CONCEPTUAL FRAMEWORK TO EVALUATE AND ENHANCE RESILIENCE OF PUBLIC-PRIVATE PARTNERSHIP PROJECTS

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submitted by **SAEED KAMALI** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Civil Engineering, Middle East Technical University** by,

Prof. Dr. Naci Emre Altun
Dean, **Graduate School of Natural and Applied Sciences** ________________

Prof. Dr. Erdem Canbay
Head of the Department, **Civil Engineering** ________________

Prof. Dr. M. Talat Birgönül
Supervisor, **Civil Engineering, METU** ________________

Prof. Dr. İrem Dikmen Toker
Co-Supervisor, **School of Construction Management and Engineering, University of Reading** ________________

Examining Committee Members:

Prof. Dr. Rifat Sönmez
Civil Engineering, METU ________________

Prof. Dr. M. Talat Birgönül
Civil Engineering, METU ________________

Assoc. Prof. Dr. Güzide Atasoy Özcan
Civil Engineering, METU ________________

Assist. Prof. Dr. Saman Aminbakhsh
Civil Engineering, Atılım University ________________

Assist. Prof. Dr. Gözde Bilgin
Civil Engineering, Başkent University ________________

Date: 13.02.2025

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name: Saeed Kamali

Signature:

ABSTRACT

CONCEPTUAL FRAMEWORK TO EVALUATE AND ENHANCE RESILIENCE OF PUBLIC-PRIVATE PARTNERSHIP PROJECTS

Kamali, Saeed
Doctor of Philosophy, Civil Engineering
Supervisor: Prof. Dr. M. Talat Birgönül
Co-Supervisor: Prof. Dr. İrem Dikmen Toker

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Public-Private Partnerships (PPPs) serve as a vital mechanism for addressing infrastructure demands by fostering collaboration between public and private entities. While these partnerships hold immense potential to revolutionize service delivery, they are frequently undermined by inherent uncertainties and disruptions that threaten their success. The concept of resilience, an evolving paradigm in project management, offers a transformative lens to mitigate these challenges and enhance project sustainability.

This study presents a comprehensive framework to evaluate and fortify the resilience of PPP projects. By synthesizing the interconnected dimensions of uncertainty, resilience, and performance, this research delineates the fundamental attributes of resilience and identifies its critical determinants. Drawing from an analysis of 15 PPP projects in Türkiye and employing Principal Component Analysis (PCA) over collected data from a second round of questionnaire survey, the study illuminates the intricate relationships among resilience, uncertainty, and project performance and proposes a comprehensive definition for resilience and its dimensions. This research systematically identifies and classifies key resilience factors into four fundamental dimensions: preparation, absorption, recovery, and adaptation.

Building upon these insights, the research culminates in the creation of the Uncertainty-Resilience Assessment Tool (URAT), an innovative instrument designed to equip practitioners with actionable strategies for evaluating the degree of uncertainty and resilience and taking the necessary actions, if required, on time to improve the level of resilience and maintaining operational continuity. By embedding resilience as a cornerstone of project planning and execution, URAT empowers decision-makers to significantly enhance the robustness and success rate of PPP initiatives in dynamic and complex environments.

Keywords: Resilience, Uncertainty, Public-Private-Partnership, Principal Component Analysis, R Programming Language

ÖZ

KAMU-ÖZEL İŞBİRLİĞİ PROJELERİNİN DİRENÇLİLİĞİNİ DEĞERLENDİRMEK VE GELİŞTİRMEK İÇİN KAVRAMSAL SİSTEM

Kamali, Saeed
Doktora, İnşaat Mühendisliği
Tez Yöneticisi: Prof. Dr. M. Talat Birgönül
Ortak Tez Yöneticisi: Prof. Dr. İrem Dikmen Toker

Şubat 2025, 197 sayfa

Kamu-Özel İşbirliği (KÖİ), kamu ve özel sektör kuruluşları arasındaki iş birliğini teşvik ederek altyapı ihtiyaçlarını karşılamada önemli bir mekanizma olarak işlev görmektedir. Bu işbirliği, hizmet sunumunda köklü değişimler yaratma potansiyeline sahip olmakla birlikte, doğası gereği barındırdığı belirsizlikler ve aksamalar nedeniyle sıklıkla başarısızlığa uğrayabilmektedir. Proje yönetiminde gelişen bir paradigma olan dirençlilik kavramı, bu tür zorlukların üstesinden gelmek ve proje sürdürülebilirliğini artırmak için dönüştürücü bir bakış açısı sunmaktadır.

Bu çalışma, KÖİ projelerinin dirençliliğini değerlendirmek ve güçlendirmek amacıyla kapsamlı bir sistem önermektedir. Belirsizlik, dirençlilik ve performans arasındaki etkileşimi bütüncül bir yaklaşımla ele alan araştırma, dirençliliğin temel bileşenlerini tanımlamakta ve belirleyici unsurlarını ortaya koymaktadır. Türkiye'de yürütülen 15 KÖİ projesi üzerinde gerçekleştirilen analizler ve ikinci tur anket çalışmasından elde edilen veriler kullanılarak yapılan Temel Bileşen Analizi (TBA), dirençlilik, belirsizlik ve proje performansı arasındaki karmaşık ilişkileri detaylandırmakta ve dirençliliğin kapsamlı bir tanımını önerilmektedir. Araştırmada, dirençliliği dört temel boyutta sistematik bir sistem önerilmiştir: hazırlık, emilim, iyileşme ve uyum sağlama.

Bu bulgular doğrultusunda araştırma, belirsizlik ve dirençliliği değerlendirmek için yenilikçi bir araç olan Belirsizlik-Dirençlilik Değerlendirme Uygulaması (BDDU)'nın geliştirilmesiyle sonuçlanmaktadır. BDDU, uygulayıcılara belirsizlik ve dirençlilik düzeyini ölçme, gerekli önlemleri zamanında alarak dirençliliği artırma ve işletim sürekliliğini sağlama konusunda uygulanabilir stratejiler sunmaktadır. Dirençliliği proje planlaması ve uygulamasının temel unsuru hâline getiren BDDU, karar vericilere dinamik ve karmaşık ortamlarda KÖİ projelerinin sağlamlığını ve başarı oranını önemli ölçüde artırma fırsatı sunmaktadır.

Anahtar Kelimeler: Dirençlilik, Belirsizlik, Kamu-Özel İşbirliği, Temel Bileşen Analizi, R Programlama Dili

Dedicated to my niece, Ayrin

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CHAPTER 1

INTRODUCTION

This chapter provides an outline of the research context. The opening section delves into the motivation behind this study, particularly focusing on the evolving challenges in construction project management and the current role of resilience in disruption management approaches. Then, the research gap is identified, and pertinent research questions are formulated in the subsequent section. The chapter then outlines the research objectives and details the methodology to address these questions. The final section offers a comprehensive overview of the thesis structure.

1.1 Research Motivation

The literature on construction project management is abundant with research studies aimed at enhancing project performance to prevent failure, a fundamental challenge in the construction industry (Burr & Castro, 2016; Loosemore et al., 2005). Disruptions inherent to projects are among the primary causes of such failures (Zou et al., 2007). These disruptive events can cause projects to deviate from their primary objectives, and the longer a project is exposed to such events, the lower the likelihood of successfully achieving its goals (Zhang, 2007). Various research streams have addressed this problem from different perspectives, leading to a wide range of approaches to improve project performance, including risk management, opportunity management, uncertainty management, change management, and crisis management. Although these proactive strategies offer valuable guidance for managing disruptions to avoid failure, the persistently high failure rate of construction projects suggests that these approaches are insufficient for managing the complexities and dynamics of modern projects (Dvir et al., 1998; Eden et al., 2000; Shenhar et al., 2001). This indicates a continued need for research to explore the questions: "Why do construction projects fail?" and "How can projects achieve their objectives even after experiencing serious disruptions?"

While the aforementioned conventional approaches differ in nature, they share a common goal: to protect projects from failure by predicting all possible threats throughout the project lifecycle during the preparation phase, thereby reducing vulnerability (Qazi et al., 2016). In simpler terms, they aim to create fail-safe projects. However, no matter how diligently project management teams work to identify potential threats, reality demonstrates that the likelihood of encountering an unidentified (unexpected) threat remains high (Eden et al., 2000; Flyvbjerg, 2007; Shenhar et al., 2009; Williams, 2005). This common reliance on predicting all possible threats makes these approaches insufficient for managing today's dynamic projects. Therefore, a paradigm shift is needed from proactive to reactive approaches—approaches that aim to create safe-to-fail projects by enabling recovery during or after a disruptive event (Naderpajouh et al., 2020; Park et al., 2011).

The concept of resilience, though still novel in project management, holds promise. It has been widely explored in other disciplines, such as psychology (Coutu, 2002), climate change (Hallegatte & Engle, 2019), organization science (DesJardine et al., 2019; Ortiz-de-Mandojana & Bansal, 2016; Sapeciay et al., 2017), ecology (Holling, 1973), supply chain management (Thomé et al., 2016) and disaster management (Bruneau et al., 2003; Paton et al., 2000; Paton & Johnston, 2001). However, the number of studies addressing resilience in project management remains limited, resulting in a significant knowledge gap regarding the resilience of construction projects. While there is a shared understanding of the concept of project resilience among scholars (Blay, 2017; Francis & Bekera, 2014; Han & Bogus, 2020, 2021; Hilu & Hiyassat, 2023; Nipa et al., 2023; Piperca & Floricel, 2023; Rahi, 2019; Rahi et al., 2019), no consensus exists on its definitions and dimensions within a project context. The definition of resilience can vary significantly due to its context-specific nature rarching goal of resilience is understood to be the ability to recover or achieve positive change during or after a disruptive event. The need for resilience is particularly critical in PPP projects, which face a higher frequency of disruptive events throughout their lifespan due to their inherent characteristics. In this context, essential questions arise: What exactly does resilience entail in construction projects? How can it be measured in PPP projects? The existing literature has yet to comprehensively address these questions. Therefore, this research seeks to fill this gap by defining project resilience, proposing a model to conceptualize project resilience, and establishing a framework for measuring resilience in PPP projects.

1.2 Research Questions

To fulfill the gap described in the literature, the following questions are raised:

- What is the definition of resilience and its dimensions, and how can this concept be practically applied in construction projects?
- What are the primary resilience indicators in PPP projects?
- How are uncertainty, as a source of disruption, resilience, and performance interconnected in the context of PPP projects?
- What are the implications of this relationship for developing a resilience assessment tool for PPP projects?

1.3 Research Objectives

The following objectives have been established to address the research questions outlined in the previous section.

- Define resilience in the context of construction projects. To achieve this, a comprehensive literature review was conducted.
- Explore the relationship between uncertainty, resilience, and performance in PPP projects. A comprehensive literature review identified critical factors related to uncertainty and resilience in PPP projects. Subsequently, a quantitative research approach was employed to examine these relationships,

with data collected from a survey of 15 participants across 15 different PPP projects in Türkiye.

- Categorize the identified resilience factors according to the respective dimensions of resilience. For this purpose, an additional survey was conducted, and the collected data was analyzed using PCA.
- Introduce a resilience assessment tool for PPP projects. This was accomplished by first proposing a conceptual model based on the findings from the surveys and later developing an uncertainty resilience assessment tool.

1.4 Research Novelty and Contribution

Upon completing this research, the contributions to the body of knowledge will include, but are not limited to, the following:

This research provides deeper insights into resilience within construction projects by providing a clear definition, explaining its dimensions, and exploring its relevance to various project management theories, including risk management, change management, opportunity management, crisis management, sustainability, and lean approaches. This approach enhances the conceptual grasp of resilience and its practical application in real-world scenarios. Moreover, this research highlights the importance of resilience as a crucial complement to traditional strategies, particularly in situations characterized by high uncertainty and severe consequences, where conventional approaches alone may fall short.

In addition to its theoretical contribution, the study offers empirical insights by identifying the key factors of uncertainty and resilience in PPP projects and thoroughly examining their interrelationships with project performance across 15 PPP projects in Türkiye. Furthermore, by categorizing resilience factors according to the four dimensions of resilience, based on empirical findings, the study provides a structured framework for understanding how these elements interact within the complex environment of PPP projects. The insights gained from this analysis are vital for developing more targeted and effective resilience strategies, enabling project managers to better anticipate and mitigate potential disruptions. Additionally, this study enriches the field by introducing a refined methodology for incorporating resilience into project management practices, ultimately strengthening project adaptability and ensuring more successful outcomes amid uncertainty.

1.5 Structure of the Dissertation

Subsequent chapters delve into the intricacies of this research. Chapter 2 offers a comprehensive review of the extant literature on PPPs, disruption management, and resilience, thereby setting the foundation for this study. Chapter 3 delineates the four-stage research methodology aligned with the previously outlined objectives. Chapter 4 presents the results of this study and provides a detailed discussion. Finally, Chapter 5 encapsulates the research by summarizing the findings and presenting the contributions, limitations, and recommendations for future research endeavors.

CHAPTER 2

LITERATURE REVIEW

In this chapter, we will delve into the literature that underpins our research. We will start by elucidating the concept of PPPs to provide a comprehensive context. This is followed by an introduction to the notation of disruption management in construction projects. Subsequently, we will examine the existing literature on Resilience. Finally, we will discuss the research gap, emphasizing the need for further research in this area.

2.1 Public-Private Partnership

2.1.1 Evolution of PPP

The parameters of public service are intrinsically tied to the notion of emancipation. As nation-states established themselves as sovereign entities over defined territories, the imperative arose to extend and fortify their influence across every corner of their lands. The imperative to safeguard sovereignty propelled the imperative to develop essential infrastructure, including transportation and health services (Akbiyikli & Eaton, 2005). However, the financial constraints faced by these states posed a formidable challenge in realizing such ambitious endeavors (Abdel Aziz, 2007). During this juncture, the concept of engaging private financing in the provisioning of public services surfaced, originating from the formative stages of modern nation-states (Gurgun & Touran, 2014; Roehrich et al., 2014)

The collaboration between public and private actors has historical roots dating back to the 16th century, as argued by Wettenhall in 2003. This view suggests that the inception of Britain's navy, strategically aimed at challenging Spanish sovereignty at sea and establishing overseas colonies, is an early example of such a partnership. During this period, a substantial portion of the British fleet comprised privately owned vessels, with influential merchants and aristocratic landowners contributing ships and financing soldiers for these maritime endeavors. Their financial backing was facilitated through licensing agreements which authorized the deployment of armed vessels to capture Spanish goods at sea, with the condition that ten percents of their value be delivered to the Crown. Although the Crown subsequently authorized these private backers to govern acquired lands and establish entities like the East India Company, it is noteworthy that this historical collaboration was not directly associated with the provision of public services. Consequently, it defies precise categorization as a partnership; rather, it represents a fusion of public and private initiatives (Wettenhall, 2003). In summary, the formation of overseas empires by Britain during this era was a joint endeavor of public and private actors, setting the stage for the later formalized concept of partnership, governed by defined rules and responsibilities, as witnessed with the concession model first introduced in France.

The initial framework for collaboration between public and private sectors took shape in 19th-century France through the concession model. Under this innovative system, the French government granted certain companies the authority to construct infrastructure like roads, railways, and water supply networks. A distinctive element of the concession model is that public authorities continue to own the facilities or services, while private contractors are given concessions or leases, making them responsible for covering operational and maintenance costs. These contractors also have the right to collect revenue and retain any profits generated. (Hodge & Greve, 2005).

As the role of the state in the market transformed, there was a discernible shift in the dynamics between public and private actors. It can be argued that providing services has inherently involved collaboration between these entities. However, the extent of their participation fluctuates depending on the evolving priorities of the state and capital owners. With the ascendancy of private interests, there has been a notable increase in private participation in service delivery. Conversely, when concerns center around citizen welfare, the role of the public sector gains prominence. This interplay between public and private roles in service delivery resembles a tide marked by a center-periphery relationship regarding surplus distribution (Simon, 2011). The core focus on capital interests has remained constant, however the role of public interest within this framework has evolved. When public interest aligns more closely with the core, the state takes on increased responsibilities. Conversely, when citizens' welfare is pushed to the margins, their well-being depends on how fairly capital is managed. This relationship underwent a significant shift in the latter half of the 20th century. After the war, the state committed to providing a broad spectrum of services without major tax increases. However, the 1973 oil crisis, which led to a tenfold spike in oil prices, disrupted industrial production and hindered the generation of surplus. As a consequence, governments faced a severe shortage of financial resources to sustain these services (Sundaresan, 2012). Additionally, the welfare state's crisis was linked to bureaucracy, with the expanded bureaucratic apparatus during this period being criticized for inefficiency and ineffectiveness, contributing to the crisis. Subsequently, the 1980s marked a new epoch that marginalized the role of the public in service delivery, paving the way for the ascendancy of private actors and the emergence of PPPs in a contemporary sense.

The United Kingdom is often credited as a trailblazer in the realm of (PPPs, driven by the ideological shift towards neoliberal transformation incorporated into its policy agenda. Friedman's crisis theory was pivotal in steering public services toward marketization (Friedman & Friedman, 1990). The Friedmans argued that the welfare state's interventionist measures restricted individual freedoms and concentrated economic and political power, leading to inefficiencies, wasteful resource allocation, and a cumbersome bureaucracy. Advocating a return to market-driven solutions, they influenced the emergence of the theory of public management, which likened state governance to that of a firm. However, recognizing the potential hazards of an entirely market-driven approach, a regulatory role was assigned to the state, laying the foundation for the New Public Management (NPM) theory (Friedman &

Friedman, 1990). NPM integrates neoclassical economic theory with private management principles, emphasizing efficiency, competition, choice, and market mechanisms (Whiteside, 2020). NPM promotes decentralization, prioritizes results over procedures, disaggregates bureaucracy, and delegates responsibility for purchasing public services from their provision, a departure from direct provision (Yescombe, 2007).

PPPs have their roots in the New Public Management (NPM) paradigm, which advocates for either privatization or outsourcing public services to the private sector. Privatization took precedence in the initial phases of NPM, but the emergence of PPPs followed suit. This shift occurred in response to public resistance to privatization and the recognition that certain services are not suitable for complete privatization, leading to the consideration and promotion of PPPs (Whiteside, 2013).

The United Kingdom was the birthplace of PPPs. To limit temporary public borrowing or tax rises and encourage private investment in service expansion, the government launched the Private Finance Initiative (PFI) in the early 90s. Private companies would finance, plan, and build public buildings and infrastructure, then lease them back to the government for as long as 30 years under the original PFI projects (Bishop & Waring, 2016). Throughout the early aughts, these initiatives played a pivotal role in expanding and modernizing public services, contributing funds to various sectors (Edwards & Shaoul, 2003). The UK government's quick promotion, touting the success of these projects, rendered PPPs appealing on a global scale. Furthermore, international institutions like the IMF and the World Bank actively fostered the adoption of PPPs.

The United Kingdom took the pioneering initiative in the realm of PPPs with the introduction of the Private Finance Initiative (PFI) in 1992. This government-led endeavor aimed to catalyze service development by leveraging private investment, all while curbing immediate public borrowing or tax hikes. The initial Private Finance Initiative projects primarily entailed private funding overseeing the design and construction of novel infrastructure. These assets were then leased back to the public through long-term contracts spanning up to 35 years (Bishop & Waring, 2016). Throughout the late 90s, these initiatives played a pivotal role in expanding and modernizing public services, contributing funds to various sectors (Edwards & Shaoul, 2003). The UK government's quick promotion, touting the success of these projects, rendered PPPs appealing on a global scale.

Therefore, developed countries such as Australia and Canada initially welcomed PPPs to revitalize their infrastructure. As an example, leading up to the Asian financial crisis of 1997, Australia's implementation of large-scale PPP projects rose continuously. Following a brief lull caused by the effects of the crisis, PPP procurement picked up steam again in the early 2000s and continued until 2008, reaching a peak of $12 billion. This was followed by a downward trend after the 2009 crisis. Currently, Australia's PPP volume has surpassed $60 billion (Zou & Yang, 2015)

The PPP has been slow to gain traction in EU countries. Although PPPs were first implemented in Europe in the late '80s as part of the Channel Tunnel project, it took another decade for the EU countries to witness a substantial rise in procurement using these methods (Liebe & Howarth, 2020) While PPPs began to gather steam in Portugal, Ireland, and Spain in the 1990s, some countries, including France, Germany, and Italy, introduced institutional structures and legislative frameworks for private investment in infrastructure in the mid-2000s (Button, 2008). The European Investment Bank (EIB) stated that the number of PPPs rose until 2010 when the number of PPPs in the EU peaked in terms of value. The projected capital value of almost 1400 PPP projects signed between 1990 and 2021 was about €370 billion (EIB, 2022).

Subsequently, developing countries, grappling with the need for fundamental infrastructure but lacking financial resources, became the next target for PPPs. This marked a peak in the mid-2000s for countries such as Türkiye, China and Brazil. Following a decrease post the global economic crisis, developing nations extensively embraced PPPs. By 2012, PPP investments in these countries had surged nearly

€170bn. Despite a subsequent decline, the developing countries remain a pivotal player in the PPP market, with the top 5 countries in 2020—Brazil, China, India, Mexico, and Bangladesh (World Bank, 2021).

PPPs were widely supported for three key reasons. First, the availability of global capital is currently the primary driver of PPP policy, as opposed to the previously held belief in the efficiency advantages that might be achieved through privatization, as was the case with privatization in the 1990s. The second consequence is that infrastructure has been reorganized, and institutions have been restructured to make it easier for financial investors to get in. Third, a legislative framework that favors private sector engagement over public sector alternatives has been crucial in facilitating this (Bayliss & Van Waeyenberge, 2018).

The worldwide financial crisis of 2007 marked the beginning of the end for the golden age of PPPs as extensive credit facilities dwindled and were no longer available. In addition, neoliberal belief—most notably, that the private sector is intrinsically effective and efficient—were debunked by market failure (Whiteside, 2018). Therefore, PPPs started to face scrutiny because they were born out of such beliefs. Particularly in developed countries, the promotion of PPPs has been abandoned. This shift was largely due to governments attempting to redirect the financing model of PPPs to align with the preferences of institutional investors' preferences for long-term and stable returns rather than returning to traditional public finance approaches. After taking a heavy hit from the global financial crisis, institutional investors are shifting their focus to find safer investments with more consistent returns over the long term (Bayliss & Van Waeyenberge, 2018). Put simply, PPPs have evolved into a lucrative instrument for large financiers, offering steady and certain earnings. However, the public implications of this tool are subject to debate and will be addressed in the subsequent sections. Before doing that, it is necessary to shed light on what PPP is by providing a comprehensive definition.

2.1.2 What is PPP?

One of the most challenging aspects of PPP is the absence of a consistent definition for this concept. The Organisation for Economic Co-operation and Development (OECD) highlighted that "there is no widely recognized definition of PPPs and related accounting framework" (OECD, 2012). Similarly, the International Monetary Fund (IMF) noted, "there is no clear agreement on what does and what does not constitute a PPP … The term PPP is sometimes used to describe a wider range of arrangements" IMF (2004). Given that countries approach PPP with diverse objectives and viewpoints, a wide range of definitions and interpretations emerge regarding the nature of PPP, and there is no universally accepted definition yet. After a comprehensive literature review, it has been identified that the definitions provided below by different organizations and scholars are among the most acceptable worldwide. Here is a collection of PPP definitions:

The United Kingdom is widely recognized as a pioneer in PPP and proposed this idea as a way to leverage the proficiency and expertise of private sector in management to improve the procurement of public infrastructure. This was made possible through the involvement of the private sector in various aspects of the project, such as designing, building, financing, and operating (HM Treasury, 2012). The concept differs from conventional procurement in that it places responsibility on the private sector for not only delivering the asset but also for managing and implementing the entire project, as well as ensuring successful operation for an extended period of time following completion (Benito et al., 2012; PWC, 2005).

The US National Council for PPP refers to PPP as a legally binding contract between a federal or local public institution and a private sector organization. This contract is designed in order to facilitate the sharing of resources, expertise, and assets between both parties to deliver a service or facility for the benefit of the general public. Moreover, in addition to sharing resources, both parties bear the risks and rewards associated with the delivery of the service or facility (Ke et al., 2010; Vrooman, 2012).

The Canadian Council for Public-Private Partnerships (CCPPP) introduces PPP as a partnership that brings together the expertise of both the public and private sectors to efficiently and effectively serve the public needs by appropriate distribution of resources, rewards and risks. According to the council, a PPP must meet two key criteria: firstly, the project should provide public services or develop public infrastructure as the ultimate objective, and secondly, risk sharing between the public and private sectors must be involved (CCPPP, 2016).

The Korean Development Institute describes PPP as an agreement in which the private sector build and operates a facility with its own capital to assist the public sector in delivering public services (Ejder, 2022; OECD, 2022) This allows for the private sector's creativity and efficiency to be utilized in such projects.

In the Netherlands, PPP represents a collaboration between the public and private sectors, as well as other entities such as NGOs, trade organizations, and knowledge institutions. The purpose of this partnership is to achieve a shared objective or carry out a specific task, and both parties share resources and expertise together with the risks and responsibilities (IOB, 2013).

The European Union doesn’t provide a formal definition of PPP; however, the Green Paper characterizes PPPs as a type of collaboration between the public and private sectors that involves funding, constructing, renovating, managing, or maintaining infrastructure or providing services. (CEC, 2004).

The OECD defines PPP as an arrangement between the government and one or more private partners (which may include operators and financiers) according to which the private partners deliver a service in a manner that aligns with the government's service delivery objectives, as well as their own profit objectives. The success of this alignment depends on an adequate transfer of risk to the private partners (ECA, 2018; OECD, 2008, 2012). This definition emphasizes that a PPP involves a long-term partnership between the public and private sectors and that the private sector partner takes on significant responsibility and risk in providing a service or facility that serves the public interest.

The IMF describes PPP as agreements where a private entity provides infrastructure assets that were conventionally the responsibility of the official government. PPPs have two important characteristics: first, the private sector emphasizes service provision as well as investment, and second, significant risk is transferred from the government to the private sector (IMF, 2006).

The World Bank Group (WBG) refers to PPP as a contractual arrangement between a government entity and a private party for delivering a public asset or service over an extended period. In this arrangement, the private party bears substantial risk and is responsible for managing the project, and their remuneration is tied to their performance. However, PPPs usually exclude service or turnkey construction contracts, which are classified as public procurement projects, as well as the privatization of utilities that have a limited ongoing role in the public sector. The WBG recommends PPP as a means for governments to acquire and implement public infrastructure and/or services by utilizing the resources and expertise of the private sector (WBG, 2022). When governments are faced with aging or insufficient infrastructure and require more efficient services, partnering with the private sector can encourage novel solutions and provide financing.

From a critical standpoint, PPPs are perceived as a form of linguistic manipulation aimed at concealing ulterior motives. Within this narrative, PPPs are equated with outsourcing or privatization. The term 'PPPs' was coined to deflect public scrutiny, masking these initiatives under seemingly innocuous principles. Essentially, privatization is repurposed to incentivize private enterprises to provide public services, often at the cost of governmental entities. The PPP policies are solely driven by entrenched interests, veiling their financial motives behind the issue's complexity, with economic concerns conspicuously absent from their agenda (Davidson, 2004).

However, many authors challenge the notion that PPPs are synonymous with privatization, citing significant distinctions between the two (Roehrich et al., 2014). Yescombe (2007) delineates primary arguments refuting the equation of PPPs with privatization. For instance, in PPPs, public authorities retain direct political responsibility for services, while asset ownership typically remains within the public sector. PPPs often involve monopolistic service provision, contrasting with privatization, which introduces competition. Moreover, the scope and expense of services in PPPs are governed by specific contracts amongst the public and private entities, unlike privatization, where regulatory mechanisms or market competition dictate them.

As can be seen from the literature, not only do different institutions promoting PPPs differ in their definitions of PPPs, but also countries use their own definitions in national laws and policies; however, there are some common elements. Therefore, Akintoye (2006) broadly defines PPP as "*a contractual agreement of shared ownership between a public agency and a private company, whereby they pool resources together and share risks and rewards, to create efficiency in the production and provision of public or private goods*".

Even though available PPP definitions vary and highlight different aspects, several common criteria can be identified (Allen, 2001; Forrer et al., 2010; Kivleniece & Quelin, 2012; KS et al., 2016; Roehrich et al., 2014). These include:

- A long-term agreement amongst the public and private sectors whereby the private entity is involved in various aspects of a project, like design, financing, building, and operation.
- Sharing resources, expertise, and responsibilities between public and private sectors to deliver a service or develop a facility that serves the general public interest.
- Efficient sharing of risks between public and private sectors.
- A Focus on the project outputs rather than inputs and a consideration of the whole life cycle implications for the project.

To summarize, given the commonalities of the above-mentioned definitions, PPP can be defined as *a long-term strategic collaborative agreement between public and private sector entities, involving the private sector in various aspects of the project, such as designing, financing, building, and operating, designed to share resources, expertise, and risks, with the ultimate goal of providing services or developing infrastructure, that serves the general public interest, in a more efficient and effective manner*.

