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Analyzing Project Complexity, Its Dimensions and Their Impact on Project Success

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Abstract: Projects are undertaken in all science, engineering, and technology fields to achieve strategic and tactical goals. It is evident from the literature that projects are becoming more complex day by day, making project complexity a domain for current research. The objective of this study is to evaluate project complexity using a systematic, comprehensive, and widely accepted definition that can capture the multidimensional nature of project complexity and its impact on project success. Therefore, an integrative systemic framework has been selected to define project complexity considering seven key dimensions: context, size, diversity, autonomy, connectivity, emergence, and belonging. The study employed structural equation modeling to analyze project complexity, its dimensions and their relationship with project success for complex engineering projects. After an extensive literature review, a validated questionnaire was developed and used to obtain responses from different countries (Pakistan, China, UAE, UK, USA, and others) in the engineering fields of aerospace, design, manufacturing, oil and gas, IT, and construction. The work shows that project complexity has a negative impact on project success for complex engineering projects. Further, analyses examined the relationship between project success and the seven dimensions of project complexity. The significance of this study lies in its evaluation of project complexity using a systematic and comprehensive definition which is different from previous studies and brings more clarity and understanding of the underlying mechanisms and causal relationships between project complexity, project success and their related factors. The findings suggest that careful consideration of these dimensions and their factors can help project managers better understand and navigate project complexity and ultimately improve project success rates.

Keywords: project success; project complexity; structural equation modeling; critical factors of project complexity; critical factors of project success; dimensions of project complexity

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1. Introduction

Organizations utilize projects to accomplish their goals and objectives across the globe. It is evident that organizations, government agencies, and corporations are investing in enhancing their project management abilities, considering their noteworthy influence on performance and project success. The field of project management is expanding rapidly in different dimensions. The ultimate objective of project management is project success [1]. Despite being a widely discussed topic, project success remains ambiguous in the area of project management [2]. Both project managers and top management concur that project success is achieved when a project is finalized within the predetermined parameters of scope, cost, time, quality, resource, and risk [3,4]. The level of project complexity has a significant impact on project success [5]. Enhancing the probability of project success is a significant concern for practitioners, industry experts, and researchers, highlighting the importance of project complexity as a crucial subject [6]. In order to achieve successful project management, it is imperative to have a thorough understanding of project complexity [7]. As projects become more complex, there is increased emphasis on the concept of project complexity and its relationship with success. The literature widely acknowledges that project complexity acts as a major player in project failure [8]. Complexity makes completing projects challenging and requires additional efforts to achieve success [9]. Project complexity, a fundamental characteristic of a project, arises from the interplay of the elements of structure, dynamics, and uncertainty [10]. It is evident from the literature that previous studies have provided inconsistent definitions of project complexity. Researchers have conducted various studies to find factors for assessing and categorizing project complexity, due to the difficulties in precisely quantifying project complexity. According to Zhang et al., between 1996 and 2020, 30% of the studies on project complexity employed empirical research methods, 22% utilized theoretical interpretation and/or review, 21% opted for a case study approach, 16% employed modeling and/or simulation, 7% used a combination of two methods, and 4% employed other methods. Case studies in the literature involve various domains including project management, engineering, technology management, construction, engineering management, production engineering, design, planning and management of technical social systems, urban and regional research, business management, and management science [11].

Project complexity has been divided into three classifications: organizational, environmental, and technical [12]. Luo et al. classified project complexity as task complexity, organizational complexity, information complexity, technology complexity, goal complexity, and environmental complexity [13]. Bakhshi et al. divided project complexity into seven dimensions: size, context, autonomy, connectivity, diversity, belonging, and emergence [6]. Project complexity was classified into various types by Rezende et al., including dynamic, structural, uncertainty, social-political, pace, novelty, and institutional complexities [14]. Luo et al. suggested a method that combined fuzzy cognitive mapping (FCM) and structural equation modeling (SEM) to systematically establish the association between project complexity and its success [15]. Literature shows that there is a lack of a unified and widely accepted definition of project complexity, which leads to different interpretations and operationalization of the concept in different contexts and disciplines [12,16,17]. Further, there is a lack of a comprehensive and systematic measurement and assessment method for project complexity that can capture the multidimensional and dynamic nature of project complexity and its impacts on project success [11]. The present study aims to provide a comprehensive and systematic measurement method of project complexity using an integrated systemic framework of project complexity. Therefore, in this study, Bakhshi's definition of project complexity has been selected, taking into account seven key dimensions, which include context, size, diversity, autonomy, connectivity, emergence, and belonging. This definition was selected based on its ability to encompass the three major perspectives on project complexity: the points of view proposed by complexity theories, system of systems and the Project Management Institute [6]. Then, using Bakhshi's definition of project complexity, the impact of project complexity and its dimensions on project success was analyzed. The following key questions have been addressed in this work:

