactiveness	Hollangel, 2015; Geambasu, 2011; Tengblad and Oudhuis, 2018;	3
Project management methods aligned with complexity	Complexity and uncertainty evaluation before choosing management style	Vidal, 2010; Zhang, 2007; Vugrin et al., 2011; J. Zhu, 2016	3
Emergency response plan	Emergency response plan and guidelines	Rahi, 2018; Akgün and Keskin,	3
Stakeholders alignment	Stakeholders: aligened vision, ligetimacy, cooperation and solidarity	Gambesu, 2011; Sapeciay et al.,	3
Timely communicate changes	Timely escalations, and share project changes and expectations within the team, mother organization, with clients and with stakeholders	Rahi, 2019; Hollangle, 2015; Sullivan-Taylor & Branicki ,2011	3
Resources monitoring	Monitor changes and resources availability in the market and within the organization	Borekci et al., 2014; Otulana, 2011; He et al., 2017	3
KPIs usage and monitoring	KPIs are used and monitored for budget, schedule, quality	Geambasu ,2011; zhu, 2016;	3
Effective communication	Effective communication with monitor and minimize communication barriers between departments	Sonnet, 2016; Sapeciay et al., 2019; Hollangle, 2015	3
Proces for information management	A clear process to manage information exchange, and having efficient information system across departments	Rahi, 2019; Pasteur, 2011; Burnard et al., 2018	3
Nurture Innovation and creativity	Test, develop, and use new products, methods, and technologies to solve existing problems	Sapeciay et al., 2019; Zhu, 2016;	3
Project OBS choice	Project OBS completeness, sufficient and efficient	Zhu et al., 2020; McManus, 2008	2
Risk management methods aligned with complexity	Complexity and unceratnity evaluation befor choosing risk management style	Vugrin et al., 2011; J. Zhu, 2016	2
Early involvement	Early involvement of project team members and stakeholders in project early phases (e.g., tender, design)	Vugrin et al., 2011; J. Zhu, 2016	2
BIM usage	Use of BIM (Building Information Modeling)	Vugrin et al., 2011; J. Zhu, 2016	2
Early purchase orders	Early purchase orders for procurement	Vugrin et al., 2011; J. Zhu, 2016	2
Operational flexability	Operational procedures flexability and alternative execution technologies	Francis and Bekera, 2014; He et al., 2017	2
Redundancy in resources	Redundancy in resources	Thomé, 2016; He et al., 2017	2
Escalation plan	Escalation plan / system	Rahi, 2018; Akgün and Keskin,	2
Learning strategy	Availability of learning strategy to insure that Lessons learned analysed to further identify project vulnerabilities and apply enhancements	Rahi, 2019; Hollangle, 2015; Tengblad and Oudhuis (2018)	2
Learn from failure and successes	Learn from failure and successes, and celebrate small successes	Patriarca et al. , 2018; Hollnagel , 2015	2
Personnel continuous training	Continuous training, theoretical teaching and improving knowledge level of personnel	Patriarca et al. , 2018; He et al.,	2
Clarity of roles	Personnel clear understanding of their tasks during the project life cycle	McManus, 2008; Rahi, 2019	2
Risk management ownership	Personnel understanding and performing their role in risk management through the project life cycle	Hollangle, 2015; Rahi, 2019	2
Participation in industry-related	Participate in networks and events related to the construction industry	Jones, 2015; Rahi, 2019	2
Effective risk management	Effective risk management practices	Geambasu, 2011; Rahi, 2019; He	2
Flexabiilty through contract	Clauses that offer flexability and possible changes to the contract to find solutions once needed	Rahi, 2019; Geambasu, 2011	2
Information platforms	Recognize Information sources and information platform training to assure that all project personnel and related parties know where and how to find the needed information	Stephenson, 2010; Thomé, 2016	2
Schedule buffer	Slack for critical activities to create flexability in schedule	Gunasekaran et al., 2011; Madni	2
Contingancy budget	Contingancy budget per project	Rahi, 2019; Madni and Jackson,	2
Project parties good relations	Maintain good relations with all project parties through communication, collaboration and mutual goals alignment	He et al., 2017; Rahi, 2019	2
Supply chain management	Supply chain integration management and agility	Tengblad and Oudhuis, 2018	2
Planning and commitment to ptoject resilience	Planning for project resilience and commitment to it	© 2023 The ICOR; Hollangle, 2015	2
Working methods compliance	Using specified working methods , measures and protocols to assure compliance with field-sepcific regulatory	Rahi, 2019	1
Continuous meetings	Continuous follow-ups meetings within the team, and with clients, partners and stakeholders to	Rahi, 2019	1
Long-term supplier relations	Long term relations/ contracts with suppliers	Rahi, 2019	1
Trust relations	Trust relationships with suppliers	Rahi, 2019	1