2.1.3 How Many Types of PPP Exist?

The concession model, which allows a private entity to oversee, operate, and collect user fees from a publicly owned asset in exchange for an initial payment and sometimes a portion of the revenue, is the historical foundation of PPPs. However, modern iterations of PPPs diverge significantly from this model (Little, 2011). The landscape of PPPs is characterized by a multitude of variations, reflecting the diverse theories and approaches of different stakeholders. While these variations may differ from one another to varying degrees, they collectively represent the evolution of PPP frameworks. In scholarly discourse, PPPs are primarily classified based on the degree of private involvement in projects. The Most well-known types of PPP are Design – Build – Transfer (DBT), Operation – Maintenance (OM), Design – Build – Operate (DBO), Build – Lease – Operate – Transfer (BLOT), Build – Own – Operate – Transfer (BOOT), Design – Build – Transfer – Operate (DBTO), Design Build – Finance – Operate (DBFO), and Build – Own – Operate (BOO) which are briefly explained in Table 2.1 (Adams et al., 2006).

Figure 2.1 illustrates the public and private sectors' engagement and their respective levels of involvement (Kwak et al., 2009).

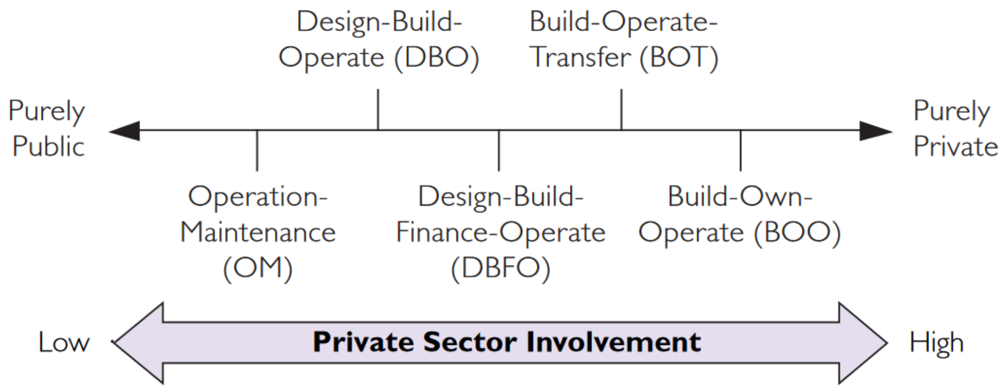


Figure 2.1. Public and private sector involvement in PPP projects (Kwak et al., 2009)

Apart from the PPP models in the preceding table, two other PPP types have become increasingly popular in recent years. The first of these is the Buy-Build-Operate (BBO) model, where a public asset is transferred to a private or quasi-public entity, typically under an agreement that mandates the modernization and operation of the asset for a defined duration. (Little, 2011). Build-Lease-Transfer (BLT) is the second option, wherein a private entity constructs and finances a project instead of the public sector before leasing it back to the client for a prearranged amount of time (Little, 2011) .

Table 2.1 List of mostly well-known PPPs.

Type of PPP	Explanations
OM	Every operation and maintenance element falls under the private sector's purview. While the private sector may not assume financing responsibilities, it may oversee a capital investment fund and decide on its allocation in collaboration with the public sector.
DBO	A project designed, built, operated, and maintained by the private sector is turned over to the public sector after a predetermined time. Although the private sector may not be responsible for financing, it may manage a capital investment fund and determine how it should be used together with the public sector.
DBFO	The private sector takes on the responsibilities of financing, designing, constructing, operating, and maintaining a project. However, in almost all instances, the public sector retains full ownership of the project.
BOT	A project is given a concession period during which the private sector oversees financing, designing, building, operating, and maintaining it. After the concession period, the asset is typically returned to the government for free.
BOO	Compared to a BOT project, with the private sector owning the asset forever, the government just commits to paying for the services for a predetermined period.

2.1.4 Pros of PPP

The primary literature includes a wide range of sources discussing the benefits of PPPs, mostly in risk sharing, value for money, and the efficiency and efficacy of privately controlled projects guaranteeing financial benefits.

2.1.4.1 Risk Sharing

Risk transfer stands out as a central focus in the discourse surrounding the benefits of PPPs. The essence of this partnership lies in assigning risks to the party best equipped to handle each specific risk, thereby allowing the public sector to alleviate some of the burdens associated with large-scale projects. For example, in PPPs, the private sector responsible for the project's entire life cycle costs – covering building, operation, and maintenance – which typically involve cumbersome bureaucratic procedures within conventional frameworks. However, identifying and allocating risks accurately between parties necessitates a meticulous contractual framework.

Various factors contribute to the diversity of risks encountered in projects, including structural issues within the country, sector-specific challenges such as healthcare emergencies like the COVID-19 pandemic, and concerns related to contract management and stakeholders. Consequently, a commonly accepted classification of risks exists in literature, typically categorized into three levels: macro, meso, and micro (Bing et al., 2005).

Macro-level risks are external factors beyond the project's control, such as political, legal, economic, social, and environmental conditions. Meso-level risks, including design, location, and required operational technology, are intrinsic to the projects. Micro-level risks revolve around stakeholder relationships, encompassing issues related to project parties rather than project specifics (Bing et al., 2005).

Strategically grouping and classifying project risks enables both public and private sector stakeholders to adopt a systematic approach to risk management. It also facilitates the adoption of common risk analysis, treatment, monitoring, and control approaches. Risk sharing among stakeholders varies depending on contextual factors. For instance, in countries like the UK, with a robust private sector and a competitive market, the private party is expected to assume more risks. Conversely, in markets dominated by the state with underdeveloped private sectors, risk transfer in PPP projects becomes less feasible for the public sector (Li et al., 2005). Therefore, it is imperative to recognize that the nature of risks and their allocation between parties is contingent upon market structures, the sector involved, and stakeholders' experience levels, emphasizing the contextual nature of risk management in PPPs.

2.1.4.2 Value for Money

The advantages of PPPs are further elucidated through the lens of Value for Money (VfM), a concept that gained prominence in 2006 (HM Treasury, 2006). VfM entails achieving the optimal balance between whole-of-life costs and quality to meet user requirements rather than simply favoring the lowest cost bid. PPPs are posited as conducive to VfM due to several characteristics (HM Treasury, 2006):

- They entail major capital investment programs necessitating effective risk management during construction and delivery.
- The service structure permits the public sector to outline its needs in terms of service outputs, promoting long-term effectiveness and accountability in the delivery of public services.
- Assets and associated risks in PPP schemes can be costed over the entire lifecycle on a long-term basis.
- Projects are sufficiently large to prevent disproportionate procurement costs.
- Stability in technology and sector aspects reduces susceptibility to rapid changes.
- Long-term planning horizons ensure assets and services are intended for prolonged use.

- The private sector's expertise and performance incentives contribute to VfM.

The promotion of PPPs based on VfM hinges on the risks assumed by the private party. To assess whether PPPs offer better value than traditional procurement, the Public Sector Comparator (PSC) is commonly used. This method compares two delivery alternatives in terms of financial and quantifiable non-financial benefits, with governments opting for the option with the lowest net present cost. Two main factors are considered in VfM calculation via the PSC: risk adjustment, which accounts for transferred risks, and application of a discount rate to compare cash flows over time (Whiteside, 2013). Net present costs are computed for both PPPs and PSC, with the lowest cost representing the best VfM. Studies, such as those conducted by the UK Treasury, suggest that PPPs yield significant cost savings compared to conventionally procured projects (Shaoul, 2005). This association between VfM and PPPs is reinforced by the opportunity to transfer risks to private actors within the PPP model.

2.1.4.3 Financial Benefits

The exaltation of private sector engagement in public service delivery, rooted in the belief that it surpasses the efficiency and effectiveness of the public sector, primarily stems from the ideologies of neoliberal and New Public Management, rather than concrete sign to a significant degree.

One argument supporting this notion is that private entities are incentivized to optimize investment in infrastructure and quality while minimizing costs or risks more effectively than the public sector (Trebilcock & Rosenstock, 2015). This competitive drive and profit-oriented nature push private investors to seek cost-saving measures, resulting in both construction and operation phases being carried out more economically. Furthermore, it is argued that PPPs can expedite the construction phase compared to traditional procurement methods, as private investors are motivated to begin operations swiftly to maximize profits.

Consequently, not only cost but also timing efficiencies are realized. Conversely, the absence of competition and differing priorities such as social benefits diminish the incentive for cost reduction and profit maximization in the public sector.

Another consideration is how PPPs influence the allocation of public resources. PPPs are appealing to governments because they distribute costs over the long term while generating immediate benefits. Governments bear operational costs rather than upfront construction expenses, rendering costly projects financially feasible without straining budgets or increasing borrowing. In this context, PPPs are likened to a "mega credit card" for both local and national governments, enabling them to bridge infrastructure gaps by leveraging limited public funds and incorporating private sector innovation to enhance operational efficiency (Bayliss & Van Waeyenberge, 2018; Hodge & Greve, 2005).

Moreover, PPPs assist governments in meeting budgetary targets. By accounting for only annual payments to project companies rather than overall liabilities, PPPs offer an off-balance sheet treatment, prioritizing short-term benefits over long-term obligations. Additionally, by freeing up resources through private sector financing, PPPs enable governments to fund public investment programs in the short term, enhancing their popularity with the electorate.

Finally, PPPs' emphasis on outputs is argued to result in higher-quality services. With fixed output specifications for extended periods, there is a heightened focus on describing service stages at the project's onset. The project company is obligated to maintain service standards throughout the operational phase, ensuring continuity of quality until the project's transfer to the public sector. This commitment to service quality underscores the potential benefits of PPPs in delivering superior public services (PWC, 2005).

2.1.5 Cons of PPP

Opposing perspectives on PPPs can be broadly categorized into 2 main domains. The first encompasses critiques in opposition to the aforementioned claims in favor of PPPs, while the second delves into additional critical points that highlight inherent issues within the PPP model.

The portrayal of PPPs as a solution for efficient infrastructure services with reduced costs and risks is criticized as an idealistic view rather than an accurate reflection of reality (Coghill & Woodward, 2005). Critics argue that the neoliberal perspective promoting PPPs overlooks market complexities and lacks consideration of alternative ideologies. Moreover, the alleged cost-saving benefits of PPPs are challenged, particularly regarding the financing mechanism, where private sector borrowing costs and profit motives inflate project expenses, often without passing savings to the public. Social costs, such as compromised service quality and safety risks, further diminish the perceived benefits of PPPs (Whiteside, 2011, 2013). Additionally, claims of PPPs positively impacting budgetary indicators are debunked, as long-term financial commitments are often concealed, creating short-term financial relief at the expense of future budgets (Loxley, 2012). Moreover, the global application of PPPs exacerbates development gaps between countries and sectors, consolidating inequalities rather than addressing infrastructure needs. The argument that PPPs enable more efficient resource allocation is scrutinized, as partnership decisions are often influenced by opaque processes and profit motives rather than societal needs (Bishop & Waring, 2016). Furthermore, the notion of balanced risk allocation in PPPs is questioned, as risks transferred to the private sector often resurface as increased project costs for the public sector. Ultimately, the theoretical advantages of risk transfer in PPPs do not always align with practical outcomes, posing significant operational risks and potential service disruptions (Whitfield, 2001).

Critiques of PPPs extend beyond their purported benefits, delving into the intricacies of PPPs' internal workings. Foremost among these critiques is the structural shift brought about by PPPs, altering the balance between capital and state in public service delivery. (Whitfield, 2001) argues that by commodifying service provision, PPPs prioritize financial flows over social needs, leading to the financialization and erosion of the public nature of services. Moreover, PPPs introduce a contradiction in governance by de-politicizing public service provision while promoting participatory decision-making. Despite the governance approach advocating multi-stakeholder involvement, PPPs often grant dominance to private actors wielding financial power, diminishing public control over policymaking. (Skelcher, 2012) warns of a democratic deficit as private actors exert influence over essential services financed by taxes, undermining accountability, and oversight. The erosion of democratic principles within PPPs is evident in the breakdown of accountability and transparency. (Willems & Van Dooren, 2016) argue that by transferring operational responsibilities to private actors, PPPs weaken the accountability of elected representatives to the public, hindering scrutiny of service delivery processes. Additionally, the commercial confidentiality surrounding PPP contracts undermines transparency, leaving citizens uninformed about decisions impacting their lives. Furthermore, the dominance of neoliberal ideologies limits governments' policy options, compelling them to embrace privatization or PPPs. Consultants advocating private sector practices influence government decision-making and procurement processes, contributing to a global proliferation of PPPs (Hodge, 2006).

The symbiotic relationship between public and private actors in PPPs further consolidates the model's dominance. Private sector interests, which rely on government support, influence policymaking, while governments depend on private financing to maintain power. This interdependence fosters an oligarchic bond, leading to corruption and favoritism in resource allocation. Moreover, PPP contracts restrict the autonomy of future governments and impose long-term financial obligations, limiting policy flexibility and perpetuating neoliberal policies. The difficulty in renegotiating PPP contracts undermines democratic decision-making and prioritizes private sector interests over public welfare (Willems & Van Dooren, 2016).

The purported cost-effectiveness of PPPs is questioned due to explicit and implicit costs. Complex bidding and negotiation processes, coupled with lengthy project cycles and changing stakeholders, inflate project costs (Whitfield, 2001). Additionally, the internal dynamics of PPPs undermine social and moral values, transforming public servants into self-interested actors prioritizing economic rationality over public welfare (Smith, 2012). In sectors like healthcare, PPPs may compromise service quality and integration, leading to ineffective delivery and potential harm to patients (Whiteside, 2013). Fundamental differences between the public and private sectors remain irreconcilable within the PPP framework, exacerbating the erosion of public values and principles.

In summary, the discourse on PPPs involves critiques spanning efficiency claims, social costs, budgetary implications, global inequalities, risk allocation, structural shifts, democratic deficits, accountability issues, ideological dominance, corruption risks, policy constraints, and social costs. These collective concerns emphasize the imperative for a comprehensive reassessment of PPP policies and practices to ensure alignment with public interests, promote equitable development, uphold democratic principles, and mitigate potential adverse impacts on society.

2.1.6 Risk Management in PPP

Construction projects are complex, chaotic and dynamic (Baccarini, 1996) and therefore associated with risk over all the stages, starting from conception and briefing through the design and construction phase. Considering the rapid growth of global interest in the PPP concept, numerous studies have explored the crucial factors for the successful delivery of PPP projects (Osei-Kyei et al., 2017; Osei-Kyei & Chan, 2017a, 2017c). Many researchers have identified a proper and realistic risk assessment as one of the noteworthy success factors in PPP projects (Ke et al., 2010; Osei-Kyei & Chan, 2015, 2017c). A thorough risk identification and proper risk allocation mechanism among different parties will decrease any future conflicts among stakeholders of the project (Pitt et al., 2006), and as a result, it will increase the success rate of PPP projects (Jin & Doloi, 2008).

Akintoye & Chinyio (2005) state that in PPP projects, risk management is fundamental and should be performed in order to ensure and maintain the best efficient operation of the facility. The financier, in turn, will examine the consortium's plans before finalizing the funding arrangements. This pre-contract scrutiny of PPP projects by the external funder is to increase the potential of PPP projects to be delivered on time, within budget (Shen et al., 2006), and the overall viability.

Successful PPP projects exhibited unique strategies and capabilities in risk management (Tiong, 2002); however, risk evaluation is so complex that it requires an analysis of risk from different perspectives of public and private entities (Grimsey & Lewis, 2002). Shen & Wu (2005) explore how various risks existing in the BOT project implementation process impact project cash flow, including revenue and cost. The first step in estimating the influence of risk involves identifying risks specific to each project. Cause-effect diagrams, brainstorming, breakdown structures, project analogies, checklists, and Crawford slips are some of the widely used risk identification methods. Regarding the literature, developing a risk checklist using a hierarchical structure is the most recommended technique to classify risks according to their sources, and it facilitates dealing with risks logically by providing a clear risk visualization (Bing et al., 2005; Li et al., 2002). Li (2003) proposed a 3-tier meta-classification method for associated risk factors in PPP projects, namely macro, meso, and micro. This classification method has been widely used in much research in the field of risk management in PPP projects (Bing et al., 2005; Hwang et al., 2013; Ke et al., 2010; Li et al., 2002). Moreover, similar risk structures are used in construction risk classification (Bing et al., 1999; Hastak & Shaked, 2000; Zhi, 1995).

The macro risk factors are at the ecological level and have their origins beyond the system boundaries of projects. These risks are frequently associated with political, legal, social, and economic conditions and natural hazards. The micro-risk factors are at project level and have their origins within the nature of each project. The micro-risk factors are usually related to project demand, location, construction, and operation problems. Lastly, the meso-risk factors focus on the project stakeholders' relationships. The differences between the public and private sectors make the meso-risk factors important, as the private sector is profit driven, whilst the public sector has social responsibility.

As a result of a comprehensive literature survey, a total number of 71 potential risk factors in PPP projects have been identified and categorized accordingly (Kamali et al., 2018). The perceived magnitude of each risk and the interrelationships of risks in PPP projects enable decision-makers to take appropriate steps in prioritizing and analyzing the project processes (Iyer & Sagheer, 2010).

A key significant characteristic of PPP is the allocation and sharing of risk among parties (Ke et al., 2010; Ke et al., 2010). Unlike other procurement methods, with PPP arrangements, risks are carefully identified and allocated to the party that has better mitigation techniques for such risks (Li et al., 2005). Risk allocation strategies were further studied, particularly in terms of governance structure (Jin & Zhang, 2011). Due to differences in PPP collaboration and policy background, the way in which risk allocation is carried out varies by region; this results in a series of risk allocation models for different regions (Ameyaw et al., 2013; Sastoque et al., 2016; Xu et al., 2010).

2.1.7 Critical Success Factors of PPP

In recent decades, a key area of interest in PPP research has been the exploration of success factors that contribute to the effectiveness of these partnerships. This focus was evident in a review of research trends on PPPs conducted between 1998 and 2008 by Ke et al. (2009) and from 1990 to 2013 by Osei-Kyei & Chan (2015); similarly, Tang et al. (2010) highlighted PPP project success as a key research focus that has garnered significant interest among scholars. Since the development of PPPs, many researchers have utilized the concept of critical success factors to better understand the most effective methods for implementing PPP policies in infrastructure development. (Liu et al., 2014). The concept has been applied to a wide range of PPP arrangements, covering various infrastructure sectors, project models, and stages of the PPP process. For instance, the critical success factors for PPP water projects in China, focusing on the transfer-operate-transfer model (Meng et al., 2011). Similarly, critical success factors have been investigated in other infrastructure sectors where PPPs have been utilized, including transportation, telecommunications, energy, and housing. (Abdul-Aziz & Jahn Kassim, 2011; Askar & Gab-Allah, 2002; Dikmen Özdogan & Birgönül, 2000; Jamali, 2004; Liu & Wilkinson, 2013).

The critical success factor concept has been utilized across various stages of the PPP process. For instance, Ng et al. (2012) investigated success factors during the feasibility stage of PPP projects, whereas Tang et al. (2013) focused on the briefing stage. Similarly, Raisbeck & Tang (2013) examined the success factors at the initial design stage of PPP projects.

There are many researchers who employed the critical success factor concept for general PPP infrastructure projects (Chan et al., 2010; Cheung et al., 2012; Hwang et al., 2013; Tiong et al., 1992; Zhang, 2005). Significant focus has also been placed on both developed and developing countries that use PPP policies to drive infrastructure development. Researchers have investigated the critical success factors essential for successfully implementing PPP projects in these nations. (Hwang et al., 2013; Jefferies et al., 2002; Li et al., 2005; Olusola Babatunde et al., 2012).

2.1.8 PPP in Türkiye

The concept of "steering but not rowing" (Barlow & Röber, 1996) gained traction amidst Türkiye's economic turmoil, sparked by the crisis of the late 1970s and exacerbated by the US embargo following the Cyprus intervention. This period devastated the socio-economic fabric of lower and middle-income groups, prompting a search for solutions (Zürcher, 2004). Following the 1980 military coup, advocates of economic liberalization seized upon the idea that transitioning to a neoliberal economy would parallel the stability brought by political intervention. Blaming the inefficiency of state enterprises, they championed integrating the private sector into public service delivery (Öniş, 2010). The PPP concept was introduced to Türkiye in 1984 in the form of a BOT by Turgut Özal, the former Turkish Prime Minister, as a solution to the energy bottleneck within those years (Dikmen Özdogan & Birgönül, 2000).

Integrating PPPs into Turkey's system was a gradual process necessitating a legal framework. The process began with the enactment of law number 3096 in 1984, regulating electricity generation, transmission, and distribution through concession agreements under the BOT model. This legislation allowed private entities to construct and operate electricity facilities for up to 99 years (Gurgun & Touran, 2014). Subsequent laws expanded the scope of PPPs, introducing models like the Transfer of Operational Rights (TOR) in 1988 and facilitating private involvement in projects requiring advanced technology or substantial financial resources in 1994. This expansion allowed the private sector to lead significant infrastructure projects such as bridges, tunnels, highways, airports, and power generation facilities. Another notable development was the introduction of Law No. 4046 in 1994, which established the Privatization High Council and the Directorate of Privatization Administration to oversee privatization efforts, aiming to improve productivity and reduce public expenditures. Additionally, the BO model introduced in 1997 enabled private companies to construct, own, and operate thermal power plants for up to 20 years. Despite these advancements, the legislative process regarding PPPs was gradual and lacked comprehensive coverage (Gurgun & Touran, 2014).

Despite these legal developments, privatization and PPPs faced obstacles and failed to accelerate in practice during the 1990s. Apart from the lack of favorable legal and institutional frameworks, various factors hindered their implementation. Legal disputes between pro and anti-privatization groups arose over the role of the private sector in public service delivery. Initial attempts to place PPPs under private law jurisdiction were thwarted by the Constitutional Court, leading to the cancellation of many contracts (Ercan & Öniş, 2001). However, a constitutional amendment in 1999 allowed public investments and services to be carried out by the private sector under private law contracts (Emek, 2015). Moreover, a fragmented political landscape, characterized by weak coalition governments, impeded neoliberal reforms, with newly established agencies like the Privatization Administration lacking the autonomy needed for effective implementation (Ercan & Öniş, 2001). Government reluctance to relinquish control over resources and tensions between public agencies further hindered progress. The introduction of different PPP models at various times reflected the desire of line ministries to maintain control over projects in their respective sectors. Additionally, the limited capacity of domestic private capital and the absence of robust foreign support contributed to the slow progress (Emek, 2015). A turning point occurred with the emergence of new political actors, notably the Justice and Development Party, bringing fresh dynamics to PPP initiatives.

Continuing its efforts to create a favorable legal framework, the government pursued reforms to simplify the legal procedures surrounding PPPs. In 2005, Law No. 5335 was enacted, proposing the transfer of operating rights for airports and passenger terminals to the private sector. Around the same time, Law No. 5396 introduced an additional article to the Fundamental Law on Health Services, advocating for the construction of health facilities through the Build-Lease-Transfer (BLT) model (Gurgun & Touran, 2014). Regulations were subsequently established to clarify the partnership between public and private entities in constructing and managing these facilities. Notably, this law established the PPP Department within the Ministry of

Health, tasked with various duties, including selecting private entities for projects, determining project design and standards, and evaluating feasibility reports.

The introduction of the BLT model marked a significant shift in healthcare delivery, with the construction of "Integrated Health Campuses" later known as "City Hospitals." Despite the initial tendering process in 2009, challenges stemming from regulatory disorganization prompted the government to draft new legislation. While the government aimed for a unified PPP law, obstacles such as sector-specific requirements and the desire of line ministries to control projects hindered its enactment. Consequently, Law No. 6428, specific to the BLT model, was passed in 2013, governing procedures for constructing city hospitals and education facilities.

According to the World Bank statistics, 294 PPP infrastructure projects with total investment of about 143 billion US Dollars have been delivered in Europe and Central Asia (ECA), over the period from 2010 to 2017. Meanwhile, Turkey contracted 150 PPP infrastructure projects with a total investment of just under 100 billion US Dollars in the same period (WBG, 2017). As it can be seen from the World Bank data, Turkey is one of the active users of PPP agreement in the infrastructure delivery among Europe and Central Asia countries over the mentioned period.

According to statistics published by the Turkish Republic Ministry of Development (TRMD), over the period of 31 years from 1986, a total number of 225 PPP contracts have been signed. The construction phase of 191 projects ended, and these projects are under operation; meanwhile, the rest of the projects (34 projects) are under construction or financial closure (T.R.M.D, 2018). Analyzing the official statistics published by the TRMD, BOT has been identified to be the most dominant PPP scheme in terms of both project number (106 of 225) and contract value (84.7 of 134.9 billion USD). Project distribution according to the contract types in terms of number and value is illustrated in Figure 2.2 (T.R.M.D, 2018).

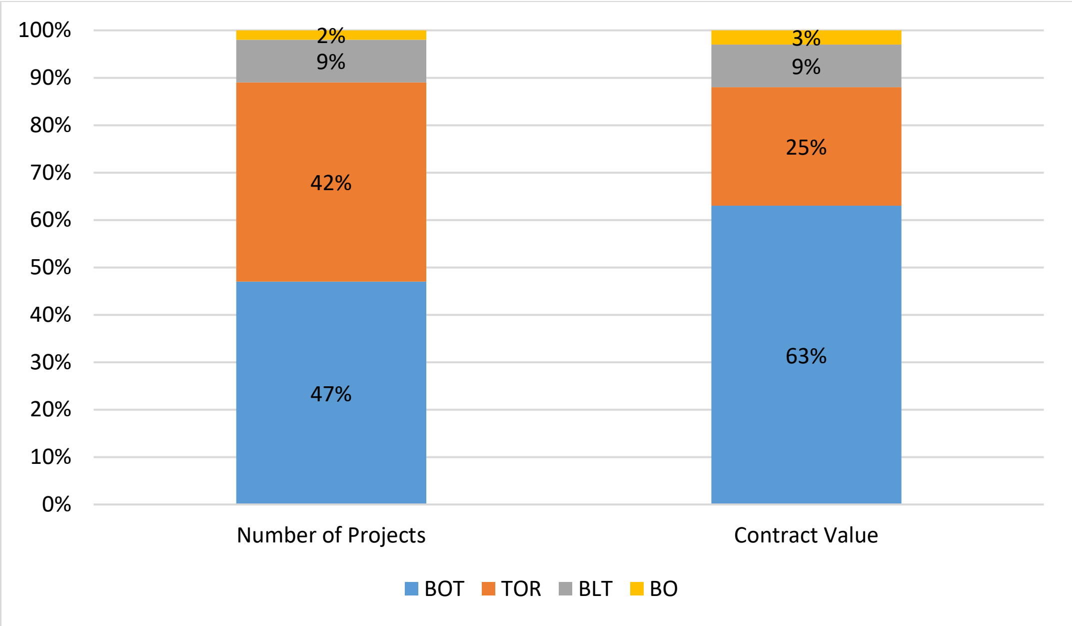


Figure 2.2. PPP project distribution in Turkey according to the contract types in terms of number and value.

The distribution of active PPP projects in different sectors for various types of contracts has been illustrated in Table 1 below. It is obvious from the example that the BOT is the most widely used contract, especially in the transportation sector, including airport, motorway, and railway projects. As can be seen in Table 2.2, the energy sector has generally attracted the largest privatizations (38.2%) among all PPP projects, whereas the health sector has the lowest (2.1%) and highest (50.0%) shares between a total number of under-operation and under- construction projects respectively (T.R.M.D, 2018).

Table 2.2 Distribution of Turkish PPP projects (investment value + lease payment) in different sectors.

Contract Type	*Phase*	*Transportation*	*Health*	*Energy*	*Port*	*Others*	*Total*
BOT	Oper.	37 $MM 10,396.16		25 $MM 4,969.45	13 $MM 143,02	14 $MM 1,751.40	89 $MM 17,260.03
	Const.	8 $MM 66,407.65			6 $MM 879.06	3 $MM 200.82	17 $MM 67,487.53
TOR	Oper.	16 $MM 12,306.65		56 $MM 18,523.53	20 $MM 3,379.88	1 $MM 6.17	93 $MM 34,216.23
	Const.						0 $MM 0.00
BO	Oper.			5 $MM 4,196.81			5 $MM 4,196.81
	Const.	17 $MM 10,175.32	4 $MM 1,532.23	0 $MM 0			0 $MM 0
BLT	Oper.		4 $MM 1,532.23				4 $MM 1,532.23
	Const.		17 $MM 10,175.32				17 $MM 10,175.32
TOTAL	Oper.	53 $MM 22,702.81	4 $MM 1,532.23	86 $MM 27,689.79	33 $MM 3,522.90	15 $MM 1,757.57	191 $MM 57,205.30
	Const.	8 $MM 66,407.65	17 $MM 10,175.32		6 $MM 879.06	3 $MM 200.82	34 $MM 77,662.85

2.2 Disruption Management

Construction project management literature is replete with abundant research studies on how to enhance the performance of projects to avert failure. Numerous research streams addressed this problem from different perspectives, which led to a wide range of approaches to enhance project performance, such as risk management, opportunity management, change management and crisis management. Distinctive methods have been developed to decrease the impact and/or the exposure duration of disruptive events in projects and, therefore, increase the projects' success rate by concentrating on the source of those events. Finding sources of disruptions has been identified as one of the crucial tasks in disruption management to reduce the duration of the project's exposure to the disruption (Sears et al., 2015). The sources of disruption can be categorized into known and unknown. Risk and opportunity management have been used to deal with known sources of disruption. In contrast, crisis and change management have been used to deal with unknown sources of disruption (Loosemore et al., 2005; Ward & Chapman, 2003). The former intends to predict and handle threats to avoid disruption, while the latter intends to decrease the project's vulnerability level prior to the disruption.