1. What factors are critical for project complexity and project success?
2. What are the mechanisms of influence between the various factors?
3. What are the impacts of various dimensions of project complexity on its success?

After an extensive literature review, the major influencing factors of project success and project complexity were selected and structural equation modeling (SEM) was utilized to analyze project complexity, its dimensions and their impact on project success. SEM is an effective path analysis tool that can manage several dependent variables and estimate factor structure and relations. In the context of analyzing project complexity, its dimensions and their relationship with project success for complex engineering projects, SEM is an appropriate tool due to the multidimensional nature of these concepts and their gradation between dimensions.

This study introduces an evaluation of project complexity based on a comprehensive conceptual framework, which is distinct from previous research as it takes an integrative and systematic approach. Furthermore, unlike prior studies that focused on specific fields like construction, IT, or transportation projects, this study covers diverse industries, such as aerospace, design, manufacturing, oil and gas, IT, and construction, from various countries. Overall, the proposed framework provides a novel perspective for understanding project complexity and is a valuable contribution to the literature. Having a clear comprehension of project success, project complexity, and their interconnection would assist project managers in making better decisions and achieving project success in a more effective manner.

2. Literature Review

2.1. Project Success

The literature clearly demonstrates that critical success factors have been widely studied. The six critical factors for success identified by Kerzner are: organizational adaptability, project manager leadership style, commitment of executives to project management, corporate comprehension of project management, and commitment to planning and control. [18]. Ten general success factors were recognized by Pinto and Slevin, including support from top management, project mission, personnel, technical duties, project schedule, consultation of clients, client acceptance, communication, monitoring and feedback, and trouble-shooting. These factors were classified into strategic and tactical subgroups and the relationships among these factors were explained. The study served as the foundation for the creation of a behavioral instrument which could be used to diagnose and assess the state of any project, based on the ten-factor model [19]. Aaron and Dov distinguished four major dimensions of success: direct business and organizational success, project efficiency, customer impact, and readiness for the future. They proposed that the significance of these dimensions is affected by project duration and the level of technological uncertainty present [20]. White and Fortune identified twenty-two critical success factors and found that the three most vital factors were clear goals/objectives, support from senior management, and adequate resources [21]. Belout and Gauvreau demonstrated that the human resource factor had a limited influence on project success [22]. They examined the construct validity of the personnel factor and established its model. Khan and Spang highlighted the significance of critical success factors for international projects and divided them into four dimensions: national factors, project, personnel, and organizational. The purpose of the categorization was to verify the influence of national factors on international projects' success. They introduced a model that demonstrated the substantial impact of national factors on the success of international projects. Furthermore, the model highlighted how these national factors also impacted the remaining three dimensions: project, personnel, and organizational [23]. Alzahrani chose thirty-five critical success factors for examination and classified them into nine groups. The study utilized techniques of logistic regression to establish predictive models for determining the project success probability. The analysis revealed that variables such as size of past projects completed, history of turnover, adequacy of plant and labor resources, quality policy, waste disposal, and company image were the most influential factors affecting project success [24]. Berssaneti investigated project management maturity and project success. In his study, he also looked into how assigning a specialized project manager and receiving top management support could influence the results. A survey was conducted among 336 participants within Brazilian organizations, from the area of project management. The objective was to investigate the relationship between project management maturity and the success dimensions represented by the vertices of the iron triangle (time, cost, and technical performance), as well as customer satisfaction. The results showed a significant association between the iron triangle dimensions of success and project management maturity, but no relationship was found with customer satisfaction [25]. From the perspective of construction projects in developing countries, Banihashemi conducted a comprehensive examination of essential success factors that contribute to the incorporation of sustainability into project management. He identified crucial success factors associated with social, environmental, and economic dimensions. A conceptual model was used to illustrate these factors, which were subsequently validated using a survey that yielded 101 questionnaires [26]. Gunduz identified forty success factors and grouped them into seven different categories: factors related to the project manager, factors related to the project, factors related to the company and work, project management factors, factors related to the client, factors related to the design team, and factors related to the contractor. He used Analytic Hierarchy Process (AHP), Relative Importance Index (RII), and the Saaty random index to prioritize the critical success factors. Financial problems, administrative aspects, and the approval mechanisms of authorities were revealed as the most significant factors affecting the project [27]. Shamim presented an overview of essential success factors by examining various perspectives, hypotheses, models and solutions, as well as discussing past testing methodologies and other aspects of project success factor propositions. The work drew upon various theories, knowledge, and ideas to explain project success through the integration of results obtained from diverse research methodologies into a conceptual framework [28]. Jaime presented the findings of an exploratory survey that involved experienced information systems project managers. The results indicated that the lack of formal evaluation of success resulted in missed opportunities for lessons learned and project management improvement [2]. Mario et al. investigated the impact of potential and realized absorptive capacity on project success, with strategic agility acting as a mediator and project complexity as a moderator. They collected data from 285 participants working in the IT sector of small to medium-sized Portuguese enterprises through online channels, necessitated by the COVID-19 pandemic. The results revealed that both potential and realized absorptive capacity had a direct influence on project success, and strategic agility played a mediating role. Furthermore, project complexity positively moderated the relationship between potential absorptive capacity and strategic agility [29].