Choice of communication moments	Wise choice of content and the suitable timing of communication moments	He et el., 2017	1
Emergency funds	Additional organizational funds for emergency	Rahi, 2019	1
Collaborative contracts	Dynamic collaborative contracts	Rahi, 2019	1
Accurate project start up information	Project information properly available and gathered front the start of the project	Rahi, 2019	1
Security and data protection	Security and data protection	Corporation, 2004	1

Decision making speed and quality	Decision making speed and quality	Zhu et al., 2020	1
Project manager attributes	Experience and attributes of the project manager	Zhu, 2016	1
Decisions based on mutual goals	Involve organization priorities and stakholder satisfaction in decision making criterias	Zhu et al., 2020	1
Balance work through emergency	Ability to balance daily operations responsive and special operations	Sonnet, 2016	1
problem solving oriented trainings	problem solving oriented trainings	Lee et al., 2013	1
De centralized decision making	De centralize decision making for qualified employees	Borekci et al., 2014;	1
Suppliers diversity	Suppliers diversity	Zhu et al., 2020	1
Internal mobilization	Internal mobilization ability for resources within the organization	Rahi, 2019	1
Flexibility from client	Ability to adjust project goals and constraints by the client	Demmer et al., 2011	1
Work insurance	Work insurance cover and awareness of its range and liabilities	He et al., 2017	1
Acceleration ability	Be able to offset the effects of disturbance on project schedule by accelerate production	He et al., 2017	1
Loss assessing	Investigate, count and verify the range and extent of actual losses	He et al., 2017	1
Capacity to adjust planning	Make new or adjusted plans that fit new situations, understand the priorities of recovery issues and make arrangements accordingly.	He et al., 2017	1
Sufficient work infrastructure	Efficient management of the physical work infrastructure needed to enable the well-functioning (workplaces, finance)	© 2023 The ICOR	1
Learning resources	Allocating learning resources	Hollangle, 2015	1
Mentoring	Mentoring and team cooperation for learning	Patriarca et al. , 2018	1
Project culture	Open, transparent and safe culture that nurture learning from mistakes	Tengblad and Oudhuis, 2018	1
multi-functional teams	Multi-functional teams (learning by doing)	Tengblad and Oudhuis, 2018	1
Informal communication	Informal conversations and events among team members, and project different parties	Tengblad and Oudhuis, 2018	1
Learning incentives and awareness	Learning incentives and awareness	Tengblad and Oudhuis, 2018	1
learning by repeating activities	learning by repeating activities	Tengblad and Oudhuis, 2018	1
Learning across organization	Share information across the organization to have consistent organizational learning	He et al., 2017	1
Insurance availability	Arrange needed work insurance coverage with awareness of its coverage, liabilities and mechanisms	He et al., 2017	1
Loss Assessment	Investigate, verify the extent and learn from the actual losses after perturbations	He et al., 2017	1
Re-Planning	Ability to adjust or replan after perturbations with understanding and according to recovery priorities	He et al., 2017	1
Capacity to accelerate	Ability to accelerate operations and productivity in order to substitute schedule time loss	He et al., 2017	1

Elements weights for the PRL resilience Framework

Category	Element	Weight	Resilience dimension
Project management approach	Operational flexability	4,5	R
Client management	Implicit objectives understanding	4,3	P, R
Project manager	Experience	4,3	P, R, L
Project management approach	Project-specific	4,3	P, R
Project management approach	Meetings	4,3	P, L
Project management approach	Learning culture	4,3	L
Information management	Information sharing platforms	4,3	P, R, L
Mother organization	Culture	4,3	P, R, L
Project manager	Efficient decision making	4,3	P, R
Partners (Suppliers, sub-contractors, joint venture)	Mobiliazing	4,2	R
Project management approach	Escalation plan	4,1	R
Client management	Client support	4,0	R
Client management	Trust relation	4,0	R
Partners (Suppliers, sub-contractors, joint venture)	long term relations	4,0	P, R, L
Partners (Suppliers, sub-contractors, joint venture)	Diversity	4,0	R
Partners (Suppliers, sub-contractors, joint venture)	Mutual goals	4,0	P, R
Mother organization	Impose learning process	4,0	L
Risk management	Opportunity management	4,0	P, R, L
Risk management	Risk culture	4,0	P, R
Project manager	Positive mindset	4,0	R
Project manager	Team oriented	4,0	P
Project team	Motivation	4,0	P, R, L
Project team	Resilience	4,0	R
Project team	Role awareness (risk role, normal role)	4,0	P
Project team	Collaboration and compassion	4,0	P, R, L
Project team	Goals alignment	4,0	P
Planning & Schedule Management	Preserve system relations	4,0	P, R
Planning & Schedule Management	Buffer	4,0	R