2.2.1 Risk and Opportunity Management

Risk, known as a threat (Carr & Tah, 2001), an uncertainty that matters (Hillson, 2014) or a measurable uncertainty (Hillson, 2003) is a potential event that may or may not happen in the future. If it happens, it may lead to a disruptive event which can positively or negatively affect the project's objectives (PMI, 2021; Tomanek & Juricek, 2015; Ward & Chapman, 2003). Reducing the negative severity of disruption is the main aim of risk management. It intends to achieve this aim by identifying those threats, predicting their occurrence and developing strategies to reduce their negative impact on the project's objectives (PMI, 2021; Qazi et al., 2016). The primary step in the risk management process is risk identification, which is predicting the possible future events that may alter the project's objectives and mostly rely on an individual's experiences, skills, interests and perception (Ward & Chapman, 2003; Zhang, 2007). The challenge is that individuals with different experiences and interests may have different perceptions of risks in a project and consequently identify and priorities risks differently. The following steps in the risk management process, risk analysis, response strategies and monitoring during the project's life cycle (Qazi et al., 2016) entirely rely upon risk identification. Thus, any unknown threat could challenge the whole risk management and considerably affect the project. Risk management intends to create value in a project by mitigating disruptions or reducing their impact (Sanchez et al., 2009; Ward & Chapman, 2003). Some scholars, however, criticized its performance and effectiveness and described it as a check-the-box process rather than a process for creating value (Erol et al., 2020).

In contrast to risk management, which targets the repercussions of a threat, opportunity management focuses on its positive consequences. In other words, opportunity can be described as a positive perception of risk (Olsson, 2007). Although the steps of opportunity management are similar to those of risk management (identification, analysis and responding) (Ward & Chapman, 2003), their responding methods are entirely different. As discussed earlier, there are four different responding strategies in risk management, including avoiding, transferring, mitigating, and accepting. In contrast, opportunity management responds by exploiting, sharing, enhancing and ignoring (Hillson, 2003). Contrary to avoiding strategy in risk management, which tries to reduce the probability of occurrence by eliminating uncertainty, exploiting strategy in opportunity management aims to raise the likelihood and make the opportunity happen (Hillson, 2001). Analogous to transferring strategy in risk management, sharing strategy seeks to allocate an opportunity to a party best able to manage it. Moreover, opposing mitigating strategy in risk management, enhancing strategy tries to increase the probability of occurrence and/or severity of impacts of an opportunity. Like accepting strategy in risk management, the ignoring strategy will be used when an opportunity cannot be exploited, shared, or enhanced (Hillson, 2001).

Both risk and opportunity management suffer from the inability to cope with disruptions fully and ensure project recovery after experiencing a shock. These approaches mainly concentrate on increasing the ability to identify the potential threat or opportunity to avoid shock; however, in the face of unidentified threats or opportunities, these approaches might be incapable of managing them and their consequences appropriately.

2.2.2 Crisis and Change Management

Crisis has been defined as "a breakdown of familiar symbolic frameworks legitimating the pre-existing sociopolitical order" (Hart, 1993). In simple words, it is an extraordinarily challenging situation (Boin & McConnell, 2007) that leads to a menace to the functioning of a system (Rosenthal et al., 2001) and disturbs its balance. A threat, the element of surprise, and short response time have been described as three inseparable properties of a crisis (Seeger et al., 1998). Crisis management, in projects, fixates on handling issues that disturb the balance of a project and tries to keep the project from being further disrupted. Crisis management employs a pre-developed plan, command center, and training (Kerzner, 2013). After facing a crisis in a project, the pre-developed plan can be applied to buy some time for the command center, which is responsible for assessing the situation and developing a strategy to reduce the initial impact of the disturbance. Training strategies try to predict the crisis's repercussions and response precisely (Boin & McConnell, 2007). Current crisis management approaches have been criticized for oversimplifying the crisis's severity, making projects more vulnerable to crisis (Kerzner, 2013). Moreover, most of these approaches ignore issues generally created during a crisis, such as behavioral instability, conflict, and information problems (Love & Smith, 2016).

Change in construction projects generally refers to work status, processes, or methods altering the initial plan or specification (Park, 2002). Change management seeks to handle these alterations by constantly monitoring and modifying the direction and structure of a project (Chen et al., 2015; Motawa et al., 2007). Change management tries to ameliorate the consequences of an already happened change, but its first attempt is to predict potential changes that are likely to occur later and reduce their impact on the project (Hayes, 2018; Motawa et al., 2007). The current literature on change management primarily aims to discern the essential factors for the success of a change process and provide practice instructions for handling change (Cox et al., 1999; Ibbs et al., 2001; Motawa et al., 2007; Stocks & Singh, 1999). Moreover, there are research studies assessing the impact of change on particular project parameters. For example, the impact of a change order on labor productivity in a construction project (Hester et al., 1991), the effect of the changing size and its impact time on a project (Ibbs et al., 2007), and the risk of safety regulations changes during projects (Williams, 2000). Another study developed an integrated change management system for the lifecycle of changes within the construction project. This generic change system aims to manage change scenarios and evaluate change effects on projects. It consists of four main stages: "start-up," "identify and evaluate," "approval and propagation," and "post-change" (Motawa et al., 2007). In the first stage, proactive requirements are defined to manage change effectively, enabling the project team to respond readily to change. Then, in addition to identifying and evaluating change causes, types, and effects, the relevant and/or involved project processes and departments in the change decision are defined in the second stage. Client approval will be taken in the third stage after reviewing potential changes against the project baseline using tangible and intangible criteria. Finally, when a dispute resolution is applicable, it needs to investigate the change's direct and indirect causes (Motawa et al., 2007). Although the change management system can reduce the aftereffects of disturbance in a project by employing the provided requirements in the "start-up" stage, the requirements are not explicitly delineated. Change management may go wrong, especially when the sources of shock are beyond those perceived or permitted (Ward & Chapman, 2003).

All approaches discussed above intend to either avoid shock or reduce the project's susceptibility to shock-induced disruption. What is ignored here is the capability of the system to handle the shock and bounce back to an equilibrium state after a disruption, which is called recovery. Ponomarov & Holcomb (2009) claimed that vulnerability reduction approaches are insufficient to deal with project disruption and play readiness and response up to guarantee recovery. Some researchers support the idea that recovery may reduce exposure to future disruption. (Blay, 2017; Holling, 1973; Raco & Street, 2011). The concept of resilience has a solid history of ensuring recovery in many domains and can benefit construction projects.

2.3 Resilience

The concept of resilience was introduced by Norman Garmezy (Coutu, 2002; Geambasu, 2011) more than half a century ago. Since then, it has been examined across various disciplines, particularly in the context of responding to potential system failures, including psychology (Coutu, 2002), climate change (Hallegatte & Engle, 2019), organization science (DesJardine et al., 2019; Ortiz-de-Mandojana & Bansal, 2016; Sapeciay et al., 2017), ecology (Holling, 1973), supply chain management (Thomé et al., 2016) and disaster management (Bruneau et al., 2003; Paton et al., 2000; Paton & Johnston, 2001). However, this concept is still a novel and promising concept in project management. A more expansive perspective on resilience extends beyond physical structures to encompass infrastructure project management, which faces inevitable threats and disruptions that can hinder project completion. Despite the widespread implementation of risk management in construction, achieving seamless project success remains challenging because of the unpredictability of certain risks. Given the inescapability of risk, uncertainty, and complexity in infrastructure projects, it is crucial to incorporate resilience into them. Compared to the current literature on resilience, the resilience of infrastructure projects has received limited attention in the literature from the management perspective. The first step to incorporating resilience into managing infrastructure projects is to understand the ground of this concept and provide an appropriate definition for it. This section provides a comprehensive literature review of resilience and its relationship with related concepts.

2.3.1 Foundational Definition of Resilience

The concept of resilience has been present for decades and applied across various disciplines, leading to a diverse array of definitions depending on the context. The definitions can vary significantly within a single context (Carlson et al., 2012). Two foundations have been identified for resilience: engineering resilience and ecological resilience (Holling, 1996).

2.3.1.1 Engineering Resilience

The concept of resilience was first applied to systems in the 1800s by an engineer to describe the strength and ductility of steel beams. Resilience was defined as the ability of a steel member to withstand force by resisting it with strength (rigidity) and absorbing it through deformation (ductility) (Alexander, 2013). This is now known as engineering resilience. In the 1950s, the concept was adopted in psychology to describe a child's capacity to withstand shock, particularly in cases of schizophrenia (Masten et al., 1990).

Engineering resilience in literature focuses on three main aspects: efficiency, predictability, and constancy. Efficiency refers to the performance level that minimizes inputs required for restoration (Hollnagel, 2014). Predictability is the extent to which a system returns to its original state based on known disruptions (Folke, 2006). Constancy, the most widely discussed focus, defines resilience as stability near an equilibrium state, measured by resistance to disturbance and the speed of return to equilibrium (Pimm, 1984). Stability in this context means maintaining balance amid oscillations (Gunderson, 2000). This focus on constancy emphasizes avoiding disruptions rather than absorbing them (Gunderson, 2000; Hollnagel et al., 2006).

The expanding definitions of engineering resilience have led to conflicting interdependencies among these focuses. For instance, stability has been associated with efficiency, predictability, and return time (Walker et al., 2004), which conflicts with earlier literature. They suggest that while return time and predictability are not always essential, they are significant in the context of human and natural systems.

In management, engineering resilience is seen as a reactive approach, responding to deviations to ensure stability and returning to previous states to meet organizational goals. Another scholar argues that this reactive nature can hinder overall resilience, as it focuses on prediction and resistance rather than flexibility and adaptation to change. This approach can initially lead to success but ultimately results in less resilient management systems if disruptions are not properly managed (McManus et al., 2008)

Despite varying definitions, engineering resilience generally implies the ability to remain stable (Parry, 1996; Paté-Cornell, 1996) and recover once disturbances are removed, provided they do not exceed the elastic limit using a stress-strain curve analogy, stability is maintained before the elastic limit; beyond this point, recovery is impossible (Gallopín, 2006).

Overall, the engineering resilience perspective emphasizes building resistance to disruptions and developing response mechanisms (Bruneau et al., 2003; Sheffi & Rice, 2005). It often involves using mathematical tools to assess the likelihood and impact of disruptions and ensuring recovery once the disruption is removed (Banahene et al., 2014).

2.3.1.2 Ecological Resilience

Engineering resilience focuses on a system's ability to resist and absorb specific forces, maintaining its functions and controls along with the relationships between its various components (Bhamra et al., 2011; Ponomarov & Holcomb, 2009). Systems characterized by engineering resilience have limited possible states and quickly return to equilibrium after a disruption, emphasizing stability (Holling, 1973; Ponomarov & Holcomb, 2009). In contrast, ecological resilience centers on a system's capacity for change and reorganization. It is measured by the magnitude of disturbance that can be absorbed before the system undergoes a fundamental change in structure, altering the variables and processes that control its behavior (Holling, 1996).

In this framework, persistence—the ability to continue despite disruptions—is prioritized over constancy because systems are frequently challenged by unpredictable external factors (Holling, 1973). Flexibility enhances persistence by allowing for change while maintaining the core objectives. Introducing lags and buffers minimizes the impact of disruptions (Holling, 1973). Ecological resilience also emphasizes the importance of dealing with change and unpredictability, recognizing that complexity makes systems vulnerable to various changes and uncertainties (Folke, 2006; Holling, 1973; Walker et al., 2004).

Systems with rigid rules aimed at constant yields often lose resilience and can collapse under disturbances that could otherwise have been absorbed (Holling, 1996). A key feature of ecological resilience is its integrative approach, which includes connectedness and diversity (Holling, 1986). This approach involves all stakeholders, enhancing disruption management through communication, commitment, and collaboration. It also helps identify early warning signs of disruptive changes and facilitates the creation of self-renewing resource systems (Gallopín, 2006).

Ecological resilience thus represents a holistic approach to managing disruptions, focusing on flexibility and the dynamic development of systems to maintain and improve their functionality (Carpenter et al., 2001; Seville et al., 2006). It addresses situations where current states and outcomes are unpredictable and immeasurable. Unlike engineering resilience, which emphasizes hardening or returning to the original state, ecological resilience aims to bounce forward, moving to a stronger or better position after disturbances. Systems with ecological resilience can withstand significant disruptions, tend to return to equilibrium gradually, and, under certain conditions, may completely transform their structure and functions (Holling, 1996).

2.3.2 Definition of Resilience

Based on these two foundations, resilience has been used in a variety of disciplines. Different definitions of resilience often hinge on whether it is viewed as a process or an outcome, using key terms like ability and capacity. For instance, resilience as an ability or capability refers to the means to perform actions (Sheffi & Rice, 2005), such as communities' ability to overcome earthquakes through knowledge sharing and redundancy (Bruneau et al., 2003). In ecological systems, ability refers to withstanding shocks during predation (Perrings, 2006), while in socio-ecological systems, it involves nullifying disruptions while maintaining overall goals (Cumming et al., 2005). In organizations, resilience as an ability is seen as a capability (Bhamra et al., 2011).

When defining resilience as a capacity, meaning the means to receive or contain, it generally applies to outcomes within a group. For example, in societies, capacity enhances absorption and recovery or stability against change (Luthans, 2002). This variation shows that even within the same focus, the notion of resilience can differ among authors.

A key motivator for resilience arises from hazards, interruptions, changes, and risks, in simple words, "disruptions." Systems requiring resilience are inherently vulnerable to both anticipated and unforeseen disruptions. Although resilience is a widely recognized term, its meaning varies significantly across different perspectives, as illustrated in Table 2.3 (Bhamra et al., 2011).

There is a broad body of knowledge on organizational resilience (Bhamra et al., 2011; Hollnagel, 2010; Linnenluecke, 2017; Naderpajouh et al., 2020; Thomé et al., 2016); however, little is known about project resilience, and there is no consensus on project resilience theoretical definition. It might be claimed that the same concept of organizational resilience can be applied to projects since projects are a kind of organization. This claim is partially valid because a project is defined as a temporary organization (Sydow & Braun, 2018); however, resilience in an organization is enabled by the long-term established relationship and challenged by the short-term transactional relationship. Relationships in a project are generally transactional (Blay, 2017). Therefore, clear conceptualization and definition of resilience in a project are needed.

Table 2.3 Definition of resilience

Field of Study	*Definition*	*References*
Organizational	"Resilience conveys the properties of being able to adapt to the requirements of the environment and being able to manage the environmental variability"	(McDonald, 2012)
Engineering	"The ability of systems to anticipate and adapt to the potential for surprise and failure"	(Hollnagel et al., 2006)
Economics	"Inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses."	(Rose, 2007; Rose & Liao, 2005)
Psychology	"The developable capacity to rebound or bounce back from adversity, conflict, and failure or even positive events, progress, and increased responsibility"	(Luthans et al., 2006)
Disaster Management	"The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities to minimize social disruption and mitigate the effects of future earthquakes"	(Bruneau et al., 2003; Cimellaro et al., 2010; Marasco et al., 2022)
Supply Chain	"The ability to proactively plan and design the Supply Chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favorable than the one prior to the event, thus gaining competitive advantage"	(Ponis & Koronis, 2012)
Infrastructure Systems	"The ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels"	(Kozine et al., 2018; Vugrin et al., 2010)
Social-Ecological Systems	"The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedback"	(Walker et al., 2004)

To the best of the authors' knowledge, few studies on project (as temporary organization) resilience exist. The scarcity of research studies on project resilience strongly indicates the concept's novelty. Geambasu (2011) introduces project resilience as "the project's capacity to maintain positive adjustments when confronted with critical events inherent in its lifecycle". She claimed that project resilience should be seen from an ecological perspective rather than engineering resilience (Geambasu, 2011). Schroeder & Hatton (2012) interpret it as "the capacity of a project to evolve successfully in the face of unexpected threats or risks". Similarly, Hillson (2014) explains project resilience as "the capacity to maintain core purpose and integrity in the face of external or internal shock and change" and rephrases it as the "bounce-back-ability" of a project. In a like manner, Giezen et al. (2015) express it as "the ability of the decision-making process to deal with unexpected and the ability to entertain flexibility and preparedness to cope with uncertainty". Resilience in complex construction projects has been defined as "the ability of project systems to cope with uncertainty" (Zhu, 2016). Finally, Blay (2017) provides a comprehensive definition as "the capability of a project to prepare for, respond to, and reduce the impact of disruption caused by the drifting environment and project complexity" and proposes recovery from a disruptive event as the consequence of project resilience.

After reviewing the studies mentioned earlier (Kamali et al., 2022), it can be concluded that although what is known from project resilience is largely based on organizational resilience, those scholars distinguish between these two concepts. While organizational resilience, built upon the organization’s permanent feature, follows the engineering resilience definition and focuses on reducing vulnerability, project resilience follows the ecological perspective and focuses on recovery (Blay, 2017). Moreover, they agree that project resilience is the ability/capability of the project to provide recovery. However, there is a disagreement about the type of event (shock, disruption, uncertainties, change, ...) that resilience is attempting to handle in a project. This disagreement and the novelty and vagueness of the project resilience concept indicate that researchers should debate this concept more. (Naderpajouh et al., 2020; Thomé et al., 2016; Zhu & Mostafavi, 2017b).

Resilience is often described as an "ability" that involves multiple stages, including resisting, recovering from disruptions to resume normalcy, and eventually adapting to the disruptive event. Recovery is seen to be the most important stage for preserving resilience in the face of disruptions (Hosseini et al., 2016).

2.3.3 Features of Resilience

Resilience varies in its conceptual elements depending on the research context. A substantial body of research has dedicated on resilience in infrastructure facing threats or recovering from natural hazards and emergencies. The Multidisciplinary and National Center for Earthquake Engineering Research (MCEER) has built a resilience framework known as the "4R" dimensions: robustness, redundancy, resourcefulness, and rapidity. This framework is used to express the seismic resilience of communities and the performance measures of critical community functions (Bruneau et al., 2003; Fei Han, 2021)

Resilience is incorporated into building design theories. According to Hassler and Kohler (2014), factors such as oversizing building components, creating redundant spaces, and ensuring reparability can improve the resilience of buildings for unknown future uses and adaptations (Hassler & Kohler, 2014). A seismic design rating system has been introduced to prioritizes "life safety" and allows for easily repairable damage to building elements, thereby achieving "overdesign" seismic resilience (Almufti & Willford, 2014).

Engineering systems' resilience concentrates on a system's ordinary functioning, capacity to withstand disruptions, and ability to recover. Maintaining and regaining normal function after disruptions has been emphasized (Hollnagel et al., 2006). Six best practices have been identified to enhance industrial process resilience: minimizing failure, limiting effects, implementing administrative controls/procedures, ensuring flexibility, maintaining controllability, and enabling early detection (Dinh et al., 2012). Supply chain resilience emphasizes maintaining stable operations through anticipation, resistance, and recovery/response (Barroso et al., 2011).

Organizational resilience focuses on the ability of organizations to answer rapidly changing business environments. Organizational responses to disruptive events have been simulated through significant levels, including detection, activation, response, adjustment, and organizational learning (Burnard & Bhamra, 2011).

Common features of resilience across various domains include resistance, recovery, adaptation, and redundancy (Table 2.4). Theorizing these features provides a clearer understanding of the context-specific measures necessary for evaluating and enhancing resilience.

Table 2.4 Features of resilience

	(Bruneau et al., 2003)	(McDonald, 2012)	(Hollnagel, 2014)	(Burnard & Bhamra, 2011)	(Francis & Bekera, 2014)	(Wood & Gidado, 2008)	(Pettit et al., 2013)	(Wang, 2015)	(Madni & Jackson, 2009)
Anticipation			*				*		
Detection	*		*	*					
Robustness	*			*		*	*	*	
Adaptation		*		*	*	*			*
Absorption	*	*			*				*
Recovery	*	*	*		*	*	*	*	
Learning			*	*					

2.3.4 Resilience and Risk

Resilience theories have become intertwined with risk management, adopting a systemic approach. Some research reveals that risk and resilience concepts involve similar methodologies (Linkov et al., 2014, 2018; Park et al., 2013). These include reviewing systems for vulnerabilities, evaluating the uncertainties of potential threats, and identifying the necessary resources and actions to address these vulnerabilities and mitigate potential losses. Both theories emphasize the importance of anticipating, planning, and preparing for risky events to evaluate and mitigate the consequences of threats.

Resilience, in essence, complements traditional risk management by extending its planning and analytical approaches beyond the pre-event phase to include during and post-event scenarios. This is particularly relevant for managing a diverse array of disruptions, especially those that are unforeseeable (Linkov et al., 2014, 2018; Naderpajouh et al., 2020; Steen & Aven, 2011). The attention of resilience shifts from merely addressing the risks themselves to understanding and managing the variations in system performance caused by these risk-induced impacts. Additionally, resilience offers a holistic perspective on risks, particularly when these risks are unmeasurable, compared to traditional risk management approaches (Fei Han, 2021; Linkov & Trump, 2019).

2.3.5 Resilience and Lean

Similar to resilience, lean methodology is a systemic attitude to enhance the performance of system through implementing lean practices. Lean production theory optimizes procedures to minimize waste by decreasing variability (Shah & Ward, 2003). Opposingly, within a production environment, resilience is operationalized by emphasizing both proactive and reactive capabilities to manage unforeseen disruptions, maintain operations, and adapt to changes (Birkie et al., 2014).

The interactions between operational resilience and lean concepts have been explored in the face of disruptions (Birkie, 2016). On the one hand, both approaches can offer long-term cost savings without significantly compromising performance. Contrarily, lean approaches typically aim to reduce redundancy, whereas resilience strategies promote redundancy through measures such as over-design and resource preloading to prepare for astonishing disturbances. This focus on redundancy highlights the trade-off between resilience and efficiency (Birkie, 2016; Fei Han, 2021).

2.3.6 Resilience and Sustainability

The resilience concept and sustainability theory are strongly interconnected and dependent, particularly within social and natural systems (Holling & Walker, 2003). In the context of social-ecological systems, resilience is viewed as a crucial aspect of sustainability, essential for maintaining system integrity amid disturbances (Folke et al., 2003). For infrastructure, these concepts are considered matching characteristics because of their overlapping or sometimes conflicting definitions, dimensions, and objectives. Consequently, integrating these concepts is recommended for evaluating the service life of structures like bridges (Bocchini et al., 2014).

Moreover, some scholars argue that resilience is a fundamental component of sustainability. For example, community resilience is seen as a critical characteristic of social systems, contributing to the overall sustainability of communities in the face of disasters (Cutter et al., 2008; Klein et al., 2003).

2.4 Point of Departure

Failure is described as one of the fundamental problems in construction projects. Disruptive events that can occur during projects are among the main causes of failure (Burr & Castro, 2016; Loosemore et al., 2005). Due to the distinctive features of each construction project, they are more susceptible to disruptive events (Zou et al., 2007). Disruptive events can cause projects to deviate from their primary objectives. The longer a project is exposed to disruptive events, the lower the likelihood of success (Zhang, 2007) in achieving the project's objectives. Construction project management literature is replete with abundant research studies on how to enhance the performance of projects to avert failure. Numerous research studies have addressed this problem from different perspectives, which has led to a wide range of approaches to enhance project performance, such as risk management, opportunity management, change management, crisis management, and lean construction.

Risk and opportunity management are successful approaches when there is a low level of uncertainty in a project and the sources of disruptive events are easily identifiable and analyzable (Besner & Hobbs, 2012). It has been claimed that less risk or opportunity management is used when the uncertainty is high in a project (Besner & Hobbs, 2012). It could be because of their low productivity in a highly uncertain environment. A project's high degree of uncertainty and ambiguity makes disruption source identification difficult or even impossible (Thamhain, 2013). These proactive approaches are commonly used to deal with disruptions with known (identified) sources. Simply, they intend to protect the project from failure by preventing disruptions from happening or reducing their impact on the project. Both can be interpreted as a shock-avoiding mechanism in a project (Blay, 2017).

They pay more attention to the source of disruption rather than managing its consequences if it happens. It makes them incapable of handling disruptions with unknown (unidentified) sources. The reason is that predicting the consequences of a disruption and its impact on a project is extremely difficult because of the complexity and drifting environment of the project (Blay, 2017). However, on the other hand, identifying all threats, which are sources of disruptions, is almost impossible. Hence, more flexible approaches are required to deal with the consequences of a disruption in a project after it occurs, even if its source is unknown or unidentified at the beginning.

Change and crisis management approaches are also proactive approaches that consider disruption from unknown sources. These approaches try to predict potential disruption, but they mainly focus on managing disruptions and reducing the susceptibility of the project to the consequences of disruptions. Therefore, they are praised for being more prosperous in coping with disruptive events with unknown sources (Blay, 2017), specifically where there is a medium to a high degree of uncertainty in a project. These approaches protect the project from failure by reducing its vulnerability to disruptive events during its life cycle.

Although the conventional approaches have differences in nature, they aim to protect projects from failure by predicting all possible threats for the whole life cycle of projects during project preparation and, therefore, reducing vulnerability (Qazi et al., 2016). They intend to provide “fail-safe” projects. However, regardless of how hard project management teams work to identify all potential threats, reality shows that the likelihood of an unidentified (unexpected) threat is still high (Eden et al., 2000; Flyvbjerg, 2007; Shenhar et al., 2009; Williams, 2005) and there will always be significant unpredictability in construction projects (Cruz & Marques, 2013). Additionally, given the high degree of complexity and uncertainty in construction projects, especially in PPP projects, which makes disruptive events unpredictable, the approaches mentioned earlier are not flexible and effective enough to provide an acceptable response and ensure success in the project (Schroeder & Hatton, 2012).

It can be claimed that this common denominator (predicting all possible threats) makes these approaches insufficient for managing today's dynamic projects. Thus, a paradigm shift is needed to resilience-based approaches, which intend to provide “safe-to-fail” projects by enabling recovery during or after a disruptive event (Naderpajouh et al., 2020; Park et al., 2011). It may supply insight into responding better to disruptive events. Resilience allows for both proactive (adjustments before a disruptive event happens) and reactive (adjustments after a disruptive event happens) practices (Hollnagel, 2015; Klein et al., 2015). From the project management perspective, it adds a “thinking in action” mindset and increases the improvisation among the project management team (Klein et al., 2015).

Resilience intends to retain the project's function by absorbing, adapting to, or restoring from disruption. The absorptive function seeks to alleviate the impact of disruptive events before they arise. The adaptive function tries to adjust and transform the project to avoid failure and keep the project running during a disruption. Finally, after facing disruption, the restoring function returns the project to equilibrium (Zhu & Mostafavi, 2017b). To date, few research studies address project resilience, and there is a significant gap in knowledge pertaining to project resilience and how to guarantee project success. To the author's knowledge, this research is the first study exploring the resilience concept in PPP projects. Aven (2011) believes that the resilience concept has the potential to eliminate the need for other proactive approaches, such as risk management (Aven, 2011, 2018). However, Kamali et al. (2022) believe project resilience is still a very new and immature concept to reach that target and negate the importance or need of conventional approaches. It can currently be considered an accompaniment to other approaches for increasing project success.

CHAPTER 3

RESEARCH METHODOLOGY

The purpose of this chapter is to present and justify the research methodology adopted for this study. Utilizing the Research Onion framework (Saunders et al., 2015), the most suitable methods that align with the aim and objectives of this research study have been selected. Following McKerchar (2008), it is essential to explicitly state the theoretical tradition and methodological criteria employed, ensuring that other researchers can understand and assess the research. Accordingly, a research methodology comprising four primary stages has been adopted. The stages of this research are illustrated in Figure 3.1.