Using a comprehensive analysis of the existing literature, the preceding discussion, and consultation with experts from the project management industry, eleven critical success factors were selected for this study. Table 1 shows the details of the critical factors for project success:

Table 1. Critical factors for project success.

S. No.	Critical Factors for Project Success (PS)	Supporting Literature
1. →	(PS1) Time	[1,15,20,24,30–34]
2. → 3. →	(PS2) Cost (PS3) Quality	
4. →	(PS4) Top management support	[27,35–44]
5. →	(PS5) Environment	[1,15,24,27,45–47]
6. →	(PS6) Stakeholders' satisfaction	[15,30,48–52]
7. →	(PS7) Customer satisfaction	[15,25,31,33,52–54]
8. →	(PS8) Planning	[21,25,27,36,45,47,55,56]
9. →	(PS9) Control	[21,25,27,36,45,47,55,56]
10. →	(PS10) Technology/Technical Tasks	[1,32–34,41,44,54]
11. →	(PS11) Clear and realistic goals/objectives/mission	[27,36,41,43,50,57–59]

2.2. Project Complexity

According to Baccarini, project complexity can be defined in the form of differentiation and interdependency. He further clarified his suggested definition, distinguishing between organizational complexity and technological complexity, two different types of project complexity. The aim of his work was to conduct a review of project complexity theory and to encourage further debate on the topic [60]. Nassar et al. created a method to assess project schedule complexity by considering the interconnectivity of activities. His measure, which quantified the extent of interrelationship among activities within a project's schedule, was stated as a percentage to make it easier for project managers to understand. Additionally, the measure was incorporated into a computerized tool that can assist managers in evaluating project complexity. To improve the functionality of widely used commercial scheduling software, such as MS Project, the utility was specifically developed as an add-in [61]. Vidal et al. categorized the factors influencing project complexity into two main categories: organizational complexity factors and technological complexity factors. They also acknowledged the existence of concerns regarding the reliability of project complexity measurement and the appropriateness of the proposed models, despite previous attempts in this direction. That is why the necessity of employing a multi-criteria decision-making (MCDM) tool for accurately evaluating project complexity was crucial. They put forward a novel model that utilized the Analytic Hierarchy Process (AHP) to find the project complexity index [62,63]. Bosch-Rekveldt et al. presented the framework of TOE (technical–organizational–environmental), which encompassed fifty factors categorized into three distinct categories: technical, organizational, and environmental [12]. They conducted an online survey and determined that respondents agreed that organizational complexity in engineering projects was a significant concern. They found that project managers exhibited a greater concern towards organizational complexity compared to environmental or technical complexities [64]. Qureshi and Kang established a model to examine how organizational complexity factors affect project complexity management. The model was created using structural equation modeling and revealed that factors such as project size, project variety, and interdependencies had a significant effect on complexity. However, the study was limited to only considering organizational factors [65]. Nguyen et al. identified thirty-six factors of project complexity, uniquely pertinent to Vietnam's transport construction projects. They developed a "cube", a hierarchical framework of project complexity using six essential elements: organizational, infrastructural, sociopolitical, environmental, technological, and scope complexities [66]. Dao et al. identified indicators of complexity and used a complexity theory and complexity management perspective to understand project complexity. They then determined the level of complexity by identifying and measuring these indicators [67]. Bakhshi developed an integrative systemic framework to define project complexity. He performed a systematic literature review to highlight prior knowledge and