Planning & Schedule Management	Re-Planning	4,0	R
Change management	Timely Sharing	4,0	P, R
Contract management	Contractual risks	4,0	R
Project management approach	Inter-disciplinary awarenss	4,0	P, R
Project management approach	Plan for resilience	4,0	P, R, L
Project management approach	Emergency response plan	4,0	R
Planning & Schedule Management	Capacity to accelerate	3,7	R
Client management	Mutual goals	3,7	P, R
Mother organization	Standardization	3,7	P, R, L
Mother organization	Mother organization alertness	3,7	L
Project team	Training	3,7	P, R, L
Project team	OBS completness	3,7	P, R
Change management	Inform client	3,7	P, R
Contract management	Alert the team	3,7	P
Project management approach	Celebrate successes	3,7	P, R
Project management approach	Learning techniques	3,7	L

Partners (Suppliers, sub-contractors, joint venture)	Qualified	3,6	P, R
Monitor and control	Loss Assessment	3,5	R, L
Mother organization	Network	3,5	P, R
Project management approach	Insurance availability	3,5	R
Monitor and control	Lead Kpls	3,3	P, L
Project manager	timely exclude personnel	3,3	P, R
Project team	Creativity	3,3	R
Contract management	Felxible cooperative contracts	3,3	R
Project management approach	Operational balance	3,3	P, R
Project management approach	Learning resources	3,3	L
Monitor and control	Processes focused monitoring	3,0	P
Project manager	Network	3,0	P, R
Project team	Team competency and combination	3,0	P, R, L
Change management	Change boundaries	3,0	P
Stakeholders management	Timely Informing	2,7	P, R
Monitor and control	Lag KPIs	2,7	P, L
Monitor and control	Audits and colleagues reviews	2,7	P, L
Mother organization	Timely support	2,7	R
Risk management	Effective risk management	2,7	P, R, L
Risk management	Project-specific	2,7	P, R
Project management approach	Informal collaboration	2,7	P, R
Project management approach	Validatio and verification process	2,7	P, L
Monitor and control	Soft KPIs	2,3	P
Change management	Liability agreement	2,3	P
Contract management	Temporal project pause	2,3	P, R
Project management approach	Work repetition	2,3	P, R, L
Project management approach	Financial Buffer	2,3	R
Partners (Suppliers, sub-contractors, ioint venture)	Ownership	2,3	P, R
Tender management	Tender realistic design	1,7	P
Stakeholders management	Effective Communication	1,3	P, R
Monitor and control	Monitor Changes (internal and external)	1,3	P
Tender management	Portfolio management and tender selection	1,3	P, R
Tender management	Knowing the client	1,3	P
Tender management	Project information completence	1,3	P
Tender management	Client's demands interpretations	1,3	P
Design management	Sub-contractor involvement	1,3	P, R
Design management	Verification	1,3	P
Design management	Design consciousness	1,3	P
Stakeholders management	Interests alignment	1,0	P, R
Tender management	Project key personnel involvement	1,0	P
Tender management	Project manager involvement	1,0	P
Tender management	Critical suppliers agreements	1,0	P, R
Mother organization	Participation in industry-related events	0,7	P, R

The PRL resilience Framework for Construction projects

Category	Element	Source	Description	Domain of contribution	Proactiveness	Reactive capacities	Learning
Client management	Implicit objectives understanding	I	Understand the client's objectives priorities, implicit interests, and worries	P, R	P	R	
	Mutual goals	B	Client- contractor mutual goals establishment and continuity (via continuous dialogue)	P, R	P	R	
	Client support	I	Client support with covering the extra time and money to solve problems, or facilitating solutions by relaxing constraints if possible.	R		R	
	Trust relation	B	Client -contractor trust and good relation	R		R	
Stakeholders management	Timely Informing	I	Timely inform stakeholders about related changes and problems	P, R	P	R	
	Interests alignment	I	Interests alignment amongst client, stakeholders, and contractor	P, R	P	R	
	Effective Communication	B	Continuous dialogue and communication with stakeholders and clients to keep alerted with their changes and interests. That is through transparency and wisely choosing moments and the content of communication (e.g., after the contract award everyone is happy, so a good moment to communicate about the project mutual goals)	P, R	P	R	
Monitor and control	Lag KPIs	B	Lag KPIs usage for after performance evaluation (output measurement)	P, L	P		L
	Lead Kpls	B	Lead KPIs usage as an early warning system before possible disruptions (predictive measurement)	P, L	P		L
	Soft KPIs	I	Alertness and observation of soft unwritten KPIs (e.g., team stress, working hours, ...,etc.)	P	P		
	Monitor Changes (internal and external)	B	Timely monitoring, informing and aligning with internal and external changes (stakeholders, market, client, mother organization)	P	P		
	Processes focused monitoring	I	Monitor processes quality and compliance with processes	P	P		