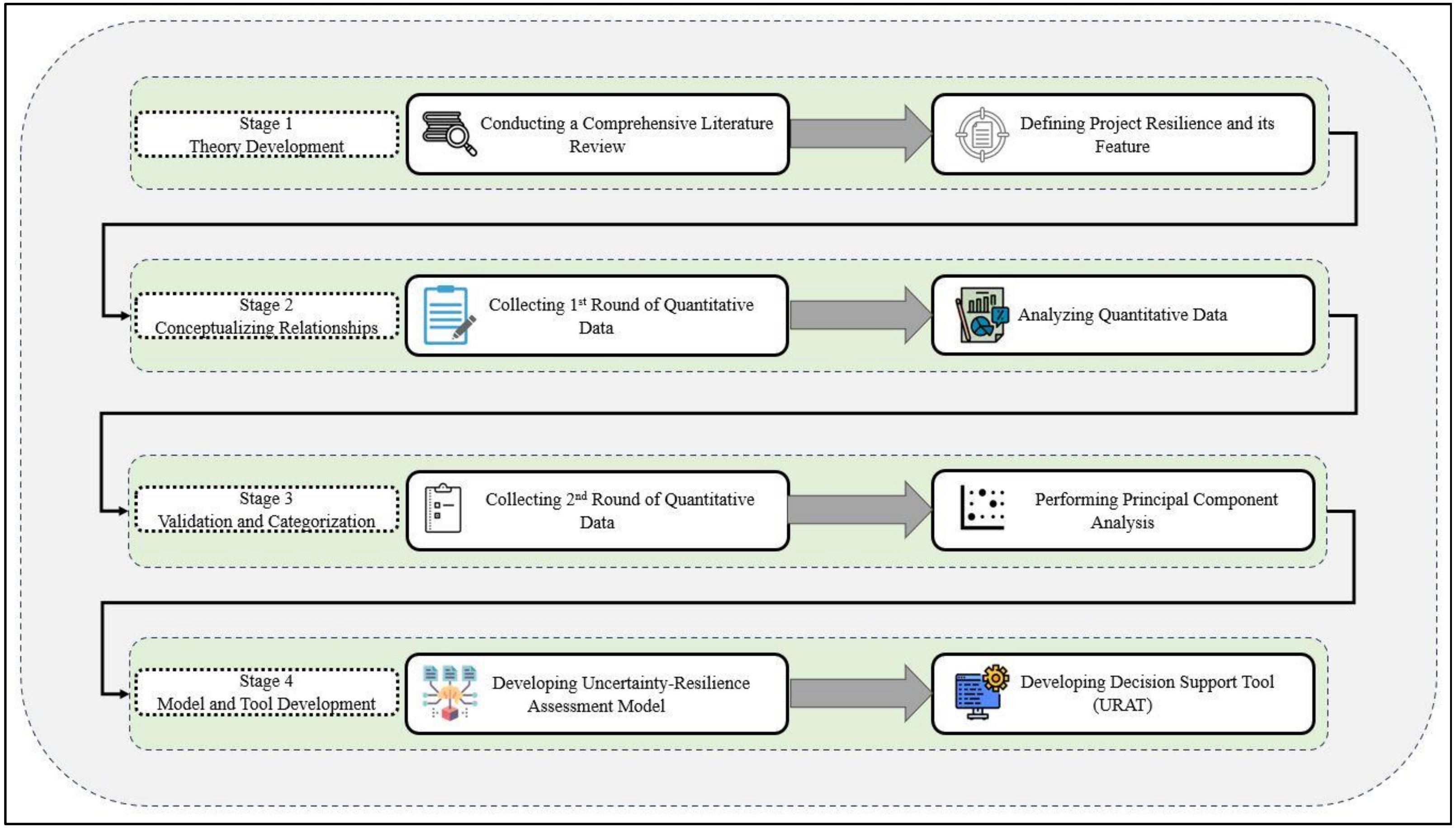


Figure 3.1 Overview of the research methodology.

- Stage 1: Given the scarce literature on resilience in project management, a theory-building methodology is employed to develop a definition of resilience specific to the field of project management.
- Stage 2: According to the mono-methods research choices, quantitative data was collected from 15 PPP projects through a questionnaire survey to conceptualize the relationship between uncertainty (as the main source of disruption), resilience, and performance of PPP projects.
- Stage 3: Similar to the previous stage, another set of quantitative data was collected through a questionnaire survey in order to validate the identified resilience factors and categorize them into four dimensions of resilience using an Explanatory Factor Analysis (EFA).
- Stage 4: In the last stage, considering the data collected during the first and second rounds of quantitative data collection and the result of PCA, an uncertainty–resilience assessment model is developed. This model serves as a foundational framework to design a decision support tool in order to help the project executer to evaluate the score of uncertainty and resilience in a PPP project and take the necessary action, ensuring that the project can withstand potential disruption effectively.

3.1 Theory Development

As aforementioned earlier, despite an increasing body of research on resilience, studies specifically addressing project resilience remain limited. This scarcity has led to a lack of consensus on its definitions and dimensions, even though scholars generally share an understanding of the concept. Given that previously established definitions will not be utilized in this research exactly, it becomes imperative to clearly articulate the concept of project resilience. This detailed definition is essential to delineate the fundamental attributes and nuances of the term, ensuring clarity and precision in its application within the context of our study. By doing so, we aim to establish a solid foundation for our analysis and facilitate a comprehensive understanding of "project resilience" that aligns with this research's specific objectives and scope.

Therefore, a theory-building methodology is employed after conducting a comprehensive literature review to understand the concept of resilience, its definition, and its features across different fields of study. This approach involves drawing conclusions by establishing and refining definitions, domains, relationships, and predictions (Burnard & Bhamra, 2011; Lynham, 2002). The aim is to provide a precise definition of project resilience that accurately describes its features within the context of a project, which will be discussed in the next chapter. Through this method, a comprehensive definition of resilience specific to the field of project management is formulated, ensuring clarity and applicability not only for the remainder of this study but also for future research and practices in the field of project management.

3.2 Conceptualizing Relationships

After defining resilience in a project and describing its features, it was essential to understand the relationship between resilience, uncertainty (as the primary source of disruption), and the performance of PPP projects. To achieve this, quantitative data was collected from 15 different PPP projects executed in Turkey. This stage involved a detailed analysis of the data to explore how resilience influences project performance under conditions of uncertainty. The methodologies employed in this analysis will be thoroughly explained in the subsequent sections.

3.2.1 Data Collection

The initial stage of the data collection process involved identifying the uncertainty, resilience, and performance factors that were to be included in the questionnaire. Questionnaire surveys are extensively used in construction management research

(Carter & Fortune, 2004; Osei-Kyei et al., 2019). They are particularly favored for exploring sensitive and emerging issues, such as PPP (Osei-Kyei et al., 2019). The absence of an interviewer in surveys, especially web-based ones, minimizes social desirability bias, leading to more honest responses from participants (Brace, 2008; Mitchell & Jolley, 2012). Furthermore, this method allows researchers to ask numerous critical questions while maintaining a high response rate (Fowler, 2013). Consequently, the survey method was considered well-suited for this study. Subsequently, the projects forming the research sample were selected. In the final stage, an online questionnaire survey was sent to the managers of these projects. Each step of the data collection process is elaborated upon in the following three sections.

3.2.1.1 Identification of Uncertainty, Resilience, and Performance Factors

In alignment with the scale development methodologies outlined by Hinkin (1998) and drawing insights from Thietart (2014), researchers encountering a shortage of factors for evaluating a specific concept have two main strategies at their disposal. The first strategy entails enhancing and refining existing factors from the field or related disciplines. The second strategy involves creating entirely new factors tailored to the specific context under study. For this research, the decision was made to adopt both strategies. This research involved an in-depth exploration of the current literature to identify the factors related to uncertainty, resilience, and performance in PPP projects. While many studies exist on factors that evaluate the degree of uncertainty and performance in PPP projects, there is a notable lack of studies focusing on factors that evaluate the degree of resilience in project management (Blay, 2017; Geambasu, 2011; Naderpajouh et al., 2020; Thomé et al., 2016). To the best of the author's knowledge, there are no studies on this topic specifically concerning PPP projects. Therefore, uncertainty and performance factors have been identified and listed in Table 3.1 and Table 3.2 directly from the available literature. It is worth noting that identifying performance indicators for PPPs is challenging due to the diverse objectives of the parties involved. The public sector typically aims for social welfare, public service quality, and accessibility, while the private sector focuses on profitability, efficiency, and return on investment. These partnerships often involve complex structures with multiple stakeholders, making it difficult to balance their varying interests. Additionally, PPPs usually span long periods, complicating the prediction and measurement of long-term outcomes. A comprehensive framework that considers these diverse objectives is needed to identify the performance factors in PPP projects. It employs robust data collection and analysis, which is beyond the scope of this study. Therefore, very simple factors that share a common understanding of performance in PPP projects are only selected from the literature. Regarding the resilience factors, after developing the resilience framework in the previous stage, available studies in the field of PPP projects were deeply reviewed to identify factors that could satisfy any of the four dimensions of the resilience framework, which was developed in line with the objective of this study.

To evaluate the alignment of the factors in the draft list with real-world project management practices and the experiences of practitioners, a brainstorming session was convened with three seasoned experts. These experts have been involved in various PPP projects in Türkiye. Among them is a project manager boasting over a decade of experience in PPP projects and two planning engineers, each with more than five years of active involvement in PPP projects. The study's objective was meticulously explained to the experts, and the draft list was presented for their input to finalize the uncertainty, resilience, and performance factors. During the intensive two-hour brainstorming session, factors pertinent to PPP projects were identified and refined. A critical component of this session was the determination of the resilience factors to be employed in the study, which are listed in Table 3.3. Conversely, the experts reached a strong consensus on the relevance of the uncertainty and performance factors outlined in the preliminary list after a few minor revisions.

Table 3.1 Uncertainty factors in PPP projects

Code	*Category*	*Uncertainty Factor*	*Description*	*References*
GU01	Governmental	Political System Instability	Government policies on infrastructure PPPs are inconsistent and unstable	(Babatunde et al., 2019; Bing et al., 2005; Jin & Zuo, 2011; Olusola Babatunde et al., 2012)
GU02	Governmental	Legislative System Instability	Laws and regulations associated with PPPs are incomplete and unstable	(Bing et al., 2005; Jin & Zuo, 2011)
GU03	Governmental	Government Approval Process Complexity	The government is inclined to follow complex procedures and inflexible rules	(Babatunde et al., 2019; Bing et al., 2005; Jin & Zuo, 2011; Olusola Babatunde et al., 2012)
SU01	Social	Community Support	An associated community doesn't endorse developing this project	(Bing et al., 2005; Chan et al., 2011; Jin & Zuo, 2011)
EU01	Economic	Regional Economy Instability	The regional economy is unstable	(Bing et al., 2005; Jin & Zuo, 2011)
EU02	Economic	Financial Market Unreliability	Reliable financing instruments are unavailable in the market	(Babatunde et al., 2019; Bing et al., 2005; Jin & Zuo, 2011; Olusola Babatunde et al., 2012)

Table 3.1 (continued). Uncertainty factors in PPP projects

Code	*Category*	*Uncertainty Factor*	*Description*	*References*
PU01	Project Specific	Unclarity of Performance Requirement	Facility performance requirements aren't clearly provided	(Jin & Zuo, 2011)
PU02	Project Specific	Design Complexity	The design of the project is complex	(Jin & Zuo, 2011)
PU03	Project Specific	Construction Complexity	Construction of the project is complex	(Jin & Zuo, 2011)
PU04	Project Specific	Operation / Maintenance Complexity	Operation and/or maintenance of the project is complex	(Chan et al., 2011; Jin & Zuo, 2011)
PU05	Project Specific	Unreliability of Reference Data	Reference data are unreliable and inaccurate	(Jin & Zuo, 2011)

Table 3.2 Performance factors in PPP projects

Code	*Description*	*References*
PF01	The innovative ideas were developed during the project	(Osei-Kyei et al., 2017; Osei-Kyei & Chan, 2017b)
PF02	Conflicts and differences of opinion have been solved adequately during the project	(Liu et al., 2015)
PF03	The solutions that have been developed really deal with the problems faced during the project.	(Osei-Kyei et al., 2017; Osei-Kyei & Chan, 2017b)
PF04	Developed solutions are durable for the future	(Xu et al., 2022)
PF05	Stakeholders are willing to work with each other in the future	(Wu et al., 2018; Xu et al., 2022; Yuan et al., 2012)

Table 3.2 (continued). Performance factors in PPP projects

Code	*Description*	*References*
PF06	The overall benefits of the project exceed its costs	(Liu et al., 2015; Xu et al., 2022; Yuan et al., 2012)
PF07	Actual schedule in comparison to planned schedule	(Liu et al., 2015; Xu et al., 2022; Yuan et al., 2012
PF08	Actual cost in comparison with the budgeted cost	(Liu et al., 2015; Xu et al., 2022; Yuan et al., 2012

Table 3.3 Resilience factors in PPP projects

Code	*Resilience Factor*	*References*
RF01	Favorable legal frameworks for dispute resolution and settlement	(Brass & Sowell, 2020; Hilu & Hiyassat, 2023; Jiang et al., 2022; Jin & Zuo, 2011; Li & Wang, 2018; Mazher et al., 2022)
RF02	Appropriate contingency planning	(Baccarini & Love, 2013; Carbonara et al., 2015; Hilu & Hiyassat, 2023; Jiang et al., 2022; Pellegrino et al., 2011)
RF03	Continuous progress monitoring of the project	(Cantarelli et al., 2012; Grau et al., 2017; Hilu & Hiyassat, 2023)
RF04	Application of virtual design and construction (VDC), such as BIM	(Ghorbany et al., 2023; Han & Bogus, 2020; Xu et al., 2022; Zhu & Mostafavi, 2017a; Zou et al., 2016)
RF05	Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	(Guo et al., 2017; Han & Bogus, 2020)

Table 3.3 (continued). Resilience factors in PPP projects

Code	*Resilience Factor*	*References*
RF06	Early detection of regulatory and technical constraints	(Tran & Molenaar, 2014)
RF07	Public / community support	(Corral & Monagas, 2017; Valdes-Vasquez & Klotz, 2013)
RF08	The risk management maturity of project and project stakeholders	(Hilu & Hiyassat, 2023; Jin, 2009; Kavishe & Chileshe, 2018; Ke et al., 2012; Mazher et al., 2022)
RF09	Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	(Carbonara et al., 2014, 2015; Zou et al., 2008)
RF10	Establishing a central coordinating PPP authority in public agencies	(Jiang et al., 2022; Li & Wang, 2018; Mostaan et al., 2017)
RF11	Effective price adjustment (escalation) and compensation mechanism	(Carbonara et al., 2015; Chan et al., 2015)

Table 3.3 (continued). Resilience factors in PPP projects

Code	*Resilience Factor*	*References*
RF12	Quick and flexible renegotiation mechanism	(Akintoye et al., 2003; Chan & Levitt, 2011; Domingues & Zlatkovic, 2015; Fischer et al., 2010; Yeo & Tiong, 2000; Zheng et al., 2008)
RF13	Effective and transparent information sharing and collaboration between stakeholders	(Hilu & Hiyassat, 2023; Ward, 2020; Zhu & Mostafavi, 2017a)
RF14	Explicit risk sharing/allocation in the contract	(Akintoye et al., 2003; Cruz & Marques, 2013; Lee & Schaufelberger, 2014; Marques & Berg, 2010)
RF15	A flexible and collaboration-supportive contract	(Cruz & Marques, 2013; Demirel et al., 2017; Jin & Zuo, 2011; Lee & Schaufelberger, 2014; Pellegrino et al., 2011)
RF16	Proper resource management and an abundance of resources in the project	(Hilu & Hiyassat, 2023)

3.2.1.2 Sampling Strategy

The sampling strategy for this study was influenced by the work of Cicmil et al. (2006), who emphasized the importance of praxis-based theory building through "project actuality research." This approach draws on practitioners' practical experiences to reflect projects' empirical realities accurately. Consequently, this study focused on managers of PPP projects in the Republic of Türkiye.

Official documents published by The Turkish Presidency of Strategy and Budget were meticulously examined, leading to the compilation of 20 potential projects. Following this, companies associated with these projects were reached out to, and finally, 15 PPP projects were selected for in-depth analysis. In adherence to confidentiality agreements, the projects scrutinized in this study are represented by their assigned ID numbers. Detailed descriptions of these projects are provided in Table 3.4.

Table 3.4 List of investigated PPP projects

ID	*Type*	*Contract Type*	*Status*
P1	Hospitals	BLT	Operation
P2	Hospitals	BLT	Operation
P3	Hospitals	BLT	Operation
P4	Hospitals	BLT	Operation
P5	Hospitals	BLT	Construction
P6	Hospitals	BLT	Construction
P7	Hospitals	BLT	Construction
P8	Hospitals	BLT	Construction
P9	Hospitals	BLT	Construction
P10	Hospitals	BLT	Construction
P11	Motorways	BOT	Construction
P12	Motorways	BOT	Construction
P13	Motorways	BOT	Operation
P14	Motorways	BOT	Operation
P15	Airport	BOT	Operation

In addition to project selection, criteria for participant selection were also established. Firstly, participants needed to have substantial experience in managing PPP projects. Secondly, they were required to have been involved in managing the selected projects. As a result, 15 managers who met these criteria were chosen to contribute data about these projects. The sample size was not expanded, as the goal of this study was not to make statistical inferences. The participant profile is detailed in Table 3.5.

All participants held senior management roles in the selected projects, including general coordinator, project manager, and technical office manager positions. They were targeted because they deal with disruptions during the project's life cycle (Thamhain, 2013). On average, they have 16 years of experience in the construction industry and mostly describe themselves as proficient or experts in PPP projects.

Table 3.5 Respondents profile

Profile	*Category*	*Distribution*
Gender	Male	11
	Female	4
Education	BSc	9
	MSc	4
	PhD	2
Years of Experience	Less than 10 years	4
	10-20 years	5
	More than 20 years	6
Experience in PPP Project	Novice	0
	Advanced Beginner	3
	Competent	4
	Proficient	3
	Expert	5

3.2.1.3 Questionnaire Survey Design

The survey questionnaire was drafted in English and comprised six pages. The first page serves as an introduction, presenting the objective of the survey questionnaire to the respondent. The second page is designed to collect detailed information about the respondents, including gender, education status, years of experience in the construction industry, and level of expertise in the field of PPP projects.

Starting from the third page, the respondents were asked to reflect on a PPP project they had been involved in and answer subsequent questions accordingly. The third page is designed to gather information about the project, such as project type, current status, and type of contract. On the fourth page, respondents were asked to rate the estimated level of the uncertainty factors, identified in Section 3.2.1.1, and its contribution to the project’s overall level of uncertainty using a 5-point Likert scale. At the end of this page, respondents were also asked to add any other source of uncertainty (if any) and rate their presence and impact to identify potential sources of uncertainty that may have been overlooked during the literature review.

Similarly, on the fifth page, respondents were asked to rate the estimated level of the resilience factors, listed in Section 3.2.1.1, and its contribution to the project’s overall level of resilience using a 5-point Likert scale. Finally, respondents were asked to rate the project's performance factors on the last page using a 5 Likert scale.

3.2.2 Data Analysis

As the preliminary step in the data analysis, data gathered from questionnaire surveys on 15 PPP projects in Turkey were consolidated into a single database. This dataset included the magnitude and relative importance scores for 11 uncertainty and 16 resilience factors, besides eight performance indicators, to evaluate the performance of the target projects. Using this data, numerical analyses were conducted to determine the individual score for each uncertainty and resilience factor and their overall score for each project. As a result, the score for uncertainty and resilience factors was determined using equation 3.1.

$$S_{ij} = M_{ij} \times \left(\frac{R_{ij}}{\sum_{i=1}^{t} R_{ij}} \right) \qquad (3.1)$$

where S_{ij} is the score of factor i at project j; M_{ij} is the magnitude of factor i at project j; R_{ij} is the relative importance of factor i at project j; and t is the total number of factors, which is 11 for uncertainty and 16 for resilience.

Next, the overall uncertainty and resilience score was calculated by aggregating each factor's individual uncertainty and resilience scores, as illustrated in equation 3.2.

$$S_k = \sum_{i=1}^{t} S_{ij} \qquad (3.2)$$

where S_k is either the overall uncertainty or resilience score for project k.

Then, the overall performance score was calculated using the arithmetic mean formula. Finally, the overall scores of the aforementioned factors were analyzed to understand the relationship between uncertainty and resilience in the PPP project.

3.3 Validation and Categorization

Following the verification of the relationship between identified resilience and uncertainty factors and their consequences on the performance of PPP projects in the previous stage, it became crucial to validate the significance of these resilience factors and categorize them into the four key features of resilience. To achieve this objective, quantitative data was gathered from experts in both academia and industry through a structured questionnaire survey.

Participants were asked to evaluate the importance of the identified resilience factors in relation to the four specified resilience features using a 5-point Likert scale. This scale ranged from "Not Important" to "Very Important," allowing for a nuanced assessment of each factor's relevance and significance. The feedback obtained from this survey provided critical insights into which resilience factors are deemed most vital by professionals and scholars, thereby aiding in the accurate categorization and understanding of resilience within the context of PPP projects. This stage involved a detailed data analysis to categorize the identified resilience factors into four features.

Since the survey results consist of discrete and ordinal Likert-point data that do not meet the multivariate normality assumption necessary for standard EFA, PCA is utilized (Fabrigar et al., 1999). PCA, as a non-parametric and multivariate statistical method, is commonly used in survey data analysis because it effectively models underlying and simplified constructs from a larger set of variables (Jolliffe, 2011). These underlying constructs (Principal Components (PCs)) found within subsets of interrelated variables suggest that these variables may be measuring aspects of the same fundamental dimensions. For instance, Zhang (2006) applied PCA to identify key indicators for optimizing value objectives and assessing concessionaire financial capability in PPP project development. Rahi (2019) applied PCA to identify the indicators that assess the resilience of IT projects. Osei-Kyei et al. (2019) employed PCA to identify the conflict prevention measures for PPP projects in developing countries. The methodologies employed in this analysis will be thoroughly explained in the subsequent sections.

3.3.1 Data Collection

Similar to the previous stage, a questionnaire survey was also deemed appropriate for this stage to obtain the field data (Dithebe et al., 2019; Li et al., 2019; Osei-Kyei et al., 2019; Osei-Kyei, Chan et al., 2019). Consequently, the potential respondents from academia and industry were selected first for the research sample. An online questionnaire survey was then distributed to them. The details of each step in the data collection process are elaborated upon in the following two sections.

3.3.1.1 Sampling Strategy

Since PPPs are still evolving in Türkiye, as in many other developing countries, accurately determining a research population for PPP studies is challenging. Therefore, a purposive sampling method with predefined criteria is often deemed the most effective approach to identifying potential respondents (Osei-Kyei et al., 2019). In this context, respondents were selected based on two criteria. First, they should possess knowledge of PPP practices and closely follow PPP developments in Türkiye. Second, they must have substantial direct hands-on experience or research experience in PPP within Türkiye. Experts from academia and industry interested in PPP projects in Türkiye or those who have published in academic journals, conference proceedings, and books on Türkiye's PPP practices and implementation were included.

According to Hair et al. (2019), a general guideline for sample size is to have at least five times as many observations as there are resilience factors to be analyzed. In this study, the survey sample maintains a ratio of 12:1 for observations to variables, surpassing this recommended threshold. To further validate the adequacy of the survey sample size, the Kaiser-Meyer-Olkin (KMO) and Bartlett’s tests were conducted. The participant profile is detailed in Table 3.6.

Table 3.6 Respondents profile

Profile	*Category*	*Distribution*
Gender	Male	146
	Female	54
Education	BSc	86
	MSc	79
	PhD	35
Years of Experience	Less than 10 years	46
	10-20 years	86
	More than 20 years	68
Experience in PPP Project	Novice	10
	Advanced Beginner	24
	Competent	41
	Proficient	73
	Expert	18

3.3.1.2 Questionnaire Survey Design

The survey questionnaire was drafted in English and comprised six pages. The first page serves as an introduction, presenting the objective of the survey questionnaire to the respondent. The second page collects detailed information about the respondents, including gender, education status, years of experience in the construction industry or academia, and level of expertise in PPP projects.

Beginning on the third page, participants were asked to evaluate the significance of the identified resilience factors in relation to the four specified resilience features using a 5-point Likert scale. Each of the four features was assessed on a separate page. The scale ranged from "Not Important" to "Very Important," enabling a nuanced assessment of each factor's relevance and significance.

3.3.2 Data Analysis

EFA using PCA is recommended by Hinkin (1998). EFA is particularly advised when the factor structure is unclear, as it helps reduce the number of observed variables. This reduction leads to a more concise representation of the original data, thereby providing evidence of construct validity (Hinkin, 1998) . Additionally, PCA ensures the one-dimensionality of items by grouping related and reliable variables into distinct components. Hair et al. (2019) explain that one-dimensionality means items are closely related and represent a single concept. PCA is essential for empirically assessing the dimensionality of a set of items, determining both the number of factors and the loading of each variable on these factors (Hair et al., 2019).

The fundamental dimensions derived from subsets of variables can be viewed as linear combinations of PCs, which maximize variance (loadings) and provide greater explanatory power for their dependent variables, such as resilience features. The objective function of PCA identifies these PCs by computing the eigenvalues (loadings) and eigenvectors associated with the correlation matrix of observed variables. The calculation of PCA is briefly explained below; for a more comprehensive explanation, refer to the works of Hair et al. (2019) and Jolliffe (2011).

PCA aims to find the directions of greatest variance in the linear combinations of $\boldsymbol{x}$ if $\boldsymbol{x}$ is a matrix of random vectors of dimension p with a finite $p \times p$ variance-covariance matrix $\mathbb{Z}[\boldsymbol{x}] = \Sigma$. Specifically, PCA seeks an orthonormal set of coefficient vectors $\vec{a}_1, \ \ldots, \vec{a}_k$ such that,

$$\vec{a}_1 = \arg\max_{\mathrm{a}:||\mathrm{a}||=1} \mathbb{Z}[\mathrm{a}'\mathbf{x}]$$

$$\vdots \qquad (3.3)$$

$$\vec{a}_k = \arg\max_{\substack{a:||a||=1 \\ a \perp a_k,\ldots,a_{k-1}}} \mathbb{Z}[a'\mathbf{x}]$$

The maxima of these functions exist because they are convex functions on a compact se. They are unique if there are no perfect collinearities in the data, up to a change in the sign of all elements of a_k. The linear combination $a_k'\boldsymbol{x}$ is referred to as the $k-th$ PC.

The motivation behind this is the directions of greatest variability provide the most information about the configuration of the data in multidimensional space. The first PC has the greatest variance and extracts the largest amount of information from the data. The second component is orthogonal to the first and has the greatest variance in the subspace orthogonal to the first component, thus extracting the greatest information in that subspace. This process continues for subsequent components. Additionally, PCs minimize the L_2 norm (sum of squared deviations) of the residuals from the projection onto linear subspaces of increasing dimensions. The first PC defines a line such that the data projections onto this line have the smallest sum of squared deviations among all possible lines. The first two PCs define a plane that minimizes the sum of squared deviations of residuals.

PCA was originally developed for analyzing multivariate normal distributions and their samples, so it works best with continuous and roughly normally distributed variables. If the original variables have vastly different scales, PCA will disproportionately favor the variable with the highest variance, skewing the results. To avoid this issue, standardized data should be analyzed where each variable has a mean of zero and a variance of one. This standardization ensures PCA examines dependencies among variables rather than scale differences, effectively analyzing the correlation matrix of the data.

To solve equation 3.3, PCA solves the eigenvalue problem for the covariance (or correlation) matrix Σ finding λ's and $\vec{a}'$s (with an identification condition $||\vec{a}_k|| = 1$) such that

$$\Sigma \vec{\mathrm{a}} = \lambda\vec{a} \quad (3.4)$$

The solution provides the set of PC weights $\vec{a}$ (factor loadings), the linear combinations $\vec{\mathrm{a}}'\mathrm{x}$ (scores), and the eigenvalues $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p$). For standardized data, where $\mathbb{Z}[x_j] = 1$, the eigenvalues represent the variances of the corresponding linear combinations. The linear combination with the largest eigenvalue has the greatest variance.

A popular measure of fit for PCs is the proportion of explained variance which calculates using the following formulas,

For an individual PC,

$$\mathrm{R}_k{}^{ind} = \frac{\lambda_1}{\lambda_1 + \lambda_2 + \cdots + \lambda_p} \quad (3.5)$$

For cumulative PCs,

$$\mathrm{R}_k{}^{cum} = \frac{\lambda_1 + \lambda_2 + \cdots + \lambda_k}{\lambda_1 + \lambda_2 + \cdots + \lambda_p} \quad (3.6)$$

High proportions of explained variance by the first few components indicate that the input variables share much in common. These proportions help determine the number of significant components.