insights regarding commonalities and distinctions in the literature. This involved analyzing over 420 published research papers, which were selected from a larger dataset of around 10,000 papers, employing their citation frequency as the criterion over the period of 1990–2015. He further identified three primary and distinct models for project complexity understanding: the points of view proposed by complexity theories, system of systems and the Project Management Institute. In defining project complexity, Bakhshi considered seven key dimensions, namely context, size, diversity, autonomy, connectivity, emergence and belonging [6]. Cristóbal et al. found that complexity could impact the evaluation, modeling, control, and targets (associated with cost, time, quality, and safety) of projects. They determined that complexity could influence the choice of project management arrangements and project organization structure, which includes the requisite skills and experience for project managers. They also examined the project complexity concept and presented the primary models associated with project complexity [68]. Rezende et al. used bibliometric analysis to explore the field of project complexity research. They found that the research area has progressed in three phases (before 1985, between 1990 and 2004, and after 2005). The first phase was marked by several isolated seminal works, the second phase observed a centralized discussion on characterizing and classifying complex projects, and the third phase focused on developing models and frameworks to aid managers in managing and adapting to complex projects. The study revealed that project complexity can be classified into different dimensions: dynamics, structural, novelty, uncertainty, social-political, pace, and institutional complexities. They also highlighted the shift in focus from mere project control to adaptability in the face of complexity. They emphasized the significance of developing the requisite skills and capabilities to effectively manage complex projects at the organizational or team level, as well as across the project's entire supply chain [14]. Kermanshachi et al. developed a framework for creating a tool that enables the effective evaluation and quantification of project complexity levels. The tool, which included a "Complexity Measurement Matrix", consisted of thirty-seven complexity indicators (CIs) that were shown to be crucial in determining the complexity of a project [17]. Mikkelsen indicated that mental models of practitioners focused on a limited number of dimensions among numerous dimensions presented in descriptive models. He further revealed that the mental models were significantly shaped by the perceiver's role within the project and to a lesser extent by the type of project and sector [69]. Rezende et al. studied project complexity factors in defense projects and found eighteen main factors and four new factors. They revealed interdependencies between these factors, forming a complex network that results in unpredictable and complex behaviors. It was found that the delivery capacity of a team influenced the perception of complexity in a project, with a lower capacity leading to a greater perception, as the team may not have the ability to manage and respond to the multiple interrelated elements. The presented systemic view diverged from the prevalent functionalist approach which has been frequently employed in frameworks of project complexity [70]. Nazeer and Carl aimed to identify and understand the essential constructs for measuring information systems (IS) project complexity. Through the use of PLS-SEM, a model was developed, revealing that IS project complexity was rooted in organizational complexity, technical complexity, and uncertainty. The project manager was responsible for managing aspects of organizational complexity, such as the project team, stakeholder management, and strategic drive. Technical complexity was determined by factors like project goals, requirements management, technology handling, and adherence to norms and standards. Uncertainty in IS projects pertained to skills management, the triple constraint, and activity management [71].