	Audits and colleagues reviews	B	External and internal audits, and colleague review for work	P, L	P		L
	Loss Assessment	Li	Investigate, verify the extent and learn from the actual losses after perturbations	R, L		R	L
Partners (Suppliers, sub-contractors, joint ventures)	long term relations	B	long term relations	P, R, L	P	R	L
	Ownership	I	Nurture Sub-contractors sense of ownership (e.g., early involvement in tender)	P, R	P	R	
	Qualified	B	Have trusted network with good quality and proven record (e.g., not the lowest price option)	P, R	P	R	
	Diversity	I	Suppliers diversity for critical items	R		R	
	Mutual goals	B	Partners shared vision and goals	P, R	P	R	
	Mobilizing	B	Ability of external mobilizing for experts from partners	R		R	
Mother organization	Culture	I	Culture of safety to communicate mistakes and support to solve	P, R, L	P	R	L
	Network	B	Mother organization network and connections (specialists, authorities, and clients) and good relations (e.g., help solve problems with clients, provide resources)	P, R	P	R	
	Timely support	B	Timely support with needed interventions and mobilizing to solve problems	R		R	
	Standardization	I	Standardization for processes and forms, where having standards enable learning across the organization and projects. Also, it facilitates faster responses and is better based on the well-defined and known process and sources of information	P, R, L	P	R	L
	Participation in industry-related events	B	Participating in construction field-specific events (e.g., The Bauma construction machinery display event).to keep updated, aware and alerted with the latest changes and technology, market resources availability, and reinforcing and expanding the organization network.	P, R	P	R	
	Impose learning process	B	Organizational set and impose specific process for learning	L			L
	Mother organization alertness	I	Mother organization sending alerting notifications of common problems and changes across the organization	L			
Risk management	Opportunity management	I	Opportunities awareness and management	P, R, L	P	R	L
	Effective risk management	B	Effective risk management (e.g., assessment beyond (probability * impact) assessment, including other factors of the available time of response, activities criticality, ..etc.)	P, R, L	P	R	L
	Project-specific	Li	Design risk management plan based on project specific characteristics, complexity and uncertainty	P, R	P	R	
	Risk culture	B	Nurture risk culture of awareness and ownership	P, R	P	R	
Project manager	Positive mindset	I	The positive mindset of the project manager	R		R	
	Network	I	Project manager network to provide experts or resources once needed	P, R	P	R	
	Team oriented	I	Un-formal meetings and daily connections with the team by project manger	P	P		
	Experience	I	Project manager experience	P, R, L	P	R	L
	timely exclude personnel	I	Timely exclude team members once needed	P, R	P	R	
	Efficient decision making	B	Manager decision making (clear communicated, avoid dispute with client to save time, fast and efficient at crisis)	P, R	P	R	
Project team	Motivation	B	Nurture team motivation and ownership (through positive comments, celebrate small successes, and incentives)	P, R, L	P	R	L
	Training	B	Project team training (processes, field coaching, cooperation, problems solving)	P, R, L	P	R	L
	Resilience	B	Positive mindset and resilience of team members	R		R	
	Role awareness (risk role, normal role)	B	Project team awareness and ownership of their own role responsibilities and their risk management role	P	P		
	Team competency and combination	B	Competent team (technical knowledge, soft aspects,., etc.) , with a suitable combination (Communicators, solvers, women, men, new, experienced) based on the project features of complexity, uncertainty and on the client	P, R, L	P	R	L
	Collaboration and compassion	B	Project team collaboration and compassion	P, R, L	P	R	L
	Creativity	B	Creativity	R		R	
	Goals alignment	I	Team members align their role goals with project goals and thresholds (budget, time,..etc..) based on contract understanding	P	P		
	OBS completeness	Li	Project roles completeness in an early stag	P, R	P	R	
Planning & Schedule Management	Preserve system relations	I	Preserve system relations (original project planning) that enable being aware and alerted to interdependencies which are already thought of and to a better extent discovered in the original planning	P, R	P	R	
	Buffer	B	Have risk and complexity based time buffer	R		R	
	Re-Planning	Li	Ability to adjust or replan after perturbations with understanding and according to recovery priorities	R		R	
	Capacity to accelerate	Li	Ability to accelerate operations and productivity in order to substitute schedule time loss	R		R	
Change management	Inform client	B	Timely and continuously inform the client about project changes and possible problems	P, R	P	R	