PCA can be extended to ordinal data using techniques from econometrics, like those used in discrete dependent variable models (logit/probit). In a factor analysis model, the relationship between an unobserved continuous variable ξ and observed indicators can be expressed as:

$$x_k = \Lambda_k\xi + \delta_k \ (k = 1, 2, \dots, p) \quad (3.7)$$

where δ_k are the measurement errors. The most common way to analyze discretization effects is to assume that there are underlying continuous variables $x_k{}^*$ that have a pre-specified relation to the underlying latent variable ξ, as in the CFA model:

$$x^{*} = \Lambda_x \xi + \delta, \mathbb{Z}[\delta] = \Theta_\delta = diag[\delta_1, \delta_2, \dots, \delta_K], \mathbb{Z}[\xi] = \phi \quad (3.8)$$

If the observed x_k's are ordinal with the categories $1, \ \dots, \ K_k$, it is assumed that they are obtained by discretizing the underlying ${x_k}^*$ according to a set of thresholds $, \alpha_{k1}, \dots, \alpha_{k,K_k-1},$

$$x_k = r \text{ if } \alpha_{k,r-1} < {x_k}^* < \alpha_{k,r} \quad (3.9)$$

where $\alpha_{k,0} = -\infty$ and $\alpha_{k,K_k} = +\infty$. Thus, the x's are dependent variables, and if the ξ's were observed, ordered dependent variable models should be used to analyze the relationships between ξ and x.

The goal of rotating PCs is to reveal the dependence structure among several variables by expressing them as a small number of unobservable latent variables, called factors. The purpose of rotating the factor loading matrix is to make interpretation easier by associating each factor with a small subset of observed variables. Ideally, the columns of the rotated loading matrix should show high values for several variables and low values for the rest, with most elements being either close to zero or far from zero, and as few as possible having intermediate values.

This approach leads to various criteria for choosing the type of rotation to simplify the structure of loadings. Varimax, quartimax, and promax are the most commonly used orthogonal methods, while oblimax provides oblique factors by allowing the factor correlation matrix (R) to be non-orthogonal. This study uses the Varimax criterion, which is widely applied in practice due to its good interpretative results. This type of rotation can be extended to PCA to simplify the structure of the problem and facilitate interpretation.

In this study, to ensure the appropriateness of the survey data for PCA, the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity are first conducted. The KMO test was used to determine if the data had compact patterns of correlation coefficients, which would yield distinct PCs from the given set of factors, indicating that the sample size was suitable for PCA. Bartlett's test was employed to confirm the existence of correlations among the variables, ensuring that the survey data could generate meaningful clusters of variables in the subsequent PCA.

Next, a correlation matrix of the variables (factors) was constructed and used for PCA. PCs were selected based on the criterion that the cumulative variance explained by the PCs should reach up to 70%. A loading threshold of 0.4 was set to determine significant loadings in rotated PCA, as recommended by existing PCA literature to facilitate the interpretation of the PCs.

Finally, the reliability of each PCA was assessed using Cronbach's alpha test. This test ensured the internal consistency of the factors identified through PCA, thereby validating the robustness of our results. R programming language was employed for the analysis using several packages to facilitate various statistical tests. The *psych* package was used for the Kaiser-Meyer-Olkin (KMO) test to determine sample adequacy. The *factoextra* package was applied to perform PCA, aiding in extracting PCs and eigenvalues. Additionally, the *ltm* package was used to obtain Cronbach's alpha, assessing the internal consistency and reliability of the identified PCs.

3.4 Model and Tool Development

After identifying the uncertainty and resilience factors and categorizing them into the four core dimensions of resilience — preparation, absorption, recovery, and adaptation — it becomes imperative to develop a robust decision support tool to assess the levels of uncertainty and resilience in PPP projects. A decision support tool is a sophisticated tool designed to assist decision-makers by efficiently processing, analyzing, categorizing, and organizing information in a structured and easily accessible format. In essence, it leverages computer-based technology to support complex decision-making and problem-solving tasks. It consolidates data from multiple sources, streamlines its organization and analysis, and facilitates the evaluation of underlying assumptions. It plays a crucial role in identifying problems, formulating models, athering, integrating, and presenting relevant information. It aids in selecting the most effective problem-solving strategies, assessing potential solutions, and ultimately determining the best course of action. Additionally, it empowers decision-makers to interact with and manipulate data, apply checklists and heuristics, and construct and utilize mathematical models, thereby enhancing the efficiency and accuracy of the decision-making process (Bhatt & Zaveri, 2002).

Achieving this objective necessitates the application of mathematical models. The methodologies underpinning this will be comprehensively detailed in the sections that follow.

3.4.1 Uncertainty–Resilience Assessment Model

To develop a decision support tool for evaluating the levels of uncertainty and resilience in PPP projects, a conceptual model (Fig. 3.2) has been designed by synthesizing and interpreting findings of the analysis discussed in the previous stages. This proposed model serves as a holistic framework for assessing and enhancing the resilience of systems or projects operating in uncertain environments. By integrating the concepts of uncertainty and resilience, along with their effects on performance, the model offers a systematic approach to understanding how both external and internal challenges influence project outcomes and how these impacts can be mitigated using Resilience Factors (RFs).

At its core, the model identifies uncertainty as a key determinant of system performance. It classifies uncertainty into four categories – governmental, economic, social, and project-specific – each encompassing a diverse set of risks with varying origins and impacts. For example, governmental uncertainty may involve political instability, sudden regulatory changes, or the complexity of approval processes, which can lead to delays in project timelines or increased costs. Economic uncertainty includes market volatility and resource price fluctuations, which can complicate budget planning and financial forecasting. Social uncertainty arises from evolving stakeholder expectations, public opinion, or cultural dynamics, potentially affecting community support and project acceptance. Lastly, project-specific uncertainty refers to risks inherent to the project itself, such as unclear performance requirements, design and construction complexities, or unreliable site and resource data. These uncertainties create a disruptive environment that challenges the system's ability to meet its goals.

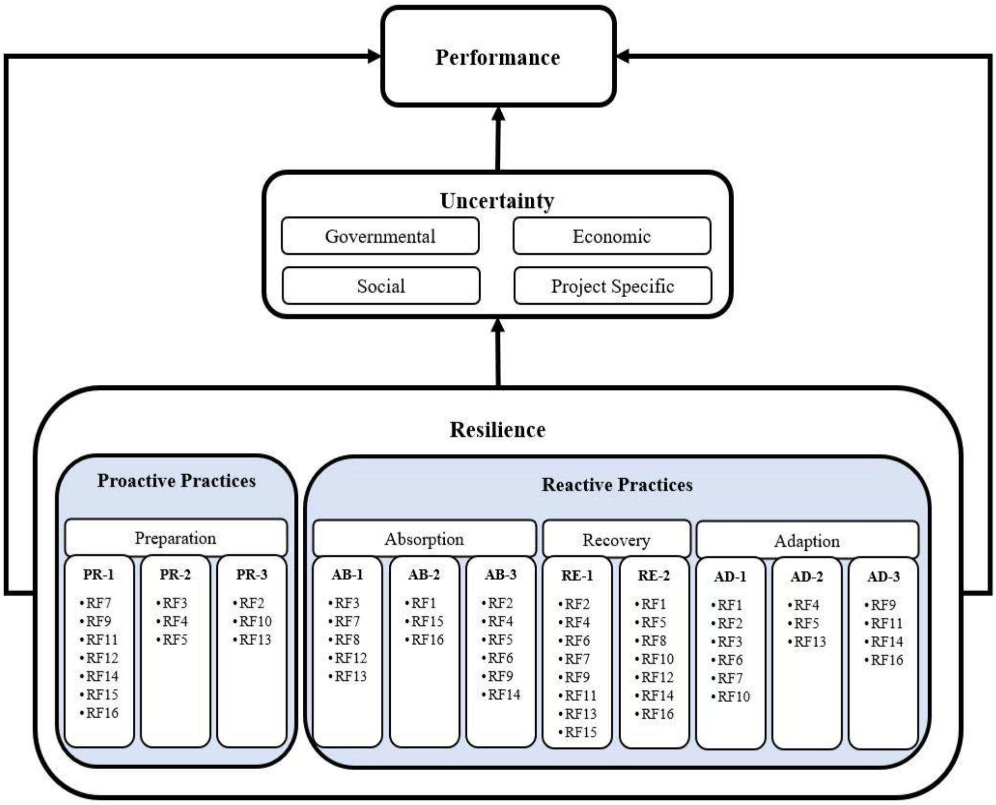


Figure 3.2. Uncertainty–resilience assessment model

To address these challenges, the model introduces resilience as a fundamental capability, defined as the system's ability to anticipate, absorb, recover, and adapt to disruptions. Resilience is categorized into two primary strategies: proactive practices and reactive practices.

Proactive practices involve preventive measures aimed at minimizing potential disruptions before they occur. These measures focus on risk identification, contingency planning, and implementing safeguards. For instance, the preparation phase includes three subcategories (PR-1, PR-2, PR-3) identified through PCA in earlier stages of this study. Specific resilience factors support these subcategories, for example, PR-1, which contributes the most to the Preparation, incorporates several resilience factors such as RF7: public-community support, RF9: adequate revenue guarantee mechanism, RF11: effective price adjustment mechanism, RF12: quick and flexible negotiation mechanism, RF14: explicit risk sharing, RF15: flexible contract, and RF16: proper resource managing plan. Proactive measures strengthen the system's robustness and reduce the likelihood of significant disruptions by addressing potential vulnerabilities in advance. It ultimately enhances the project's resilience by identifying vulnerabilities and mitigating risks well in advance, ensuring smoother operations and improved project outcomes.

Reactive practices, on the other hand, are strategies activated after disruptions have occurred. These practices aim to minimize the damage, restore functionality, and enable the system to adapt to new conditions. The reactive approach is divided into three primary components: absorption, recovery, and adaptation. The absorption phase focuses on minimizing the initial impact of the disruption, while recovery emphasizes restoring operations to normal levels as quickly as possible. Adaptation ensures that the system evolves and improves its resilience in response to the lessons learned from the disruption. Based on the results of the PCA analysis, these components are further divided into subcategories: three subcategories for absorption (AB-1, AB-2, AB-3), two for recovery (RE-1, RE-2), and three for adaptation (AD-1, AD-2, AD-3).

Absorption focuses on the system's capacity to absorb shocks without significant performance degradation. It comprises three subcategories (AB-1, AB-2, AB-3) identified through PCA. Among these, AB-1 is vital in enhancing the system's ability to absorb disturbances. It is supported by several resilience factors, including RF3: continuous progress monitoring, RF7: community support, RF8: mature risk management, RF12: flexible and fast negotiation mechanism, and RF13: effective collaboration and information sharing between stakeholders. These factors collectively strengthen the system's ability to mitigate the immediate impact of disruptions and maintain operational stability.

The recovery phase emphasizes the rapid restoration of normal operations following a disruption. This phase is divided into two subcategories (RE-1 and RE-2), with RE-1 having the most significant influence on the system's recovery. The resilience factors associated with RE-1 include RF2: contingency planning, RF4: application of virtual design, RF6: early detection of regulatory and technical constraints, RF7: public support, RF9: proper revenue guarantee mechanism, RF11: effective price adjustment mechanism, RF13: transparent information sharing between stakeholders, and RF15: a flexible contract. These resilience factors facilitate quick and effective recovery, ensuring the system can return to its normal operational state with minimal downtime and cost overruns.

The adaptation phase ensures that the system evolves and learns from disruptions, improving its resilience to future challenges. This phase consists of three subcategories (AD-1, AD-2, AD-3), with AD-1 having the most significant influence on the system's adaptability. The resilience factors associated with AD-1 include RF1: appropriate legal framework for dispute resolution, RF2: proper contingency planning, RF3: continues progress monitoring, RF6: early detection of regulatory and technical constraints, RF7: community support, and RF10: a central coordinating authority in public agency. These factors enable the system to adapt its processes, structures, and strategies, fostering a continuous improvement cycle that enhances future resilience.

The model underscores the possibility that implementing or enhancing resilience measures in a project may inadvertently lead to increased uncertainty. This relationship stems from the fact that certain resilience strategies, while effective in mitigating specific risks, can unintentionally introduce new uncertainties or intensify existing ones. Consequently, it is essential to reassess the level of uncertainty following an evaluation of resilience. This iterative approach allows for identifying and mitigating any unintended consequences resulting from resilience-focused interventions. By doing so, decision-makers can achieve an optimal balance between risk reduction and the overall stability and performance of the project.

This model offers a comprehensive framework for maintaining and enhancing project performance amidst uncertainty by implementing well-defined resilience practices. Effectively balancing proactive and reactive strategies enables decision-makers to mitigate risks while simultaneously fostering a culture of continuous learning and improvement. This iterative approach not only ensures the system's adaptability to unforeseen challenges but also supports the achievement of long-term projects or organizational objectives with more excellent stability and efficiency.

3.4.2 Uncertainty–Resilience Assessment Tool

This section outlines the development of a decision support tool for evaluating the level of uncertainty (P_{LoU}) and resilience (P_{LoR}) in PPP projects. The tool utilizes findings from earlier stages of the study and provides decision-makers with actionable insights to mitigate risks promptly.

The first step of the assessment tool is to determine the project's level of uncertainty using equation 3.10.

$$P_{LoU} = \left(\frac{\sum_{i=1}^{n} US_i}{n}\right) \qquad (3.10)$$

where P_{LoU} is the project level of uncertainty; n is the number of uncertainty groups (in this study, n=4: governmental, social, economic, and project specific); US_i is the uncertainty score of each group i, which is calculated in equation 3.11.

$$US_i = \sum_{i=1}^{t}\left(M_i \times \left(\frac{RI_i}{\sum_{i=1}^{t} RI_i}\right)\right) \qquad (3.11)$$

where US_i is the uncertainty score for group i; t is the number of uncertainty factors in each group (in this study, t = 3 for governmental, 1 for social, 2 for economic, and 5 for project-specific factors); M_i is the magnitude of factor i, which a value between

1 and 5 (very low / low / moderate / high / very high) entered by the user; RI_i is the relative importance of factor i

The relative importance (RI_i) of each factor is determined by taking the average importance scores derived from 15 PPP projects analyzed in the second round of data collection during stage two. This ensures that the weighting of each factor is informed by empirical data and reflects the typical significance of each factor across different projects.

The second step of the assessment tool involves determining the project's level of resilience for the project using equation 3.12.

$$P_{LoR} = \left(\frac{\sum_{i=1}^{n} RS_i}{n}\right) \tag{3.12}$$

where P_{LoR} is the project level of resilience; n is the number of resilience dimensions (in this study, n=4: preparation, absorption, recovery, and adaptation); RS_i is the score of resilience for each dimension i, which is calculated in equation 3.13.

$$RS_i = \sum_{i=1}^{t} (W_i \times R_i) \tag{3.13}$$

where RS_i is the resilience score for dimension i; t is the number of subcategories in each dimension i (in this study, t = 3 for preparation, absorption, adaptation and t = 2 for recovery). This value corresponds to the number of PCs identified through PCA. W_i denotes the standardized weights, representing the relative contribution of each PC's variances; Ri is the resilience level for each PC under resilience dimensions.

The standardized weight for each PC is calculated using the proportion of its variance to the total variance, as shown in equation 3.14.

$$W_i = \frac{V_i}{\sum_{i=1}^{z} V_i} \tag{3.14}$$

where W_i is the standardized weights for PC i; z is the number of PCs for each dimension of resilience (in this study, z = 3 for preparation, absorption, adaptation and z = 2 for recovery); and V_i is the variance identified through PCA.

This formula ensures that the wights are normalized and reflects the relative contribution of each PC to the total score.

The resilience level for each PC, Ri, is determined in equation 3.15.

$$R_i = \sum_{i=1}^{t}\left(M_i \times \left(\frac{RI_i}{\sum_{i=1}^{t} RI_i}\right)\right) \qquad (3.15)$$

where R_i is the resilience level for each PC i; t is the number of resilience factors in each component (in this study, for example, t = 7 for the PR-1, 6 for AB-3, and so on); M_i is the magnitude of factor i, which a value between 1 and 5 (very low / low / moderate / high / very high) entered by the user; RI_i is the relative importance of factor i

The relative importance (RI_i) of each factor is determined by averaging importance scores obtained from 15 PPP projects analyzed during the second round of data collection in stage two. This approach ensures that the weighting of each factor is informed by empirical data and accurately reflects the typical significance across different projects.

After calculating the levels of uncertainty and resilience for the targeted project, the degree of congruence is evaluated using predefined intervals: 1.00 – 2.33 (low), 2.33 – 3.67 (moderate), and 3.67 – 5.00 (high). A nested logical function systematically compares the uncertainty and resilience scores against these intervals. The congruence evaluation determines whether uncertainty and resilience align with the same interval. Based on the analysis, the formula categorizes the relationship into three outcomes: effective congruence (resilience sufficiently counteracts uncertainty) and partial congruence Moderate (balance between uncertainty and resilience) or incongruence (resilience may not be sufficient to handle uncertainty). In light of the congruence test results, tailored recommendations will be developed and presented to the user, offering actionable strategies to enhance resilience, reduce uncertainty, or both, thereby fostering improved project outcomes.

The proposed model and decision support tool were presented to distinguished experts, each bringing a unique perspective shaped by their extensive experience, in order to evaluate the validity of the model and the functionality of the decision support tool. The first was a renowned academic with over 25 years of research expertise in risk management, uncertainty analysis, and PPP projects. Their numerous publications have made significant contributions to advancing these fields. The second was a project manager with more than a decade of hands-on experience managing and implementing PPP projects in Türkiye, offering valuable insights into such ventures' practical challenges and operational complexities.

Both experts provided highly positive feedback, affirming the model’s logical structure and the tool’s practical effectiveness. They emphasized that the tool is handy for identifying and assessing uncertainty and resilience levels during the early stages of PPP projects. They noted that this capability is essential for supporting informed decision-making, enabling project stakeholders to anticipate potential disruptions, and improving project outcomes. The seamless integration of theoretical rigor and practical utility in the model and tool highlights their potential to bridge the gap between academic research and real-world project management applications.

3.5 Concluding Remarks

The research design illustrated in Figure 3.1 was executed in four distinct stages. The initial stage involved developing a definition of resilience in projects. In the second stage, considering this definition, the relationship between uncertainty, resilience and performance was studied within the PPP projects in Türkiye. The third stage consisted of studies aimed at categorizing the resilience factors identified in the second stage into the dimensions of resilience presented in the first stage. Finally, in the last stage, an uncertainty-resilience assessment tool is developed to assist project executors in PPP projects to quantitatively assess the uncertainty and resilience scores of projects, identify areas requiring improvement, and take appropriate actions to enhance project performance, ensuring that the project can withstand potential disruptive events effectively. The outcomes from each will be elaborated upon in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the key findings from the detailed analysis of the collected data and interprets their significance. It is divided into three sections, each addressing chronologically a different stage of the methodology. This chapter serves as the focal point of the dissertation, integrating data and interpretation to enhance understanding and contribute to the scholarly discourse.

4.1 Project Resilience

Since there is no consensus in the literature on a definition of project resilience and its dimensions, and the previously established definitions will not be used in this research exactly as they are, this section, in considering the first stage of the methodology, aims to define project resilience within the context of this study, which will be further utilized in the subsequent stages of this dissertation.

Project Resilience is a multifaceted concept that refers to a project's capacity to anticipate, withstand, recover from, and adapt to disruptions, ensuring sustained performance and successful outcomes. This capability is crucial in ensuring that projects survive unexpected challenges and thrive in the face of adversity. This concept can be explained through how a project deals with disruptive events to keep the desired level of performance or how quickly and effectively it can recover its performance after experiencing disruption. Figure 4.2. illustrates the changes in performance levels over time after a disruption occurs through four distinct stages: preparation, absorption, recovery, and adaptation, the most commonly accepted resilience stages in the literature (see Table 2.4.).

The first stage, preparation, involves proactive identification and assessment of potential disruptions that might affect the project. This stage is crucial as it sets the foundation for resilience by enabling project managers to anticipate challenges and develop strategies to mitigate disruptions or their impacts.

When a disruption occurs, the project enters the absorption phase. In this stage, resilience efforts are focused on withstanding and managing the immediate impacts of the disruption. The goal during absorption is to prevent performance loss (minimal differences between P1 and P2) as much as possible or slow down the performance loss (maximal differences between T2 and T3) as much as possible to provide sufficient time to take necessary recovery action to avoid failure in a project.

The project transitions into the recovery phase as the disruption's impacts are fully understood. The primary focus here is restoring performance levels to their pre-disruption state or even improving them. Rapid and effective recovery (minimal differences between T3 and T4) is essential for minimizing downtime and ensuring the project remains on track to meet its objectives.

The final stage, adaptation, is about learning from the disruption and making necessary adjustments to enhance project behavior in the face of future disruption. This stage emphasizes the importance of reflecting on the experiences and insights gained during the disruption. By integrating these lessons into the project's processes and strategies, project managers can better prepare for similar challenges in the future. Adaptation ensures that the project evolves and becomes more robust over time, capable of handling a wider range of disruptions more efficiently.

The diagram also highlights the dynamic nature of performance over time in response to disruptions. Initially, the project performed at a desired level, but the occurrence of a disruption causes a decline in performance. Performance gradually improves as the project moves through the absorption and recovery phases, eventually stabilizing or exceeding the original levels through adaptation. This performance trajectory underscores the critical role of resilience in maintaining and enhancing project outcomes despite adverse conditions.

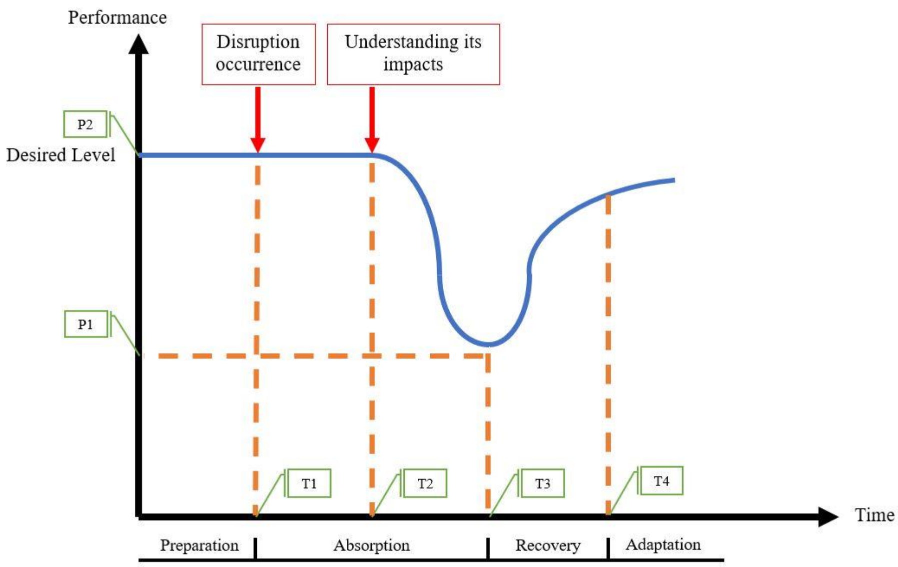


Figure 4.1. Project resilience (modified from (Nipa et al., 2023))

The diagram effectively illustrates this resilience process, highlighting the importance of each stage and overall performance dynamic over time. Emphasizing resilience not only ensures the continuity of project activities but also enhances the project's ability to achieve its long-term goals in the face of unforeseen challenges.

4.2 Relationship Between Uncertainty and Resilience in PPP Projects

This section outlines the results of the second stage of this research. It starts with presenting the quantitative findings from the questionnaire survey. These findings are then integrated to analyze the relationship between uncertainty and resilience factors and their impact on the performance of PPP projects.

4.2.1 Quantitative Findings

The quantitative findings of this study were derived using the data analysis procedure described in Section 3.2.2. The following sections present and analyze the uncertainty, resilience, and performance scores of 15 PPP projects executed in Türkiye.

4.2.1.1 Uncertainty Scores

The PPP projects examined in this study faced varying levels of uncertainty as a source of disruption. For 11 assessed factors, uncertainty scores were calculated using Equation (3.1). Subsequently, as per Equation (3.2), these individual uncertainty scores were summed to determine the total uncertainty score for each project. Figure 4.2 illustrates the intra-project and inter-project comparisons of uncertainty factors and the total uncertainty scores.

	Hospitals										Motorways				Airport
Uncertainty Factors	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
UF01	0.279	0.333	0.030	0.032	0.140	0.273	0.349	0.414	0.333	0.111	0.065	0.043	0.444	0.444	0.543
UF02	0.186	0.333	0.121	0.290	0.140	0.455	0.465	0.276	0.333	0.167	0.516	0.174	0.444	0.333	0.174
UF03	0.372	0.417	0.606	0.516	0.209	0.273	0.279	0.517	0.250	0.444	0.290	0.652	0.356	0.356	0.348
UF04	0.093	0.250	0.242	0.065	0.140	0.455	0.465	0.310	0.167	0.333	0.290	0.696	0.444	0.178	0.348
UF05	0.465	0.417	0.758	0.258	0.465	0.455	0.465	0.276	0.333	0.556	0.194	0.391	0.444	0.444	0.543
UF06	0.279	0.250	0.485	0.129	0.372	0.273	0.209	0.138	0.111	0.444	0.129	0.043	0.133	0.089	0.543
UF07	0.279	0.333	0.242	0.194	0.465	0.136	0.209	0.103	0.444	0.694	0.387	0.261	0.267	0.267	0.196
UF08	0.465	0.250	0.485	0.387	0.372	0.364	0.372	0.207	0.333	0.417	0.290	0.261	0.444	0.444	0.348
UF09	0.349	0.417	0.121	0.290	0.372	0.364	0.372	0.069	0.167	0.167	0.290	0.043	0.444	0.267	0.348
UF10	0.465	0.417	0.121	0.290	0.372	0.273	0.209	0.069	0.111	0.333	0.129	0.043	0.556	0.356	0.543
UF11	0.279	0.333	0.485	0.194	0.465	0.205	0.209	0.207	0.167	0.111	0.194	0.043	0.200	0.267	0.543
Uncertainty Score	*3.512*	*3.750*	*3.697*	*2.645*	*3.512*	*3.523*	*3.605*	*2.586*	*2.750*	*3.778*	*2.774*	*2.652*	*4.178*	*3.444*	*4.478*
Ave. Uncertainty Score	3.336										3.262				4.478
Ave. Uncertainty Score	3.392														

Figure 4.2. Results of the project uncertainty analysis

In addition to each project's separately displayed uncertainty scores, Table 4.1 presents the average uncertainty scores and average relative importance for the 11 factors across all 15 projects.

Table 4.1 Average uncertainty scores and relative importance in 15 PPP projects

Factor ID	*Avg. U*ncertainty Score	*Avg. Relative Importance*
UF01	0.256	3.334
UF02	0.294	3.467
UF03	0.392	3.934
UF04	0.298	3.400
UF05	0.431	4.400
UF06	0.242	3.067
UF07	0.299	3.200
UF08	0.363	3.734
UF09	0.272	3.267
UF10	0.286	3.334
UF11	0.260	3.267

4.2.1.2 Resilience Scores

The PPP projects examined in this study consist of varying levels of resilience. For 17 assessed factors, resilience scores were calculated using Equation (3.1). Subsequently, as per Equation (3.2), these individual resilience scores were summed up to determine the total resilience score for each project. Figure 4.3 illustrates the intra-project and inter-project comparisons of resilience factors and the total resilience scores.

	Hospitals										Motorways				Airport
Resilience Factors	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**
RF1	0.102	0.171	0.167	0.122	0.167	0.087	0.209	0.240	0.161	0.190	0.205	0.024	0.229	0.146	0.242
RF2	0.102	0.229	0.074	0.184	0.111	0.261	0.093	0.160	0.214	0.095	0.364	0.095	0.286	0.024	0.121
RF3	0.136	0.229	0.019	0.020	0.167	0.109	0.093	0.240	0.214	0.063	0.045	0.024	0.286	0.024	0.379
RF4	0.051	0.171	0.148	0.041	0.167	0.109	0.047	0.180	0.107	0.190	0.205	0.381	0.286	0.049	0.242
RF5	0.136	0.286	0.074	0.184	0.148	0.087	0.093	0.040	0.071	0.190	0.091	0.024	0.357	0.073	0.379
RF6	0.153	0.129	0.296	0.122	0.222	0.087	0.140	0.320	0.214	0.238	0.023	0.286	0.229	0.390	0.242
RF7	0.339	0.357	0.296	0.245	0.111	0.174	0.209	0.180	0.357	0.317	0.273	0.286	0.229	0.146	0.379
RF8	0.102	0.214	0.296	0.184	0.111	0.022	0.140	0.120	0.161	0.397	0.273	0.238	0.214	0.024	0.136
RF9	0.424	0.286	0.296	0.327	0.222	0.087	0.209	0.240	0.446	0.317	0.205	0.595	0.229	0.390	0.379
RF10	0.271	0.171	0.370	0.184	0.222	0.217	0.349	0.180	0.286	0.317	0.136	0.286	0.286	0.390	0.242
RF11	0.034	0.171	0.296	0.245	0.167	0.087	0.093	0.320	0.446	0.079	0.045	0.095	0.229	0.220	0.136
RF12	0.203	0.229	0.167	0.082	0.111	0.087	0.209	0.320	0.161	0.127	0.205	0.024	0.171	0.146	0.242
RF13	0.136	0.286	0.463	0.163	0.148	0.087	0.140	0.160	0.214	0.317	0.136	0.214	0.286	0.073	0.379
RF14	0.136	0.171	0.296	0.082	0.074	0.087	0.093	0.080	0.071	0.254	0.091	0.024	0.086	0.098	0.379
RF15	0.254	0.286	0.074	0.184	0.148	0.130	0.093	0.040	0.107	0.095	0.205	0.024	0.286	0.049	0.242
RF16	0.203	0.286	0.463	0.245	0.148	0.196	0.279	0.240	0.161	0.143	0.182	0.143	0.286	0.195	0.303
Resilience Score	***2.780***	***3.671***	***3.796***	***2.612***	***2.444***	***1.913***	***2.488***	***2.820***	***3.393***	***3.333***	***2.682***	***2.762***	***3.971***	***2.439***	***4.424***
Ave. Resilience Score	**2.925**										**2.964**				**4.424**
Ave. Resilience Score	**3.035**														

Figure 4.3. Results of the project resilience analysis

Apart from each project's separately displayed resilience scores, Table 4.2 presents the average resilience scores and average relative importance for the 16 factors across all 15 projects.

Table 4.2 Average resilience scores and relative importance in 15 PPP projects

Factor ID	*Avg.* Resilience Score	*Avg. Relative Importance*
RF01	0.164	3.000
RF02	0.161	3.000
RF03	0.136	2.933
RF04	0.158	3.133
RF05	0.149	2.867
RF06	0.206	3.400
RF07	0.260	3.933
RF08	0.175	3.400
RF09	0.310	4.067
RF10	0.261	4.133
RF11	0.178	3.200
RF12	0.166	3.200
RF13	0.213	3.800
RF14	0.135	2.867
RF15	0.148	2.933
RF16	0.231	3.933

4.2.1.3 Performance Scores

A mean formula is utilized to simplify the evaluation process of performance factors across all 15 projects. Initially, the mathematical mean formula is applied to calculate each project's performance score (Figure 4.4). Subsequently, this formula is used to determine the average performance scores, as illustrated in Table 4.3.

Table 4.3 Average performance scores in 15 PPP projects

Factor ID	*Avg. Performance Score*
PF1	3.11
PF2	3.47
PF3	2.63
PF4	3.53
PF5	2.63
PF6	3.00
PF7	2.63
PF8	3.37

	Hospitals										Motorways				Airport
Performance Factors	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
PF1	2	4	4	4	3	4	5	2	3	2	1	3	4	4	2
PF2	3	4	4	5	3	4	4	3	4	2	1	4	5	2	3
PF3	1	3	3	4	2	3	4	2	1	1	1	3	4	4	4
PF4	3	4	3	4	1	4	5	3	5	2	2	4	5	4	3
PF5	1	3	3	4	1	3	4	2	1	2	2	5	3	4	5
PF6	1	4	4	5	1	4	5	3	1	2	3	4	4	4	4
PF7	2	3	3	4	3	3	3	2	1	2	1	3	4	3	5
PF8	3	5	4	4	3	5	5	3	1	3	1	4	5	3	5
Performance Score	2.0	3.8	3.5	4.3	2.1	3.8	4.4	2.5	2.1	2.0	1.5	3.8	4.3	3.5	3.9
Ave. Performance Score	3.04										3.25				3.88
Ave. Performance Score	3.15														

Figure 4.4. Results of the project performance analysis

4.2.2 Interpretation of Uncertainty and Resilience Scores

To interpret the uncertainty and resilience scores calculated in the previous sections, a summary of the results is shown in Figure 4.5. The scores have been color-coded for clarity, with green indicating desirable conditions (higher scores for resilience and performance and lower scores for uncertainty) and red indicating undesirable conditions (lower scores for resilience and performance and higher scores for uncertainty). This color coding makes it easier to understand the status of each project. An analysis of these scores across 15 different PPP projects reveals significant trends and interrelationships among these factors.

The uncertainty scores for hospital projects fluctuate widely, with P4 showing a notable dip and P10 having a relatively high score. This variability in uncertainty is mirrored in the resilience scores, which also show significant variation, with P6 notably lower than the others. The performance scores, however, reveal a pattern where higher resilience is associated with higher performance. For instance, P3 and P9, which have high resilience scores of 3.80 and 3.39, also exhibit high-performance scores of 4.25 each. Conversely, P6, with a low resilience score of 1.91, shows a correspondingly low performance score of 2.13. This suggests that for hospital projects, increased resilience effectively mitigates the negative impact of uncertainty on performance, leading to better overall outcomes.

Motorway projects generally exhibit lower uncertainty scores, except for P13, which peaks at 4.18. Interestingly, P13 also has the highest resilience score of 3.97 among motorways, which correlates with the highest performance score of 4.38. This demonstrates that despite high uncertainty, robust resilience measures can sustain high performance. Other motorway projects, like P11 and P12, maintain moderate levels of both resilience and performance, indicating a balanced approach to managing uncertainty.

The single airport project (P15) has the highest uncertainty score of 4.48, indicating significant challenges. However, it also has a high resilience score of 4.42, which supports a moderate performance score of 3.50. This project exemplifies resilience's critical role in counteracting uncertainty's adverse effects. Despite facing the highest uncertainty, the airport project's high resilience score has helped maintain a relatively good performance level, highlighting the importance of resilience in high-stakes environments.

The data suggests a clear relationship between resilience and performance, particularly in the presence of uncertainty:

- **High Uncertainty, Low Resilience, Low Performance:** Projects like P6 (hospital) with high uncertainty and low resilience show low performance, indicating that insufficient resilience fails to buffer against uncertainties.
- **High Uncertainty, High Resilience, High Performance:** Projects such as P13 (motorway) and P15 (airport) demonstrate that high resilience can significantly mitigate the negative impact of high uncertainty, leading to better performance outcomes.
- **Moderate Scores:** Projects with moderate scores in all three dimensions, such as P11 and P12 (motorways), show that a balanced approach can maintain steady performance without extreme fluctuations.

In summary, the results underscore the importance of resilience in managing uncertainty and sustaining performance. High resilience levels are crucial for high performance, especially in projects with high uncertainty. This relationship is evident across different projects, highlighting resilience's universal applicability as a critical factor in project management and performance optimization.

	Hospitals										Motorways				Airport
Scores	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Uncertainty	3.51	3.75	3.70	2.65	3.51	3.52	3.60	2.59	2.75	3.78	2.77	2.65	4.18	3.44	4.48
Resilience	2.78	3.67	3.80	2.61	2.44	1.91	2.49	3.06	3.39	3.33	2.68	2.76	3.97	2.44	4.42
Performance	2.00	3.75	4.25	2.13	2.50	2.13	2.00	3.75	4.25	3.88	3.50	3.75	4.38	1.50	3.50

Figure 4.5. Summary of the uncertainty, resilience and performance scores

4.3 Resilience Criteria for PPP Projects

4.3.1 Data Adequacy Evaluation

The suitability of our survey data for PCA was evaluated using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity, as shown in Table 4.4. The KMO test result exceeds the minimum acceptable value of 0.5 and indicates that the survey data variables exhibit sufficient correlation to form compact patterns of correlation coefficients. This suggests that the sample size is appropriate for deriving distinct PCs that capture the underlying structure of these factors (Kaiser, 1974).

Furthermore, Bartlett's test of sphericity yielded a highly significant result, providing strong evidence of correlations among the resilience factors. This supports the validity of conducting PCA, ensuring that the survey results can effectively cluster these variables into meaningful components.

These preliminary assessments confirm the foundational adequacy of the data for subsequent PCA analysis, facilitating the exploration of the interrelationships and structural composition of these resilience factors in greater detail.

Table 4.4 Summary of KMO and Bartlett's tests

		Preparation	*Absorption*	*Recovery*	*Adaptation*
KMO	MSA	0.77	0.72	0.78	0.76
	x^2 statistic	776.46	1098.64	1961.73	819.08
Bartlett	df	136	136	136	136
	p-value	<0.001	<0.001	<0.001	<0.001

Note: MSA represents a measure of sampling adequacy, and df indicates degrees of freedom for χ^2 statistic.

4.3.2 Preparation Feature

4.3.2.1 Factor Extraction

PCA was conducted to elucidate the underlying structure of resilience factors identified in the survey data. Table 4.5 presents the eigenvalue summary derived from the correlation matrix of these factors, highlighting the variance explained by each PC. This method reduces the original variables into smaller orthogonal PCs that retain maximum variance within the data.

Table 4.5 Eigenvalues summary for preparation

PCs	*Eigenvalue*	*Variance (%)*	*Cumulative Variance (%)*
PC-1	0.96	52.89	52.89
PC-2	0.21	11.42	64.31
PC-3	0.17	9.12	73.43
PC-4	0.10	5.24	78.66
PC-5	0.08	4.51	83.18
PC-6	0.07	3.65	86.83
PC-7	0.04	2.19	91.55
PC-8	0.04	1.94	93.49
PC-9	0.02	1.35	94.83
PC-10	0.02	1.27	96.11
PC-11	0.02	1.02	97.13
PC-12	0.02	0.83	97.96
PC-13	0.01	0.73	98.69
PC-14	0.01	0.61	99.29
PC-15	0.01	0.42	99.71
PC-16	0.01	0.29	100.00

As illustrated in Table 4.5, the eigenvalues and their corresponding percentages of variance are listed for each PC. The analysis identified 16 PCs, reflecting the interrelationships among the resilience factors in the preparation stage. A criterion of capturing at least 70% of the cumulative variance was applied to determine the number of PCs to retain, in line with established best practices in PCA methodology (Jolliffe, 2011). The first PC (PC-1) emerged as the most dominant, explaining 52.89% of the variance, followed by PC-2 and PC-3, which explained 11.42% and 9.12% of the variance, respectively. Collectively, the first three PCs accounted for 73.43% of the total variance, signifying their crucial role in capturing the primary sources of variability among the resilience factors in the preparation stage.

The retained PCs are instrumental in presenting the underlying constructs of preparation within the surveyed domains. Each PC corresponds to a distinct subset of resilience factors, characterized by high loadings and significant contributions to the overall variance structure. This structured reduction facilitates a deeper understanding of how specific groups of factors coalesce to influence resilience outcomes across different stages, including Preparation, Absorption, Recovery, and Adaptation.

4.3.2.2 Factor Rotation

Table 4.6. displays the outcomes in the rotated component matrix, indicating which factors constitute each PC based on the significance of the factor loadings. To aid in the interpretation of PCs, a loading threshold of 0.4 was set to determine significant loadings, in accordance with established PCA literature (Hair et al., 2013; Pituch & Stevens, 2016). Only factor loadings with absolute values greater than 0.4 are displayed, while those smaller than 0.4 are suppressed. This approach facilitates the identification of clear and distinct patterns of factor loadings across the different resilience stages.

The rotated component matrix in Table 4.6. highlights the specific resilience factors associated with each PC. In PC-1, six factors (RF9, RF11, RF12, RF14, RF15, RF16) with significant loadings were identified. For PC-2, significant loadings are found in

RF3, RF4, and RF5. Lastly, PC-3 is significantly influenced by two factors (RF10, and RF13).

Table 4.6 Rotated factor's loading for preparation

RFs	*PC-1*	*PC-2*	*PC-3*
RF1			
RF2			0.420
RF3		0.570	
RF4		0.751	
RF5		0.768	
RF6			
RF7	0.427		
RF8			
RF9	0.726		
RF10			0.688
RF11	0.825		
RF12	0.676		
RF13			0.630
RF14	0.684		
RF15	0.671		
RF16	0.744		

The factor loadings indicate the extent to which each factor correlates with the individual PCs. For instance, in the first component (PC-1), six resilience factors (RF9: Adequate revenue guarantee mechanism, RF11: Effective price adjustment (escalation) and compensation mechanism, RF12: Quick and flexible renegotiation mechanism, RF14: Explicit risk sharing/allocation in the contract, RF15: A flexible and collaboration-supportive contract, RF16: Proper resource management and an abundance of resources in the project) load strongly, suggesting a common underlying theme captured by PC-1. Similarly, PC-2 is primarily defined by RF3: continuous progress monitoring of the project, RF4: Application of virtual design and construction, and RF5: Application of sensing technology for monitoring and disruption detection, which have high loadings, while PC-3 is significantly influenced by RF10: Establishing a central coordinating PPP authority in public agencies and RF13: Effective and transparent information sharing and collaboration between stakeholders.

The rotated PCA results provide a simplified structure, making it easier to interpret the practical implications of the PCs. Each PC correlates substantially with a group of resilience factors, indicating shared variance and potentially common underlying constructs. The PCs are ranked in descending order of their explanatory power, as shown by their eigenvalues and the proportion of variance explained. PC-1, being the most significant, captures the largest proportion of variance (53%), followed by PC-2 (11%) and PC-3 (10%).

The identified PC structures provide valuable insights into the relationships between resilience factors. Understanding which factors belong to each PC helps in interpreting the practical meanings of the PCs. The significant factor loadings serve as indicators for understanding the underlying themes captured by each PC, offering a clearer view of how these resilience factors interrelate.

4.3.2.3 PCs Reliability Assessment

To evaluate the internal consistency reliability of the identified PCs, Cronbach's alpha test was performed for the selected factors within each PC from the rotated PCA results. The results, as shown in Table 4.7., provide a summary of the reliability of the scales formed by the subordinate resilience factors. Cronbach's alpha values for all PC scales with more than one subordinate resilience factor exceed the empirical threshold of 0.6, indicating acceptable to good internal consistency reliability. This reliability is crucial for ensuring that the factors within each PC consistently measure the same underlying construct. High internal consistency enhances the validity of the PCs, supporting their use in further analyses and practical applications.

Table 4.7 Cronbach's alpha coefficient of PCs in preparation

PCs	*Coefficient of Cronbach's alpha*
PC-1	0.850
PC-2	0.758
PC-3	0.634

4.3.3 Absorption Feature

4.3.3.1 Factor Extraction

During the factor extraction process for the Absorption phase, PCA was performed on the resilience factors. The eigenvalue summary is shown in Table 4.8. indicates the amount of variance explained by each PC. The first three PCs were selected for further analysis, as they cumulatively explain approximately 77.11% of the total variance in the dataset, with the first component contributing 41.83%, the second 25.38%, and the third 9.90%.

Table 4.8 Eigenvalues summary for absorption

PCs	*Eigenvalue*	*Variance (%)*	*Cumulative Variance (%)*
PC-1	0.79	41.83	41.83
PC-2	0.48	25.38	67.21
PC-3	0.19	9.90	77.11
PC-4	0.09	4.94	82.05
PC-5	0.07	3.54	85.58
PC-6	0.05	2.80	88.38
PC-7	0.04	2.09	92.76
PC-8	0.03	1.48	94.24
PC-9	0.03	1.45	95.69
PC-10	0.02	1.12	96.81
PC-11	0.02	0.97	97.77
PC-12	0.02	0.90	98.67
PC-13	0.01	0.60	99.27
PC-14	0.01	0.50	99.76
PC-15	0.00	0.21	99.98
PC-16	0.00	0.02	100

The implications of the extracted PCs are significant. Each PC correlates substantially with a group of resilience factors, capturing the common variance among these factors and highlighting the underlying dimensions within the data. The higher the eigenvalue of a PC, the more it contributes to explaining the overall variance. By retaining PCs that account for up to 70% of the cumulative variance, the analysis ensures that the most important dimensions of the data are captured while maintaining interpretability.

This step is crucial for simplifying the structure of the resilience factors and facilitating a more straightforward interpretation of the underlying constructs within the Absorption phase. The next step involves interpreting these extracted PCs by examining the factor loadings and identifying the subordinate resilience factors contributing to each PC.

4.3.3.2 Factor Rotation

The rotated PCA results, as shown in Table 4.9., for the Absorption phase were analyzed to identify the significant loadings of each factor on the first three PCs. The loadings represent the correlation between the original variables (resilience factors) and the PCs.

For PC-1, RF3: continuous progress monitoring of the project, RF7: public/ community support, RF8: The risk management maturity of project and project stakeholders, RF12: quick and flexible renegotiation mechanism, and RF13: effective and transparent information sharing and collaboration between stakeholders, exhibit strong loadings. These factors have high positive loadings, indicating a significant correlation with the first PC and contributing to a common underlying dimension. For PC-2, RF11: effective price adjustment (escalation) and compensation mechanism, RF15: flexible and collaboration-supportive contract, and RF16: proper resource management and abundance of resources in the project, load significantly, suggesting they share a common variance that defines the second PC. Lastly, RF2: appropriate contingency planning, RF4: application of virtual design and construction, RF5: application of sensing technology for monitoring and disruption detection, RF6: early detection of regulatory and technical constraints, RF9: adequate revenue guarantee mechanism, and RF14: explicit risk sharing/allocation in the contract, show significant loadings on PC-3, indicating a close relationship and contribution to the third PC. These results provide insight into the structure of the resilience factors, highlighting the primary dimensions captured by the PCs in the absorption stage.

Table 4.9 Rotated factor's loading for preparation

RFs	*PC-1*	*PC-2*	*PC-3*
RF1			
RF2			0.446
RF3	0.432		
RF4			0.633
RF5			0.646
RF6			0.414
RF7	0.598		
RF8	0.629		
RF9			0.650
RF10			
RF11		0.704	
RF12	0.566		
RF13	0.531		
RF14			0.670
RF15		0.838	
RF16		0.876	

4.3.3.3 PCs Reliability Assessment

Cronbach's alpha test was performed to evaluate the internal consistency reliability of the identified PCs in the adaptation phase. The results are summarized in Table 4.10. and indicate the degree to which the resilience factors within each PC are consistent.

The alpha values for PC-1, PC-2, and PC-3 are 0.674, 0.668, and 0.706, respectively, demonstrating good internal consistency, indicating that the resilience factors within these components are more reliably measuring the same underlying construct.

Table 4.10 Cronbach's alpha coefficient of PCs in absorption

PCs	*Coefficient of Cronbach's alpha*
PC-1	0.674
PC-2	0.668
PC-3	0.706

4.3.4 Recovery Feature

4.3.4.1 Factor Extraction

In the factor extraction process for the Recovery phase, PCA was employed to identify the key components explaining the variance in the resilience factors. The result is shown in Table 4.11. The first two components were selected for further analysis, as they explain more than 70% of the total variance, ensuring that the majority of the information in the original data is captured by these two components.

Table 4.11 Eigenvalues summary for recovery

PCs	*Eigenvalue*	*Variance (%)*	*Cumulative Variance (%)*
PC-1	1.82	62.89	62.89
PC-2	0.55	19.07	81.96
PC-3	0.20	7.03	89.00
PC-4	0.13	4.44	93.43
PC-5	0.05	1.69	95.12
PC-6	0.04	1.47	96.58
PC-7	0.02	0.55	98.22
PC-8	0.01	0.49	98.71
PC-9	0.01	0.41	99.12
PC-10	0.01	0.31	99.43
PC-11	0.01	0.25	99.69
PC-12	0.00	0.1	99.78
PC-13	0.00	0.07	99.85
PC-14	0.00	0.06	99.91
PC-15	0.00	0.05	99.96
PC-16	0.00	0.04	100.00

The first PC accounts for 62.89% of the total variance, while the second PC explains an additional 19.07%, bringing the cumulative variance explained by the first two components to 81.96%. These two components are thus considered sufficient to represent the underlying structure of the resilience factors in the Recovery phase. The remaining components contribute minimally to the variance, with their cumulative contribution only slightly increasing the explained variance, indicating their lesser importance in the overall factor structure.

4.3.4.2 Factor Rotation

The rotated PCA results for the Recovery phase were analyzed to identify the significant loadings of each factor on the first two PCs. The varimax rotation was applied to enhance interpretability. Table 4.12. lists the resilience factors along with their corresponding loadings on PC-1 and PC-2. Loadings greater than 0.4 are considered significant and are highlighted to indicate which factors are strongly associated with each PC.

The results indicate that PC-1 is primarily associated with the resilience factors RF4: application of virtual design and construction, RF6: early detection of regulatory and technical constraints, RF7: public/ community support, RF9: adequate revenue guarantee mechanism, RF11: effective price adjustment (escalation) and compensation mechanism, RF13: effective and transparent information sharing and collaboration between stakeholders, and RF15: a flexible and collaboration-supportive contract, all showing significant loadings above the 0.4 threshold. Similarly, PC-2 is associated with the resilience factors RF1: favorable legal frameworks for dispute resolution and settlement, RF5: application of sensing technology for monitoring and disruption detection, RF8: the risk management maturity of project and project stakeholders, RF10: establishing a central coordinating PPP authority in public agencies, RF12: quick and flexible renegotiation mechanism, RF14: explicit risk sharing/allocation in the contract, and RF16: proper resource management and abundance of resources in the project, each exhibiting significant loadings.

Table 4.12 Rotated factor's loading for recovery

RFs	*PC-1*	*PC-2*
RF1		0.832
RF2	0.402	
RF3		
RF4	0.779	
RF5		0.829
RF6	0.623	
RF7	0.808	
RF8		0.743
RF9	0.509	
RF10		0.477
RF11	0.825	
RF12		0.541
RF13	0.824	
RF14		0.662
RF15	0.841	
RF16		0.824

4.3.4.3 PCs Reliability Assessment

The internal consistency and reliability of the identified PCs in the Recovery phase were assessed using Cronbach's alpha test, with the results presented in Table 4.13. The calculated Cronbach's alpha coefficients indicate excellent internal consistency reliability for both PC-1 ($\alpha = 0.89$) and PC-2 ($\alpha = 0.80$). These coefficients exceed the generally accepted threshold of 0.60, suggesting that the resilience factors grouped under each PC consistently measure related constructs within the recovery phase.

Table 4.13 Cronbach's alpha coefficient of PCs in recovery

PCs	*Coefficient of Cronbach's alpha*
PC-1	0.89
PC-2	0.80

4.3.5 Adaptation Feature

4.3.5.1 Factor Extraction

In the factor extraction process for the adaptation phase, PCA identified the key components explaining the variance in the resilience factors. The results revealed that the first three PCs cumulatively accounted for 70.04% of the variance, making them the most significant in capturing the underlying structure of the adaptation phase information. The eigenvalue summary, provided in Table 4.14, shows the variance explained by each component. Specifically, PC-1 explained 38.59% of the variance, PC-2 explained 22.30%, and PC-3 explained 9.15. These three components were thus retained for further analysis to interpret the resilience factors within the adaptation phase.

Table 4.14 Eigenvalues summary for adaptation

PCs	*Eigenvalue*	*Variance (%)*	*Cumulative Variance (%)*
PC-1	0.50	38.59	38.59
PC-2	0.29	22.30	60.89
PC-3	0.12	9.15	70.04
PC-4	0.07	5.25	75.29
PC-5	0.06	5.01	80.30
PC-6	0.04	3.42	83.72
PC-7	0.03	2.63	89.68
PC-8	0.03	2.45	92.13
PC-9	0.03	2.21	94.35
PC-10	0.02	1.88	96.23
PC-11	0.02	1.34	97.57
PC-12	0.01	0.98	98.55
PC-13	0.01	0.68	99.22
PC-14	0.01	0.52	99.74
PC-15	0.00	0.26	100
PC-16	0.00	0.00	100

4.3.5.2 Factor Rotation

The rotated PCA results for the adaptation phase were analyzed to identify the significant loadings of each resilience factor on the first three PCs. Table 4.15 presents the resilience factors along with their corresponding loadings on PC-1, PC-2, and PC-3. The analysis revealed varying degrees of association between the factors and the PCs, highlighting the underlying structure and interrelationships among the resilience factors.

Table 4.15 Rotated factor's loading for adaptation

RFs	*PC-1*	*PC-2*	*PC-3*
RF1	0.451		
RF2	0.666		
RF3	0.717		
RF4		0.779	
RF5		0.709	
RF6	0.776		
RF7	0.804		
RF8			
RF9			0.606
RF10	0.499		
RF11			0.600
RF12			
RF13		0.550	
RF14			0.680
RF15			
RF16			0.557

RF1: favorable legal frameworks for dispute resolution and settlement, RF2: appropriate contingency planning, RF3: continuous progress monitoring of the project, RF6: early detection of regulatory and technical constraints, RF7: Public/ community support, and RF10: establishing a central coordinating PPP authority in public agencies had notable loadings on PC-1, indicating their relevance in the components. Factors such as RF4: application of virtual design and construction, RF5: application of sensing technology for monitoring and disruption detection, and RF13: effective and transparent information sharing and collaboration between stakeholders, had significant loadings on PC-2, while RF9: adequate revenue guarantee mechanism, RF11: effective price adjustment (escalation) and compensation mechanism, RF14: explicit risk sharing/allocation in the contract, and RF16: proper resource management and abundance of resources in the project exhibited higher loadings on PC-3.

4.3.5.3 PCs Reliability Assessment

In the adaptation phase, Cronbach's alpha test was performed to assess the internal consistency and reliability of the identified PCs. The results, summarized in Table 4.16, indicate the reliability of the resilience factors associated with each PC. PC-1 and PC-2 exhibit good internal consistency, with alpha values of 0.78 and 0.77, respectively, suggesting that the factors grouped within these components reliably measure the same underlying constructs. PC-3 shows a lower alpha value of 0.63, which is acceptable and indicates some internal consistency.

Table 4.16 Cronbach’s alpha coefficient of PCs in adaptation

PCs	*Coefficient of Cronbach’s alpha*
PC-1	0.78
PC-2	0.77
PC-3	0.63

4.4 The Uncertainty–Resilience Assessment Tool

4.4.1 URAT Architecture

The Uncertainty–Resilience Assessment Tool (URAT) is an advanced, computer-based decision support system specifically designed to assist project executor(s) in evaluating the levels of uncertainty and resilience associated with a PPP project during its crucial initial stages. By systematically analyzing potential uncertainty factors, URAT provides a comprehensive understanding of vulnerabilities that could impact the project’s performance and assesses its capacity to withstand and recover from disruptions. This empowers stakeholders to make informed, data-driven decisions and take proactive measures to mitigate risks, ensuring the project stays on track, even when faced with unforeseen challenges.

URAT features a predictive framework that evaluates critical indicators such as financial, technical, and operational stability, as well as external factors like regulatory changes, market fluctuations, and environmental conditions. These insights help project executor(s) identify potential areas of concern early, enabling the design and implementation of targeted resilience management strategies. This not only reduces the likelihood of disruptions but also strengthens the project's overall resilience, significantly increasing its chances of long-term success.

In addition, URAT promotes collaboration among project stakeholders by providing a shared platform for analyzing data, discussing potential risks, and developing contingency plans. Its intuitive interface and customizable features make it adaptable to a wide range of project types and scales, ensuring it meets the specific needs of each PPP initiative. By fostering a proactive approach to managing uncertainty and building resilience, URAT supports the development of robust and sustainable projects, delivering benefits to both public and private sector participants. The URAT architecture is simply shown in Figure 4.6. The architecture consists of four main components: User Interface, Empirical Data, the URAT Engine, and the Report. These components work together to provide a seamless flow of analysis.