	Liability agreement	I	Mutual liability agreement (time & money) before execute scope change orders	P	P		
	Change boundaries	I	Set fixed period for client to change scope (e.g., design baselines)	P	P		
	Timely Sharing	B	Timely show and share project changes within the team	P, R	P	R	
Contract management	Alert the team	I	The contract manager continuously alerts the project team to possible contractual concerns	P	P		
	Flexible cooperative contracts	B	Collaborative and flexible contract features (e.g., two-stage contracts, allow work pauses once needed, possible by passing certain clauses in the contract to facilitate solutions once needed)	R		R	
	Contractual risks	I	Realistic contractual risk responsibility distribution (e.g., underground conditions)	R		R	
	Temporal project pause	I	Ability to pause the work course when it is needed (large change order, disruption) till understanding its cascading effect. (e.g., contract facilitates this need)	P, R	P	R	
Project management approach	Project-specific	Li	Project-specific management methods based on project characteristics and complexity understanding	P, R	P	R	
	Meetings	B	Weekly progress meetings for key project personnel (project manager, procurement manager, design lead, work preparation, construction lead, risk manager)	P, L	P		L
	Informal collaboration	B	Informal collaboration and conversations for project team and involved parties	P, R	P	R	
	Inter-disciplinary awareness	I	Personnel understanding of each other roles and dependencies (e.g., quarterly meetings across specialization to explain and evaluate each other roles)	P, R	P	R	
	Operational balance	I	Balance tasks between disruptive events related tasks and original tasks	P, R	P	R	
	Celebrate successes	B	Celebrate small successes as a team (e.g., schedule fixed, milestones accomplished)	P, R		R	L
	Learning techniques	I	Small size evaluation summaries for learning, and setting timely learning moments through the project (e.g., every 3 months)	L			L
	Work repetition	I	Repetitive projects with possible repetitive team members	P, R, L	P	R	L
	Learning culture	I	Nurture a culture of learning among the project team (meetings, informal conversations, trainings)	L			L
	Learning resources	I	Allocated learning resources (personnel responsible, budget, ...,etc.))	L			L
	Financial Buffer	B	buffer in the project budget and emergency budget from the mother organization if needed	R		R	
	Plan for resilience	Li	Planning for project resilience and commitment to it	P, R, L	P	R	L
	Operational flexibility	Li	Operational procedures flexibility and alternative work techniques availability	R		R	
	Escalation plan	Li	Having specific escalation criteria and plan for all project's specializations through the project life cycle	R		R	
	Emergency response plan	Li	Emergency response plans and guidelines to specify who does what and when, once a perturbation occurs, for different types of perturbations.	R		R	
	Validation and verification process	I	Set official reviewing, validation and verification points through the project life cycle (e.g., stage gates review process) which are also learning points. This help keep aligned with client and contractual requirements , discover current deviations and anticipate future events	P, L	P		L
	Insurance availability	Li	Arrange needed work insurance coverage with awareness of its coverage, liabilities and mechanisms	R		R	
Information management	Information sharing platforms	B	Having open shared platform to share information and changes	P, R, L	P	R	L
Tender management	Portfolio management and tender selectic	I	Effective portfolio management to balance the interests of business continuity (win the tender) and project success (chose projects that highly fit company abilities (technical knowledge, organizational,...etc.)	P, R	P	R	
	Project key personnel involvement	B	Involvement of work preparation, control, procurement and execution	P	P		
	Project manager involvement	B	Involve project manager in the tender (scope and construction method)	P	P		
	Knowing the client	I	Collect information and learning about the client	P	P		
	Critical suppliers agreements	I	Critical suppliers analysis and early agreement (un formal agreement)	P, R	P	R	
	Project information competence	B	Sufficient project information in the tender phase (given by the client and/or self-investigated)	P	P		
	Tender realistic design	I	Verify the tender design to be: realistic, applicable, constructable	P	P		
	Client's demands interpretations	I	Efficient interpretation of client demands: written verification matrix and discussion with client	P	P		
Design management	Sub-contractor involvement	I	Early involvement of key sub-contractors in the design phase	P, R	P	R	
	Verification	I	Design verification system against client requirements	P	P		
	Design consciousness	I	Design consciousness to be aligned with the project thresholds(time, budget ...etc.)	P	P		