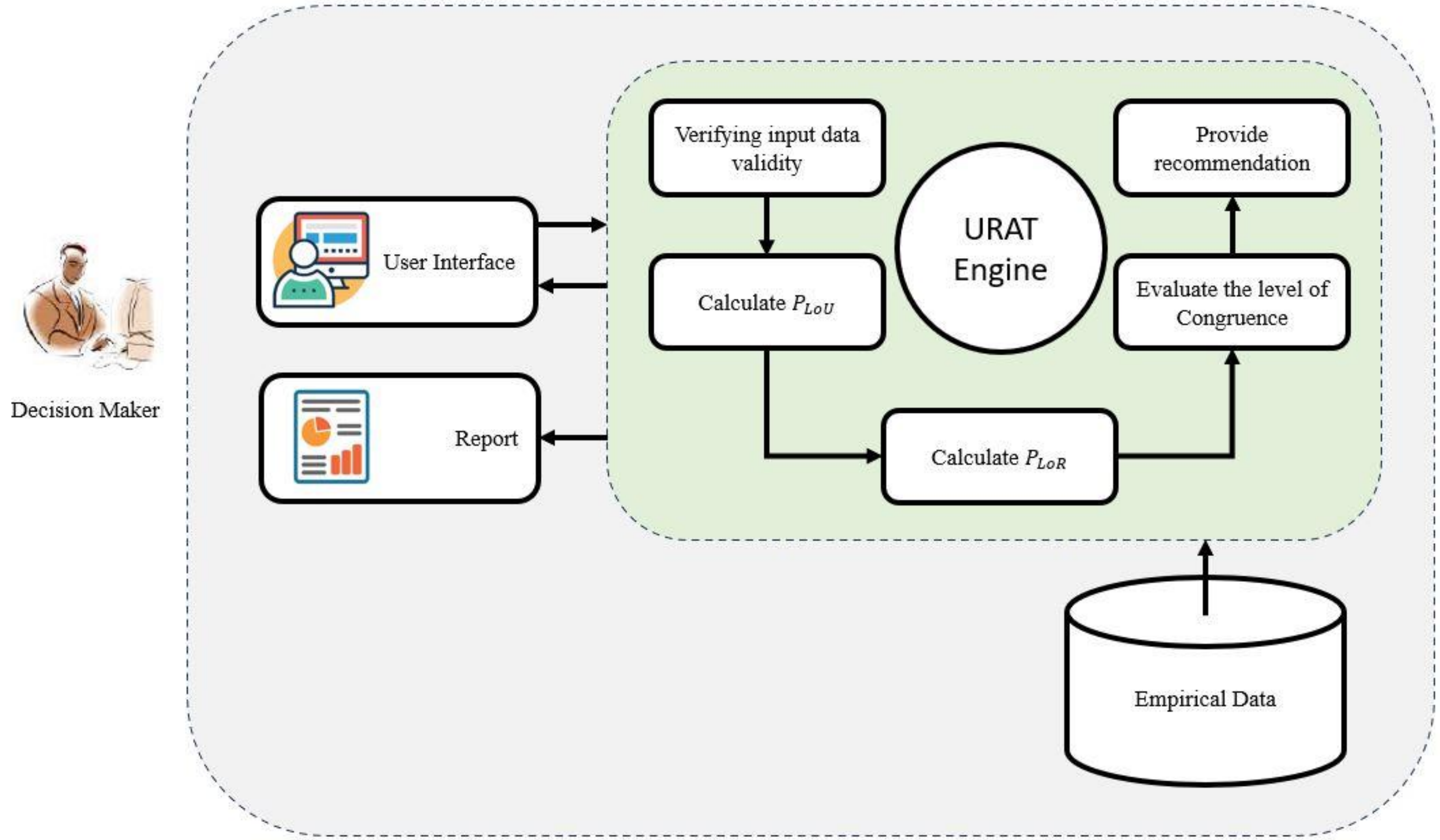


Figure 4.6 URAT architecture

The User Interface functions as the primary point of interaction between the system and its users, offering an intuitive and interactive dashboard that displays key metrics, including a comprehensive list of uncertainty and resilience factors. This interface allows users to input data within a defined acceptable range to ensure accuracy and prevent miscalculations. Accurate and relevant input is essential for enabling the URAT Engine to perform a comprehensive analysis, as any data inaccuracies could compromise the system's predictive and evaluative capabilities.

The Empirical Data component forms the foundational layer of the URAT system. It consists of real-world data pertinent to PPP projects, including the relative importance of various uncertainty and resilience factors, derived from the first round of data collection in this study. It also includes the number of subcategories and their standardized weights for each resilience dimension derived from the second round of data collection in this study. This data provides the necessary context and baseline for the URAT Engine to operate effectively, ensuring that the system can produce precise and reliable results. The empirical data is systematically integrated into the URAT Engine, where the core computational processes are executed.

The URAT Engine functions as the analytical core of the system, seamlessly processing data obtained from both the User Interface and the Empirical Data component. It quantifies the project's overall level of uncertainty while independently calculating resilience levels for each dimension, providing a nuanced and comprehensive assessment. These calculations offer a detailed view of the project's capacity to absorb shocks, recover from disruptions, and adapt to evolving challenges. From an academic perspective, the URAT Engine integrates advanced principles from resilience theory and computational modeling, enabling robust and systematic evaluations of project dynamics. This integration ensures that the insights generated are both theoretically grounded and practically applicable, supporting evidence-based decision-making and promoting more resilient project management practices.

The Graphical Report offers a clear and concise visual representation of the analysis results. It summarizes the key findings of the URAT Engine, including the quantified uncertainty and resilience scores. The report facilitates an easy comparison of these scores, enabling project executors to assess whether the desired level of alignment between uncertainty and resilience has been achieved. By presenting complex data in an accessible format, the Graphical Report serves as a critical tool for communicating results, fostering understanding, and ensuring alignment in the decision-making process.

4.4.2 Demonstration of URAT

To demonstrate the functionality, applicability, and accuracy of the URAT, a real case project was conducted. A PPP project in Türkiye was selected for evaluation, and each phase of the URAT process was executed in collaboration with an expert, who is a project manager with over a decade of experience in managing and implementing PPP projects. This case study served as a practical validation of the tool, showcasing its capabilities in a real-world context. Through this evaluation, nearly all features of the URAT model were systematically applied and demonstrated, providing a comprehensive illustration of its functionality. The details of which are outlined below.

The URAT session begins with a brief introduction to the tool, providing an overview of its purpose and key functionalities (Figure 4.7). Additionally, as depicted in Figure 4.8, a flowchart is presented to visually simplify and clarify the tool's process, offering users a clear understanding of how the various steps within the system are interconnected. This visual representation is a guide, ensuring users use the tool effectively.

Dear User

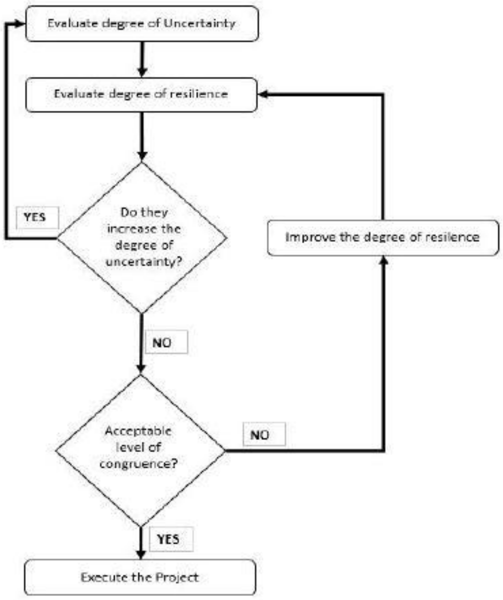
Welcome to the Uncertainty–Resilience Assessment Tool (URAT), a decision support system designed to help you effectively evaluate and balance uncertainty and resilience in PPP projects.

It is designed with user-friendliness at its core, providing an intuitive interface and straightforward workflows to guide you through the assessment process.

As the user, you are expected to provide accurate data and interpret the results to make informed decisions. URAT has been designed to assist you every step of the way:
* Input your project data as prompted.
* Use the provided scores and recommendations to evaluate the current status of the project
* Review the color-coded feedback to quickly identify critical areas.

On the following page, you will be asked to evaluate the availability level of uncertainty and resilience factors. Please provide your rating on a scale of 1 to 5, where 1 represents "Very Low" and 5 represents "Very High."

For effective and accurate use of this tool, please follow the flowchart provided below:



URAT was developed as part of a PhD study on Resilience in PPP projects which was conducted within the Civil Engineering Department at Middle East Technical University in Türkiye.

To help us enhance the tool's performance and further its development, we would greatly appreciate your valuable feedback. Please feel free to share your thoughts and suggestions by reaching out to us at saeedkamali2002@gmail.com.

Thank you for your support!

Figure 4.7 The URAT tools Introduction page

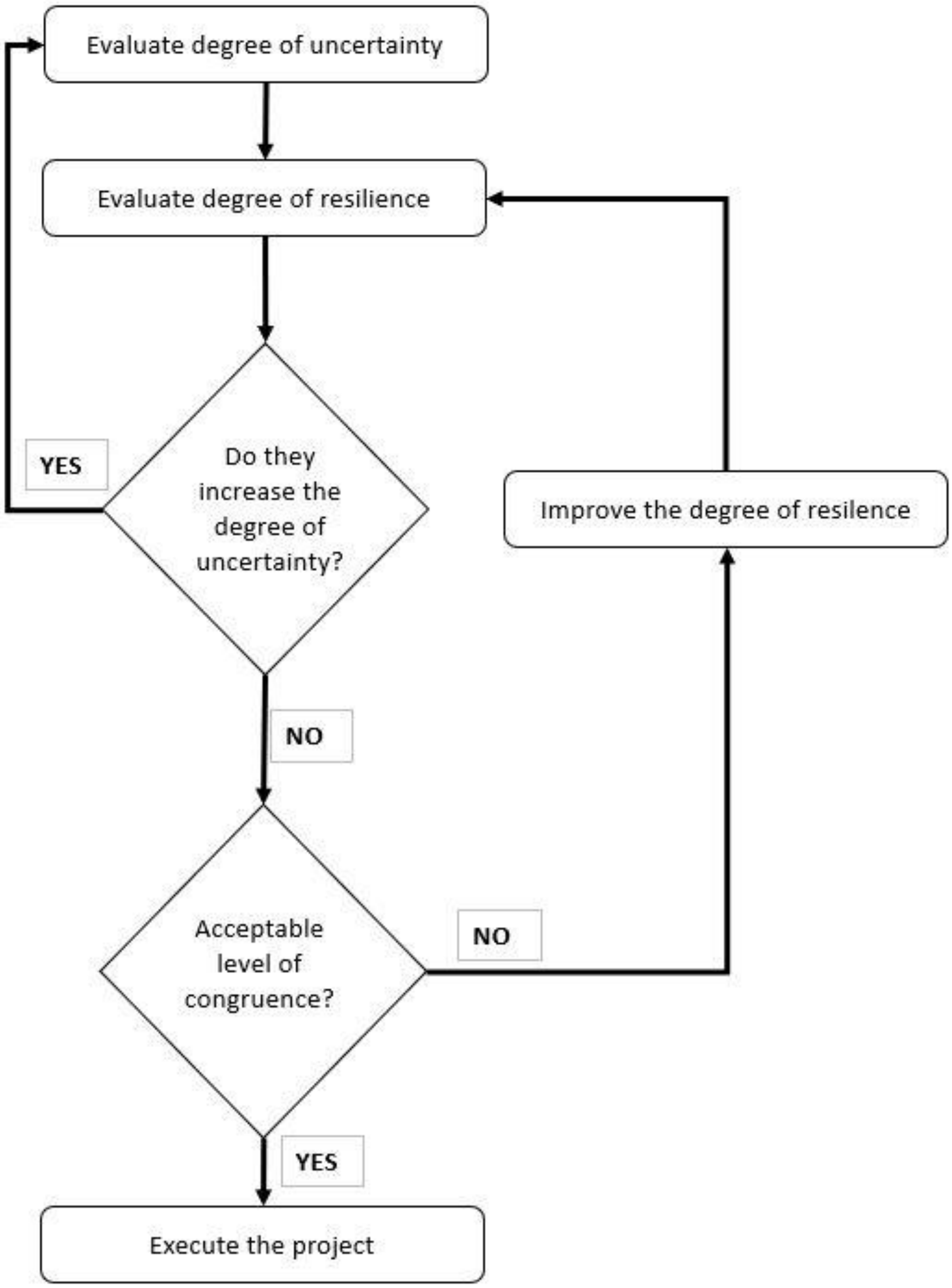


Figure 4.8 Uncertainty resilience assessment process

The flowchart illustrates the iterative decision-making process within the URAT, which is designed to ensure projects are thoroughly prepared to manage disruptions. The process begins with evaluating the project's degree of uncertainty by quantifying key factors. This is followed by an assessment of the project's resilience degree. Once these evaluations are complete, the interaction between resilience and uncertainty is analyzed to determine whether the existing resilience measures inadvertently increase the degree of uncertainty. If it is found that resilience factors contribute to increased uncertainty, the degree of uncertainty is reevaluated. Conversely, if no such increase occurs, the system assesses whether an acceptable level of congruence between uncertainty and resilience has been achieved. This congruence ensures the project's resilience capacity sufficiently counterbalances the identified uncertainties. If the level of congruence meets the acceptable threshold, the project is deemed ready for execution. However, if the desired congruence is not achieved, the process loops back to further refine and enhance resilience measures until the required alignment is reached. This structured and iterative approach guarantees effective management of uncertainties, continuous optimization of resilience, and thorough project preparation for successful implementation.

Following this, the user is prompted to evaluate the degree of availability of various uncertainty factors within the project. This evaluation uses a five-point Likert scale, where 1 represents very low availability or near nonexistence of the selected factor, and 5 indicates very high availability (Figure 4.9). This structured rating process is the initial step in assessing the project's overall uncertainty and provides critical input for subsequent analyses conducted by the URAT Engine.

1. Please rate the availability degree of uncertianty factors in the project

1: very low - 2: Low - 3: Moderate - 4: High - 5: Very High

ID	Uncertainty Factors	Degree of Availability
GU01	Political System Instability	2.7
GU02	Legislative System Instability	3.2
GU03	Government Approval Process Complexity	3.7
SU01	Community Support	3.1
EU01	Regional Economy Instability	3.7
EU02	Financial Market Unreliability	2.8
PU01	Unclarity of Performance Requirement	3.5
PU02	Design Complexity	3.7
PU03	Construction Complexity	3.1
PU04	Operation / Maintenance Complexity	3.1
PU05	Unreliability of Reference Data	2.9

Figure 4.9 User interface for entering uncertainty factors data

In the next section, the user is prompted to evaluate the degree of availability of various resilience factors within the project. To enhance user-friendliness and maintain consistency, this evaluation also employs a five-point Likert scale, where a rating of 1 represents very low availability or near nonexistence of the selected factor, and a rating of 5 indicates very high availability (Figure 4.10).

2. Please rate the availability degree of resilience factors in the project

1: very low - 2: Low - 3: Moderate - 4: High - 5: Very High

ID	Resilience Factors	Degree of Availability
RF1	Favourable legal frameworks for a dispute resolution and settlement	2.9
RF2	Appropriate contingency planning	2.7
RF3	Continuous progress monitoring of project	2.3
RF4	Application of virtual design and construction (VDC), such as BIM	2.7
RF5	Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	2.7
RF6	Early detection of regulatory and technical constraints	3.1
RF7	Public/ community support	3.5
RF8	The risk management maturity of project and project stakeholders	2.6
RF9	Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	3.9
RF10	Establishing a central coordinating PPP authority in public agencies	3.3
RF11	Effective price adjustment (escalation) and compensation mechanism	2.8
RF12	Quick and flexile renegotiation mechanism	2.7
RF13	Effective and transparent information sharing and collaboration between stakeholders	3
RF14	Explicit risk sharing/allocation in the contract	2.4
RF15	A flexible and collaboration-supportive contract	2.6
RF16	A proper resource management and abundance of resources in the project	3.1

Figure 4.10 User interface for entering resilience factors data

As previously mentioned, the User Interface is designed to prevent the entry of out-of-range data to ensure accurate calculations. If the user inadvertently inputs a value outside the acceptable range (1 to 5), an error message is displayed (Figure 4.11), prompting the user to reenter the value correctly. This feature safeguards the integrity of the data and maintains the reliability of the system's analyses.

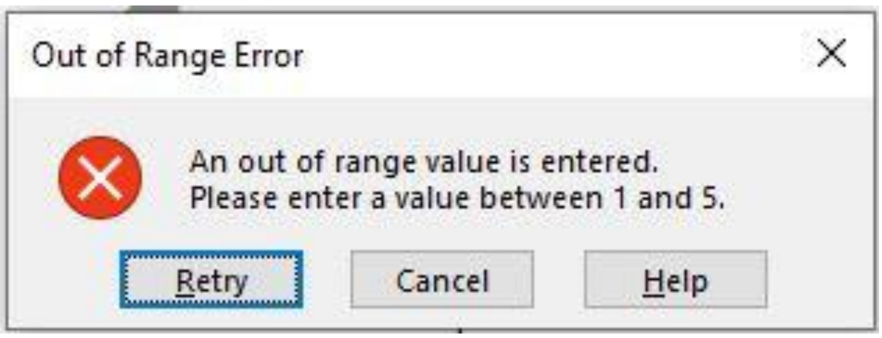


Figure 4.11 Out of range error

The value entered for each resilience or uncertainty factor triggers a dynamic color-coded visualization within the User Interface, as shown in Figures 4.9 and 4.10. This system ranges from red to green, where red indicates an undesirable value, such as a high uncertainty level or a low resilience level. In contrast, green represents a desirable value, such as a low level of uncertainty or a high level of resilience. This color-coded illustration enhances the tool's usability, offering an intuitive and user-friendly way for users to interpret the data. Providing immediate visual feedback allows users to quickly identify areas requiring closer attention or corrective action, facilitating more efficient decision-making and project management.

Once the user enters the values, the URAT Engine calculates each subcategory and dimension's uncertainty and resilience scores (Figures 4.12). It then provides the overall uncertainty and resilience scores, allowing the user to assess the level of congruence between these values. This evaluation is guided by a set of straightforward rules, helping the user determine whether the current balance between uncertainty and resilience is acceptable or requires adjustments. These rules serve as a practical framework for interpreting the results and identifying areas needing further attention to ensure project stability and success.

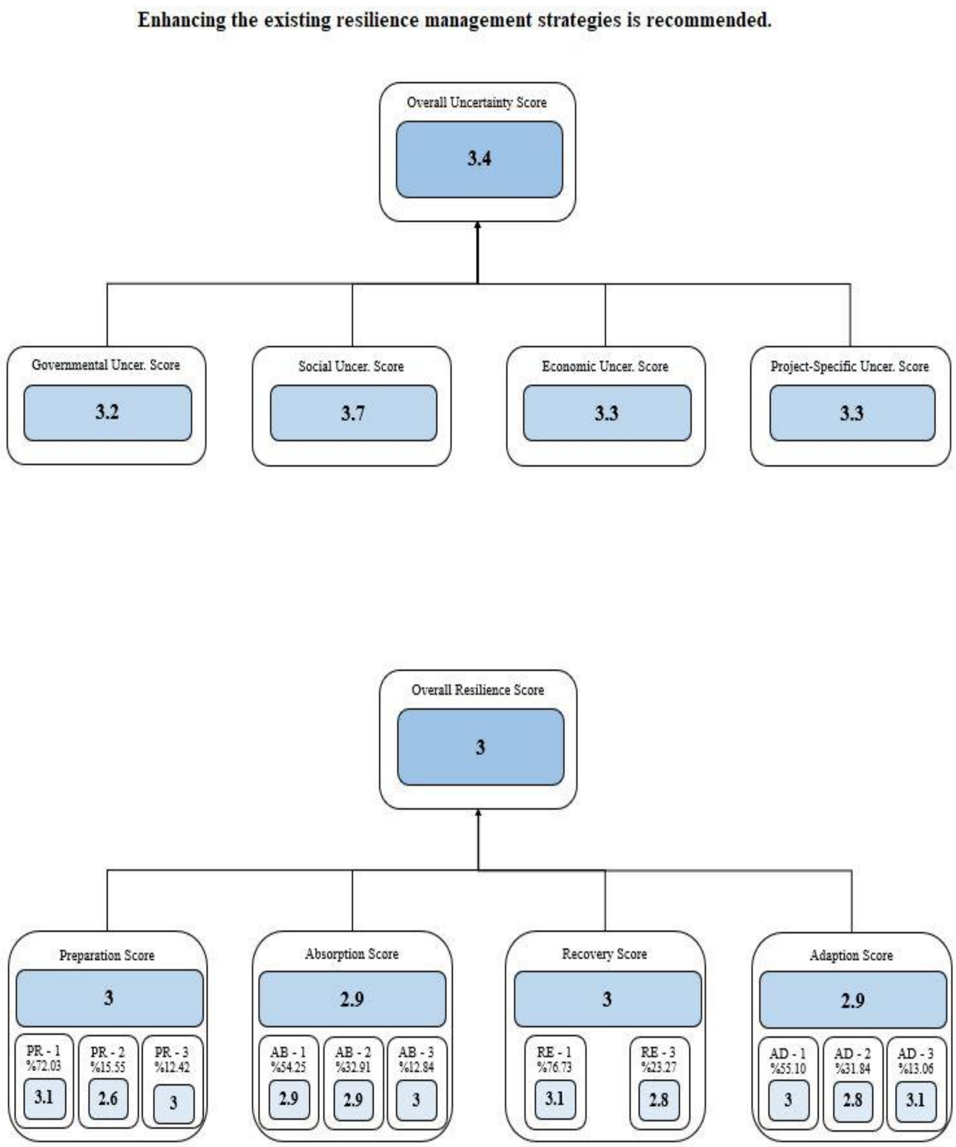


Figure 4.12 Report on overall uncertainty and resilience scores of the project

If the overall uncertainty score significantly exceeds the overall resilience score, it is strongly advised to implement more resilience-based management strategies to enhance the project's overall resilience. Without such measures, there is a high risk of project failure, as the current level of resilience may be insufficient to absorb, recover from, or adapt to potential disruptions that could arise during project implementation due to the elevated level of uncertainty. Strengthening resilience in this context is essential for mitigating risks and ensuring the project's successful completion despite uncertainties.

Enhancing the existing resilience management strategies is recommended if the overall uncertainty score is close to the overall resilience score, as observed in the selected case study project (Figure 4.12). Increasing the gap between these scores will strengthen the project's ability to absorb, recover from, and adapt to potential disruptions that may arise in the future. By bolstering resilience, the likelihood of project success is significantly improved as the system becomes better equipped to handle unforeseen challenges and maintain stability throughout implementation.

If the overall uncertainty score is lower than the overall resilience score, it indicates that the current level of resilience within the project provides almost enough capability to absorb, recover from, and adapt to potentially disruptive events. In simpler terms, the project is expected to proceed successfully under the present conditions. However, experts often advise caution, as the future inherently carries uncertainty. Therefore, while additional improvements to the resilience level may not be strictly necessary, enhancing resilience where feasible is recommended to safeguard the project against unforeseen challenges further and ensure its success.

CHAPTER 5

CONCLUSION

This chapter will succinctly summarize the key findings, critically evaluate the study's implications, and assess the extent to which the research objectives have been achieved. Additionally, it will address the study's limitations and propose avenues for future research, focusing on opportunities for further advancement in the field. By offering this conclusion, the chapter will underscore the broader impact of the research, highlighting its practical applications and theoretical contributions.

5.1 Summary of the Main Findings

Resilience plays a critical role in construction projects, not only for maintaining system reliability during disruption but also for shaping the processes of planning, designing, and constructing structures and facilities. Despite the lack of consensus in the literature regarding the definition and dimensions of project resilience, this research redefines resilience as a multifaceted concept. It encompasses a project's ability to anticipate, endure, recover from, and adapt to disruptions, thereby ensuring sustained performance and successful outcomes. This capability is essential for enabling projects to navigate unexpected challenges and thrive amidst adversity.

After redefining the concept of resilience, various projects were analyzed to uncover the relationship between resilience and performance, revealing a strong interplay with uncertainty. In hospital projects, uncertainty levels vary significantly. For example, P4 exhibits low uncertainty, while others, like P10, experience substantially higher levels. This variability is reflected in resilience scores, where certain projects, such as P6, demonstrate markedly lower resilience. Performance closely aligns with resilience: projects with higher resilience, like P3 and P9, achieve superior performance scores, whereas P6, characterized by low resilience, struggles with poor performance. These findings suggest that resilience plays a critical role in mitigating the adverse effects of uncertainty and enhancing overall outcomes in hospital projects.

In motorway projects, uncertainty levels are generally lower, with the exception of P13, which records the highest uncertainty score in this category. Interestingly, P13 also achieves the highest resilience and performance scores, illustrating that strong resilience can sustain high performance even under significant uncertainty. Other motorway projects, such as P11 and P12, maintain moderate resilience and performance levels, reflecting a balanced and steady approach to managing uncertainty.

The single airport project, P15, faces the highest level of uncertainty across all the projects analyzed. However, its high resilience score enables it to achieve a moderate performance level, emphasizing the vital role of resilience in overcoming substantial challenges. Despite contending with the greatest uncertainty, P15 demonstrates relatively strong performance, underscoring resilience as a key factor in high-stakes environments.

Overall, the findings emphasize the pivotal relationship between resilience and performance, particularly in the face of uncertainty. Projects with high uncertainty but low resilience, such as P6 in the hospital category, tend to exhibit low performance, indicating that inadequate resilience fails to counterbalance uncertainty. Conversely, projects like P13 (motorway) and P15 (airport), which combine high uncertainty with robust resilience, demonstrate that strong resilience can effectively mitigate the negative impacts of uncertainty, leading to superior performance outcomes. Projects with moderate scores across uncertainty, resilience, and performance, such as P11 and P12 (motorways), exemplify the benefits of a balanced approach, ensuring consistent performance without extreme fluctuations.

In summary, this study highlights resilience as a critical determinant of performance in the context of uncertainty, across diverse project types. A high level of resilience is indispensable for maintaining strong performance, particularly in environments marked by significant uncertainty. These findings establish resilience as a universally important factor in project management, essential for optimizing performance and achieving successful outcomes in challenging scenarios.

Considering the provided definition of resilience and its four dimensions, a PCA was conducted to systematically categorize the identified resilience factors into these dimensions. This analytical approach reduced complexity by grouping related factors, ensuring that each dimension reflected distinct yet interrelated aspects of resilience, thereby providing a structured framework for evaluating and interpreting resilience in various contexts.

The factor loadings in the preparation stage demonstrate the degree of correlation between each resilience factor and the PCs, with PC-1 showing strong associations with six factors (10, 12, 13, 15, 16, and 17), suggesting a common underlying theme. PC-2 is primarily defined by high loadings on Factors 3, 4, and 5, while PC-3 is significantly influenced by Factors 11 and 14. The rotated PCA results simplify the structure, making it easier to interpret the practical implications of the PCs, each of which correlates strongly with a specific group of resilience factors, indicating shared variance and potential common constructs. Ranked by their explanatory power, with PC-1 capturing the most variance (22%), followed by PC-2 (11%) and PC-3 (10%), these PCs provide valuable insights into the relationships between resilience factors. Understanding these relationships and the significant factor loadings help clarify the underlying themes of each PC, offering a clearer view of how these resilience factors interrelate.

While in the absorption stage, the factor loadings reveal how strongly each resilience factor correlates with the PCs. PC-1 is strongly associated with six factors, indicating a shared underlying theme, while PC-2 and PC-3 are defined by different groups of factors with high loadings. The rotated PCA results simplify the structure, making it easier to interpret the practical significance of each PC. Ranked by the variance they explain—PC-1 at 22%, followed by PC-2 at 11% and PC-3 at 10%—these components provide insights into the relationships between resilience factors.

Understanding these relationships helps clarify the underlying themes and connections among the resilience factors.

The rotated PCA results for the Recovery phase were analyzed to determine the key factor loadings on the first two PCs, with varimax rotation applied for better interpretability. Results highlight the resilience factors and their corresponding loadings on PC-1 and PC-2, with loadings above 0.4 considered significant. The analysis shows that PC-1 is strongly associated with resilience factors RF2, RF4, RF-6, RF8, RF10, RF12, RF14, and RF16, all of which have loadings above the threshold. Similarly, PC-2 is linked to resilience factors RF1, RF5, RF7, RF9, RF11, RF13, RF15, and RF17, each showing significant loadings.

The rotated PCA results for the Adaptation phase were examined to identify significant loadings of resilience factors on the first four PCs. For example, RF1 had notable loadings on PC-1 (0.451) and PC-4 (0.506), indicating its relevance to these components. RF2, RF3, RF6, RF7, and RF8 were strongly associated with PC-1, while RF4 and RF5 were more linked to PC-2. RF10, RF12, and RF17 also showed higher loadings on PC-3, and RF1 and RF16 were significant for PC-4.

The study culminated in the development of the Uncertainty-Resilience Assessment Tool (URAT), a practical and systematic tool that operationalizes the conceptual framework of resilience. URAT provides decision-makers with an intuitive, step-by-step approach to evaluate levels of uncertainty and resilience in projects, generating actionable recommendations for enhancement. With integrated data visualization features and a user-friendly interface, the tool ensures accessibility for a wide range of users, including project managers, policymakers, and other stakeholders.

URAT was designed with a focus on practicality and scalability. Its validation using empirical data establishes its reliability, while its alignment with established project management practices ensures seamless applicability. Beyond its role in resilience assessment, URAT serves as a strategic planning resource, empowering decision-makers to strengthen resilience and effectively mitigate potential disruptions proactively. This dual functionality underscores the tool's value in promoting robust, sustainable project outcomes across diverse contexts.

5.2 Contribution of the Research

As highlighted in the literature review, current disruption management practices predominantly emphasize identifying, analyzing, and preparing mitigation strategies to address disruptive events. However, these approaches often fall short in enhancing a project's capacity to handle such events effectively, whether anticipated or unforeseen, detected or missed by traditional risk management systems. Additionally, mitigation plans frequently lack the context-specific adaptability necessary to address the inherent uncertainty and unpredictability of disruptive events, limiting their effectiveness.

This study advances the understanding of resilience in construction projects by providing a clear and comprehensive definition, delineating its dimensions, and exploring its integration into various project management frameworks, including risk management, change management, opportunity management, crisis management, sustainability, and lean approaches. This dual theoretical and practical focus enriches the conceptual foundation of resilience while demonstrating its relevance and applicability to real-world project scenarios. Furthermore, the research underscores the critical role of resilience as a complement to traditional strategies, particularly in environments marked by high uncertainty and significant consequences, where conventional methods alone may prove insufficient.

Beyond its theoretical contributions, the study provides empirical insights by identifying the key factors of uncertainty and resilience in PPP projects and examining their interrelationships with project performance across 15 PPP projects in Türkiye. By categorizing resilience factors into four distinct dimensions based on empirical findings, the research establishes a structured framework for understanding the dynamic interactions of these elements within the complex environment of PPP projects. This framework is instrumental in devising more targeted and effective resilience strategies, enabling project managers to better anticipate, adapt to, and mitigate potential disruptions.

In addition, this study resulted in the development of the Uncertainty-Resilience Assessment Tool (URAT), a practical and systematic tool designed to evaluate and enhance project resilience. URAT provides an intuitive, step-by-step framework for assessing uncertainty and resilience, offering actionable recommendations. Beyond assessment, it is a strategic resource to strengthen resilience and mitigate disruptions, promoting sustainable and robust projects.

Ultimately, this dissertation contributes to the broader field by offering a refined approach to integrating resilience into project management practices. The findings enhance both the theoretical understanding and practical application of resilience, paving the way for more robust and successful project outcomes, even in the face of uncertainty and volatility.

5.3 Limitations of the Research and Recommendations for Future Studies

Incorporating resilience into construction project management is still a relatively new and developing area of research that calls for further exploration (Thomé et al., 2016). The emergence of any new research field inevitably brings a range of definitions, methodologies, tools, and processes—and the concept of project resilience is no different. The author acknowledges the research's value but notes several limitations encountered during the study, opening up potential future research directions.

The existing literature on project resilience is still relatively scarce. This dissertation reviewed resilience research from multiple angles to address this gap to propose a definition and conceptual framework for project resilience. Additional research is required to further develop the ideas presented and highlight the importance of resilience in project management. This opens up a wealth of promising avenues for future exploration.

The conceptual model in this study was formulated based on the data gathered from 15 PPP projects in Türkiye. Although this sample size is adequate for the analysis used, a larger sample size may provide more accuracy since the findings may be influenced by respondents' interpretations. Additionally, the study’s results primarily represent the viewpoints of managers involved in Turkish PPP projects. Future research could include a broader range of projects from different countries to achieve more generalizable results or conduct comparative studies.

The resilience criteria developed in this study are derived from exploratory findings using PCA. However, the results of PCA may vary depending on the survey's sample size, the respondents' characteristics, and their areas of expertise. As a result, these resilience factors would benefit from further validation through Confirmatory Factor Analysis (CFA) and could be tailored to specific project contexts and disruptive events. Future research could, for instance, focus on refining each resilience factor into more detailed subordinate factors to better address these variations or introducing new resilience factors under any of the four recommended dimensions.

To advance the findings of this study, it is recommended to integrate artificial intelligence (AI) into future research on uncertainty and resilience assessment. AI technologies, such as machine learning algorithms and predictive analytics, can significantly enhance the accuracy, efficiency, and scalability of evaluating uncertainty and resilience. AI can offer a more robust and dynamic framework for resilience assessment by analyzing large datasets, identifying patterns, and providing real-time insights. Incorporating AI would enable decision-makers to address complex and rapidly changing project environments more effectively. It could automate data analysis, improve prediction accuracy, and support adaptive decision-making. Moreover, AI-driven tools could personalize resilience strategies based on context-specific factors, ensuring more targeted and actionable recommendations. This recommendation underscores the potential of AI to transform the study and application of resilience, paving the way for more innovative and impactful research in the field.

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APPENDICES

A. Correlation Matrix for Preparation Phase

	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16
RF1	1	0.26	-0.06	0.01	-0.06	-0.1	0.09	-0.06	0.08	0.03	0.08	0.07	-0.03	0.04	-0.02	-0.06
RF2	0.26	1	0.02	-0.06	-0.06	0.09	-0.15	-0.12	-0.05	0.14	-0.15	-0.05	0.06	-0.26	-0.13	-0.12
RF3	-0.06	0.02	1	0.26	0.28	0.06	-0.07	0.11	-0.06	-0.04	0.05	0.04	-0.06	0.06	0.13	0.06
RF4	0.01	-0.06	0.26	1	0.46	-0.03	0.03	0.14	-0.02	0.1	0.06	0.01	0.23	0.04	-0.02	-0.06
RF5	-0.06	-0.06	0.28	0.46	1	0.2	0.02	0.12	-0.11	0.07	-0.17	-0.06	0.16	-0.06	-0.1	-0.15
RF6	-0.1	0.09	0.06	-0.03	0.2	1	-0.18	0.14	-0.28	-0.07	-0.35	-0.23	-0.07	-0.25	-0.14	-0.27
RF7	0.09	-0.15	-0.07	0.03	0.02	-0.18	1	0.04	0.32	0.06	0.24	0.16	0	0.28	0.11	0.22
RF8	-0.06	-0.12	0.11	0.14	0.12	0.14	0.04	1	-0.09	-0.06	-0.12	-0.07	-0.07	-0.05	0.03	-0.11
RF9	0.08	-0.05	-0.06	-0.02	-0.11	-0.28	0.32	-0.09	1	-0.1	0.61	0.39	-0.09	0.43	0.4	0.45
RF10	0.03	0.14	-0.04	0.1	0.07	-0.07	0.06	-0.06	-0.1	1	-0.08	-0.06	0.34	-0.2	-0.21	-0.14
RF11	0.08	-0.15	0.05	0.06	-0.17	-0.35	0.24	-0.12	0.61	-0.08	1	0.46	-0.11	0.54	0.49	0.57
RF12	0.07	-0.05	0.04	0.01	-0.06	-0.23	0.16	-0.07	0.39	-0.06	0.46	1	-0.03	0.35	0.5	0.49
RF13	-0.03	0.06	-0.06	0.23	0.16	-0.07	0	-0.07	-0.09	0.34	-0.11	-0.03	1	-0.25	-0.06	-0.12
RF14	0.04	-0.26	0.06	0.04	-0.06	-0.25	0.28	-0.05	0.43	-0.2	0.54	0.35	-0.25	1	0.45	0.47
RF15	-0.02	-0.13	0.13	-0.02	-0.1	-0.14	0.11	0.03	0.4	-0.21	0.49	0.5	-0.06	0.45	1	0.58
RF16	-0.06	-0.12	0.06	-0.06	-0.15	-0.27	0.22	-0.11	0.45	-0.14	0.57	0.49	-0.12	0.47	0.58	1

B. Correlation Matrix for Absorption Phase

	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16
RF1	1	0.26	-0.06	0.01	-0.06	-0.1	0.09	-0.06	0.08	0.03	0.08	0.07	-0.03	0.04	-0.02	-0.06
RF2	0.26	1	0.02	-0.06	-0.06	0.09	-0.15	-0.12	-0.05	0.14	-0.15	-0.05	0.06	-0.26	-0.13	-0.12
RF3	-0.06	0.02	1	0.26	0.28	0.06	-0.07	0.11	-0.06	-0.04	0.05	0.04	-0.06	0.06	0.13	0.06
RF4	0.01	-0.06	0.26	1	0.46	-0.03	0.03	0.14	-0.02	0.1	0.06	0.01	0.23	0.04	-0.02	-0.06
RF5	-0.06	-0.06	0.28	0.46	1	0.2	0.02	0.12	-0.11	0.07	-0.17	-0.06	0.16	-0.06	-0.1	-0.15
RF6	-0.1	0.09	0.06	-0.03	0.2	1	-0.18	0.14	-0.28	-0.07	-0.35	-0.23	-0.07	-0.25	-0.14	-0.27
RF7	0.09	-0.15	-0.07	0.03	0.02	-0.18	1	0.04	0.32	0.06	0.24	0.16	0	0.28	0.11	0.22
RF8	-0.06	-0.12	0.11	0.14	0.12	0.14	0.04	1	-0.09	-0.06	-0.12	-0.07	-0.07	-0.05	0.03	-0.11
RF9	0.08	-0.05	-0.06	-0.02	-0.11	-0.28	0.32	-0.09	1	-0.1	0.61	0.39	-0.09	0.43	0.4	0.45
RF10	0.03	0.14	-0.04	0.1	0.07	-0.07	0.06	-0.06	-0.1	1	-0.08	-0.06	0.34	-0.2	-0.21	-0.14
RF11	0.08	-0.15	0.05	0.06	-0.17	-0.35	0.24	-0.12	0.61	-0.08	1	0.46	-0.11	0.54	0.49	0.57
RF12	0.07	-0.05	0.04	0.01	-0.06	-0.23	0.16	-0.07	0.39	-0.06	0.46	1	-0.03	0.35	0.5	0.49
RF13	-0.03	0.06	-0.06	0.23	0.16	-0.07	0	-0.07	-0.09	0.34	-0.11	-0.03	1	-0.25	-0.06	-0.12
RF14	0.04	-0.26	0.06	0.04	-0.06	-0.25	0.28	-0.05	0.43	-0.2	0.54	0.35	-0.25	1	0.45	0.47
RF15	-0.02	-0.13	0.13	-0.02	-0.1	-0.14	0.11	0.03	0.4	-0.21	0.49	0.5	-0.06	0.45	1	0.58
RF16	-0.06	-0.12	0.06	-0.06	-0.15	-0.27	0.22	-0.11	0.45	-0.14	0.57	0.49	-0.12	0.47	0.58	1

C. Correlation Matrix for Recovery Phase

	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16
RF1	1	0.32	0.24	0.16	0.75	0.1	0.21	0.65	0.19	0.16	0.16	0.33	0.17	0.47	0.18	0.7
RF2	0.32	1	0.26	0.33	0.15	0.24	0.36	0.18	0.21	0.08	0.17	0.17	0.33	0.04	0.27	0.16
RF3	0.24	0.26	1	0.34	0.27	0.05	0.21	0.32	0.01	0.26	0.06	0.17	0.08	0.16	0.06	0.08
RF4	0.16	0.33	0.34	1	0.19	0.38	0.66	0.15	0.22	0.23	0.59	0.1	0.64	0.09	0.59	0.06
RF5	0.75	0.15	0.27	0.19	1	0.07	0.09	0.57	0.05	0.26	0.12	0.28	0.07	0.51	0.15	0.69
RF6	0.1	0.24	0.05	0.38	0.07	1	0.41	0.07	0.38	0.16	0.54	0.08	0.39	0.13	0.4	0.12
RF7	0.21	0.36	0.21	0.66	0.09	0.41	1	0.24	0.2	0.1	0.57	0.12	0.71	0.08	0.67	0.15
RF8	0.65	0.18	0.32	0.15	0.57	0.07	0.24	1	0	0.23	0.04	0.14	0.11	0.48	0.08	0.55
RF9	0.19	0.21	0.01	0.22	0.05	0.38	0.2	0	1	0.41	0.56	0.43	0.27	0.2	0.4	0.25
RF10	0.16	0.08	0.26	0.23	0.26	0.16	0.1	0.23	0.41	1	0.25	0.6	0.06	0.16	0.24	0.32
RF11	0.16	0.17	0.06	0.59	0.12	0.54	0.57	0.04	0.56	0.25	1	0.18	0.57	0.28	0.74	0.26
RF12	0.33	0.17	0.17	0.1	0.28	0.08	0.12	0.14	0.43	0.6	0.18	1	0.18	0.21	0.2	0.42
RF13	0.17	0.33	0.08	0.64	0.07	0.39	0.71	0.11	0.27	0.06	0.57	0.18	1	0.04	0.71	0.14
RF14	0.47	0.04	0.16	0.09	0.51	0.13	0.08	0.48	0.2	0.16	0.28	0.21	0.04	1	0.14	0.6
RF15	0.18	0.27	0.06	0.59	0.15	0.4	0.67	0.08	0.4	0.24	0.74	0.2	0.71	0.14	1	0.33
RF16	0.7	0.16	0.08	0.06	0.69	0.12	0.15	0.55	0.25	0.32	0.26	0.42	0.14	0.6	0.33	1

D. Correlation Matrix for Adaptation Phase

	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12	RF13	RF14	RF15	RF16
RF1	1	0.43	0.47	0.04	0.02	0.29	0.28	-0.05	0.04	0.25	-0.16	0.15	0.16	0.05	0.2	-0.07
RF2	0.43	1	0.57	-0.02	-0.12	0.41	0.44	0.06	0.18	0.29	-0.19	0.02	0.06	0.06	0.13	0.25
RF3	0.47	0.57	1	0.04	0.03	0.43	0.48	0.13	0.07	0.29	-0.32	0.1	0.09	0.11	0.28	0.11
RF4	0.04	-0.02	0.04	1	0.38	0.05	-0.08	0.18	-0.04	0.06	-0.06	0.11	0.29	0.02	0	-0.21
RF5	0.02	-0.12	0.03	0.38	1	-0.06	-0.15	0.04	-0.05	0.05	-0.06	0.05	0.22	0.01	0.1	-0.22
RF6	0.29	0.41	0.43	0.05	-0.06	1	0.62	0.07	0.12	0.28	-0.26	0.22	0.08	0.1	0.31	0.04
RF7	0.28	0.44	0.48	-0.08	-0.15	0.62	1	0.21	0.29	0.35	-0.2	0.11	-0.07	0.06	0.21	0.16
RF8	-0.05	0.06	0.13	0.18	0.04	0.07	0.21	1	0.1	0.17	-0.11	-0.03	-0.02	-0.01	-0.08	0.06
RF9	0.04	0.18	0.07	-0.04	-0.05	0.12	0.29	0.1	1	0.1	0.17	0.01	-0.16	0.18	-0.03	0.25
RF10	0.25	0.29	0.29	0.06	0.05	0.28	0.35	0.17	0.1	1	-0.15	0.14	0.2	0.08	0.1	0.01
RF11	-0.16	-0.19	-0.32	-0.06	-0.06	-0.26	-0.2	-0.11	0.17	-0.15	1	-0.07	-0.12	0.15	-0.1	0.2
RF12	0.15	0.02	0.1	0.11	0.05	0.22	0.11	-0.03	0.01	0.14	-0.07	1	0.23	-0.08	0.12	-0.09
RF13	0.16	0.06	0.09	0.29	0.22	0.08	-0.07	-0.02	-0.16	0.2	-0.12	0.23	1	-0.03	0.14	-0.28
RF14	0.05	0.06	0.11	0.02	0.01	0.1	0.06	-0.01	0.18	0.08	0.15	-0.08	-0.03	1	0.15	0.2
RF15	0.2	0.13	0.28	0	0.1	0.31	0.21	-0.08	-0.03	0.1	-0.1	0.12	0.14	0.15	1	-0.03
RF16	-0.07	0.25	0.11	-0.21	-0.22	0.04	0.16	0.06	0.25	0.01	0.2	-0.09	-0.28	0.2	-0.03	1

E. Sample of First Questionnaire Survey

Section 1: <u>Participant Information Sheet</u>

What is the aim of this study?

The research aims to get a better grasp of phenomena affecting Public-Private Partnership (PPP) projects' ability to cope with uncertainty.

Who is doing this research and why?

Saeed Kamali is carrying out this survey towards his PhD study under the supervision of Prof. Dr. M. Talat Birgönül and Prof. Dr. İrem Dikmen Toker at the Civil Engineering Department of the Middle East Technical University.

Are there any exclusion criteria?

This study seeks to focus on PPP Projects in Türkiye.

What personal information will be required from me?

Education status, gender, years of experience in construction industry and level of experience in PPP projects.

What will I be expected to do?

You will be expected to answer questions about your opinion and experiences in PPP projects.

How long will it take?

No more than 20 minutes.

Once I take part, can I change my mind?

Yes, your participation in this survey is based on voluntary bias. Thus, you can withdraw at any time before, during or after completing the survey. However, we will miss the opportunity to learn from your rich experiences.

If you wish to withdraw before or during the survey, you should close the browser (Information will not be stored before clicking on submit button on the last page).

If you wish to withdraw after submitting the survey, please just send your withdrawal request to the main researcher. You will not be asked to explain your reasons for withdrawing.

Are there any risks in participating?

No. There is no risk for participating in this survey.

Will my participation in this study be kept confidential?

Yes, at no time will your true identity or that of the project be disclosed.

I have some more questions; who should I contact?

If you have any questions or require further clarification about this research study, don't hesitate to get in touch with me on saeed.kamali{at}metu.edu.tr or supervisors Prof. Dr. M. Talat Birgönül and Prof. Dr. İrem Dikmen Toker.

What will happen to the results of the study?

The results will be reported as part of the PhD study

I confirm that I have read and understood the information given above and agree to participate in this survey voluntarily.

Name and Surname: …………………………………

Email: ……………………………

Section 2: <u>Participant Information</u>

What is your gender?

Female / Male / Prefer not to say

What is your education status?

B.Sc. / M/Sc. / PhD. / Other (please specify………..)

How many years of experience do you have in the construction industry?

………………….

How do you express yourself in the field of Public-Private Partnership Projects?

Novice / Advanced Beginner / Competent / Proficient / Expert

Section 3: Project Information

Please think of a PPP project you have been involved in to answer the questions in this and the following sections.

Project Name?

…………………….

Project Type?

Airport/ Hospital (Health Campus) / Motorway / Railway / Sea Port & Marina / Power Plants / Other (please specify………..)

Project Current Status?

Planning / Construction / Operation / Completed / Other (please specify……)

Section 4: <u>Project Uncertainty</u>

Considering the specified project in Section 3, please rate the estimated level of each uncertainty source at the beginning of the project in the first column and rate its contribution to the project's overall level of uncertainty in the second column.

(1: Very Low, 2: Low, 3: Medium, 4: High, 5: Very High)

Uncertainty Factors	Estimated Level of availability (1-5)	Contribution to the project's overall level of uncertainty (1-5)
Political system instability (government policies on infrastructure PPPs are inconsistent and unstable)		
Legislative system instability (laws and regulations associated with PPPs are incomplete and unstable)		
Government approval process complexity (government inclines to follow complex procedures and inflexible rules)		
Community support (the associated community doesn't endorses developing this project)		
Regional economy instability (regional economy is unstable)		
Financial market reliability (reliable financing instruments are unavailable in the market)		
Clarity of performance requirement (facility performance requirements aren't clearly provided)		
Design complexity		
Construction complexity		
Operation / maintenance complexity		
Reliability of reference data (reference data are unreliable and inaccurate)		

If you expected any other source of uncertainty, could you please explain it and rate its estimated level at the beginning of the project and its contribution to the project's overall uncertainty?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………..

Section 5: Project Resilience

Considering the specified project in Section 3, please rate the availability of the factors below and rate the effectiveness and importance of them in coping with uncertainty based on your general experiences in all PPP projects you have been involved in.

(1: Very Low, 2: Low, 3: Medium, 4: High, 5: Very High)

Resilience Factors	Availability within the specified project (1-5)	Importance in coping with uncertainty (1-5)
Favourable legal frameworks for a dispute resolution and settlement		
Appropriate contingency planning		
Continuous progress monitoring of project		
Application of virtual design and construction (VDC), such as BIM		
Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)		
Early detection of regulatory and technical constraints		
Public/ community support		
The risk management maturity of project and project stakeholders		
Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition		
Establishing a central coordinating PPP authority in public agencies		
Effective price adjustment (escalation) and compensation mechanism		
Quick and flexile renegotiation mechanism		
Effective and transparent information sharing and collaboration between stakeholders		
Explicit risk sharing/allocation in the contract		
A flexible and collaboration-supportive contract		
A proper resource management and abundance of resources in the project		

If other strategies are used in the project to cope with uncertainty, could you please explain them and rate their availability degree together with their effectiveness and importance level?

………………………………………………………………………………………

Section 6: <u>Project Performance</u>

Considering the specified project in Section 3, please rate the availability of items below.

(1: Very Low, 2: Low, 3: Medium, 4: High, 5: Very High)

Performance Factors	Availability within the project (1-5)
The innovative ideas were developed during the project	
Conflicts and differences of opinion have been solved adequately during the project	
The solutions that have been developed really deal with the problems faced with during the project.	
Developed solutions are durable for the future	
Stakeholders are willing to work with each other in the future	
The overall benefits of the project exceed its costs	
Actual Schedule in comparison to Planned Schedule	
Actual Cost in comparison with the Budgeted Cost	

Thank you for taking the time to complete this survey.

I really appreciate your effort and the time you devoted to filling out the questionnaire.

F. Sample of Second Questionnaire Survey

Section 1: <u>Participant Information Sheet</u>

What is the aim of this study?

The research aims to get a better grasp of phenomena enhancing resilience Public-Private Partnership (PPP) projects.

Who is doing this research and why?

Saeed Kamali is carrying out this survey towards his PhD study under the supervision of Prof. Dr. M. Talat Birgönül and Prof. Dr. İrem Dikmen Toker at the Civil Engineering Department of the Middle East Technical University.

Are there any exclusion criteria?

This study seeks to focus on PPP Projects in Türkiye.

What personal information will be required from me?

Education status, gender, years of experience in construction industry and level of experience in PPP projects.

What will I be expected to do?

You will be expected to evaluate the importance of some factors that enable PPP projects to prepare for, absorb, recover from and adapt to disruptive events that may occur during the project's life cycle.

How long will it take?

No more than 20 minutes.

Once I take part, can I change my mind?

Yes, your participation in this survey is based on voluntary bias. Thus, you can withdraw at any time before, during or after completing the survey. However, we will miss the opportunity to learn from your rich experiences.

If you wish to withdraw before or during the survey, you should close the browser (Information will not be stored before clicking on submit button on the last page).

If you wish to withdraw after submitting the survey, please just send your withdrawal request to the main researcher. You will not be asked to explain your reasons for withdrawing.

Are there any risks in participating?

No. There is no risk for participating in this survey.

Will my participation in this study be kept confidential?

Yes, at no time will your true identity be disclosed.

I have some more questions; who should I contact?

If you have any questions or require further clarification about this research study, don't hesitate to get in touch with me on saeed.kamali{at}metu.edu.tr or supervisors Prof. Dr. M. Talat Birgönül and Prof. Dr. İrem Dikmen Toker.

What will happen to the results of the study?

The results will be reported as part of the PhD study

I confirm that I have read and understood the information given above and agree to participate in this survey voluntarily.

Name and Surname: …………………………………

Email: ……………………………

Section 2: Participant Information

What is your gender?

Female / Male / Prefer not to say

What is your education status?

B.Sc. / M/Sc. / PhD. / Other (please specify………..)

How many years of experience do you have in the construction industry?

………………….

How do you express yourself in the field of Public-Private Partnership Projects?

Novice / Advanced Beginner / Competent / Proficient / Expert

Section 3: Preparation

Please rate how important the following factors are in enabling a PPP project to anticipate a disruptive event.

(1: Not Important, 2: Less Important, 3: Neutral, 4: Important, 5: Highly Important)

Resilience Factors	Level of Importance (1-5)
Favourable legal frameworks for a dispute resolution and settlement	
Appropriate contingency planning	
Continuous progress monitoring of project	
Application of virtual design and construction (VDC), such as BIM	
Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	
Early detection of regulatory and technical constraints	
Public/ community support	
The risk management maturity of project and project stakeholders	
Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	
Establishing a central coordinating PPP authority in public agencies	
Effective price adjustment (escalation) and compensation mechanism	
Quick and flexile renegotiation mechanism	
Effective and transparent information sharing and collaboration between stakeholders	
Explicit risk sharing/allocation in the contract	
A flexible and collaboration-supportive contract	
A proper resource management and abundance of resources in the project	

Considering your experience, if there are any other factors that may enhance a PPP project's capacity to anticipate potential disruptions, please explain them.

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Section 4: <u>Absorption</u>

Please rate how important these factors are in enabling a PPP project to withstand and/or absorb the negative effects of disruptive events to prevent or slow down the performance of the project.

(1: Not Important, 2: Less Important, 3: Neutral, 4: Important, 5: Highly Important)

Resilience Factors	Level of Importance (1-5)
Favourable legal frameworks for a dispute resolution and settlement	
Appropriate contingency planning	
Continuous progress monitoring of project	
Application of virtual design and construction (VDC), such as BIM	
Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	
Early detection of regulatory and technical constraints	
Public/ community support	
The risk management maturity of project and project stakeholders	
Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	
Establishing a central coordinating PPP authority in public agencies	
Effective price adjustment (escalation) and compensation mechanism	
Quick and flexile renegotiation mechanism	
Effective and transparent information sharing and collaboration between stakeholders	
Explicit risk sharing/allocation in the contract	
A flexible and collaboration-supportive contract	
A proper resource management and abundance of resources in the project	

Considering your experience, if there are any other factors that may enhance a PPP project's capacity to withstand and/or absorb the negative effects of disruptions to prevent or slow down performance loss, please explain them.

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Section 5: <u>Recovery</u>

Please rate how important these factors are in enabling a PPP project to quickly recover from disruptive event and restore the lost performance.

(1: Not Important, 2: Less Important, 3: Neutral, 4: Important, 5: Highly Important)

Resilience Factors	Level of Importance (1-5)
Favourable legal frameworks for a dispute resolution and settlement	
Appropriate contingency planning	
Continuous progress monitoring of project	
Application of virtual design and construction (VDC), such as BIM	
Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	
Early detection of regulatory and technical constraints	
Public/ community support	
The risk management maturity of project and project stakeholders	
Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	
Establishing a central coordinating PPP authority in public agencies	
Effective price adjustment (escalation) and compensation mechanism	
Quick and flexile renegotiation mechanism	
Effective and transparent information sharing and collaboration between stakeholders	
Explicit risk sharing/allocation in the contract	
A flexible and collaboration-supportive contract	
A proper resource management and abundance of resources in the project	

Considering your experience, if there are any other factors that may enhance a PPP project's capacity to quickly recover from disruptions and restore lost performance, please explain them.

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Section 6: <u>Adaptation</u>

Please rate how important these factors are in enabling a PPP project to apply insights gained from disruptions and ultimately adapt to them in the future.

(1: Not Important, 2: Less Important, 3: Neutral, 4: Important, 5: Highly Important)

Resilience Factors	Level of Importance (1-5)
Favourable legal frameworks for a dispute resolution and settlement	
Appropriate contingency planning	
Continuous progress monitoring of project	
Application of virtual design and construction (VDC), such as BIM	
Application of sensing technology for monitoring and disruption detection (IoT, AI, etc.)	
Early detection of regulatory and technical constraints	
Public/ community support	
The risk management maturity of project and project stakeholders	
Adequate revenue guarantee mechanism (Minimum rate of return, minimum revenue, land-capping, full toll, restrictive competition, etc	
Establishing a central coordinating PPP authority in public agencies	
Effective price adjustment (escalation) and compensation mechanism	
Quick and flexile renegotiation mechanism	
Effective and transparent information sharing and collaboration between stakeholders	
Explicit risk sharing/allocation in the contract	
A flexible and collaboration-supportive contract	
A proper resource management and abundance of resources in the project	

Considering your experience, if there are any other factors that may enhance a PPP project's capacity to apply insights gained from disruptions and effectively adapt to them in the future, please explain them.

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CURRICULUM VITAE

Saeed KAMALI

EDUCATION

Degree	Institution	Graduation Year
MS	EMU, Civil Engineering, Famagusta (TRNC)	2014
BS	IAUM, Civil Engineering, Mashhad (IR)	2012
High School	NODET High School, Sabzevar (IR)	2004

FOREIGN LANGUAGES

Persian (Farsi), English, Turkish

PUBLICATIONS

1. Kamali, S., Birgönül, M.T., Dikmen, I., “Resilience in Construction Projects: A New Approach to Manage Disruption”, 7th International Project and Construction Management Conference, Istanbul, Turkey, Oct. 20-22, 2022.

2. Kamali, S., “Illustration of uncertainty and complexity factors in PPP projects”, 1st National Civil Engineering Symposium, Kyrenia, North Cyprus, Jun. 25-26, 2021.

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6. Çelik, T., Kamali, S., "Multidimensional Comparison of Lightweight Steel and Reinforced Concrete Structures", Technical Gazette, Vol. 25, No. 4, pp. 1234-1242, 2018.

7. Çelik, T., Kamali, S., "Gap Analysis for the Potential Use of Steel Construction in Cyprus", 11th International Congress on Civil Engineering (11ICCE), Tehran, Iran, May. 8-10, 2018.

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14. Kamali, S., "How to Write a Scientific Research Article", LAP LAMBERT Academic Publishing, Saarbrücken, Germany, 2015, ISBN: 978-3-659-68327-5.

15. Improving Thermal Comfort in Building and Reducing the Indoor Air Temperature Fluctuation in Cyprus by Utilizing the Phase Change Materials, M.S. Thesis, Eastern Mediterranean University, Civil Engineering Department, 2014.

16. Kamali, S., "Review of Building Free Cooling System Coupled with Phase Change Material", in Proceedings of the 11th International Congress on Advances in Civil Engineering (ACE'14), Istanbul, Turkey, Oct. 21-25, 2014.

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