Zhang et al. undertook a systematic and comprehensive literature review, centering on the concept, dimensions, assessment, and underlying mechanisms of project complexity. The primary goal of the study was to minimize disparities in previous research by providing a concise summary of the definition and operationalization of project complexity. The study introduced an inclusive framework that provided a comprehensive perspective on the current comprehension of project complexity and suggested potential avenues for further exploring this aspect in future research [11]. Chantal examined the role of project complexity in driving innovation within megaprojects. The paper critically evaluated innovation dimensions and their correlation with project complexity based on a cross case study involving two megaprojects. Additionally, the study uncovered interactions between different innovation dimensions. Project complexity was recognized as a contingent factor influencing the relationship between innovation and project performance. The paper suggested policy recommendations, including the evaluation of innovation adoption in conjunction with complexity reduction, as well as the improved integration of innovation in megaproject planning [72]. Ghaleb et al. investigated the existing state and potential future trends in the construction project complexity (CPC) literature sourced from the Scopus database. The review employed systematic bibliometric and scientometric methods, including co-occurrence and co-citation analysis. Notable research areas within the CPC literature included identifying and measuring project complexity, schedule performance, cost estimation, system integration, dynamic capabilities, and risk assessment and uncertainty. Furthermore, the study suggested potential research directions focusing on safety performance, organizational resilience, and integrated project delivery (IPD) [73]. Marin and Anita conducted a comprehensive review of existing studies on project complexity elements. Based on the frequency of occurrence in surveys, the paper identified eight distinct groups of complexity characteristics that contractors need to be mindful of during construction projects. Additionally, fifteen specific elements of complexity were classified for each project complexity group, based on their frequency of occurrence in surveys. The study involved construction project managers to precisely determine the key complexity elements from the contractor's perspective. As a result, the research successfully classified the groups and associated key elements that determine the complexity of a construction project from the contractor's standpoint [74].

Using a comprehensive analysis of the existing literature, the preceding discussion, and consultation with experts from the project management industry, thirty-three critical factors for seven dimensions of project complexity were selected for this study. Table 2 shows the details:

Table 2. Latent and observed variables for project complexity.

Dimensions of Project Complexity	Critical Factors for Project Complexity (PC)	Supporting Literature
(D1) Context	(PC1) Cultural configuration	[6,62,63,75–80]
	(PC2) Environment complexity	[6,65,75,78,81–84]
	(PC3) Level of competition	[6,12,14,66,78,85–87]
	(PC4) Geological condition	[5,6,10,46,66,75,88–92],
	(PC5) Political issues	[93–98]
(D2) Size	(PC6) Number of teams/groups/structures to be coordinated	[6,62,63,65,78,99–103]
	(PC7) Largeness of capital investment	[6,62,63,65,66,78,80,104,105]
	(PC8) Number of investors/financial resources	[6,12,62,63,65,76,78,80,87]
	(PC9) Number of information systems	[6,62,63,65,76,78,80,84,106]
	(PC10) Number of activities	[6,12,61,65,76,78,95,107,108]
	(PC11) Number of objectives/goals	[6,12,62–65,76,78,80,84]
	(PC12) Number of hierarchical level	[6,65,75,76,78,88,108–111]
	(PC13) Project duration	[5,10,12,56,64,66,78,87,102,112–114]
(D3) Diversity	(PC14) Cultural variety/diversity	[6,78,115–120]
	(PC15) Variety of information systems to be combined	[6,62,63,65,78–80,84,121]
	(PC16) Geographic location of the stakeholders	[6,62,63,65,78,80,84]
	(PC17) Variety of organizational interdependencies	[6,16,65,78,80,93,121]
	(PC18) Variety of the interests of the stakeholders	[6,12,65,76,78,80,84]
	(PC19) Variety of technologies	[5,6,66,78,86,93,104,105]
(D4) Autonomy	(PC20) Process interdependencies	[6,76,78,95,122,123]
	(PC21) Availability of resources	[5,6,12,65,86,87,93,95,124–129]
	(PC22) Dependencies with the environment	[6,12,62,63,65,78,80,130]
	(PC23) Interdependencies between actors	[6,65,78,80,84,121]
	(PC24) Dependencies between schedules	[6,62,63,65,78,95,106]
(D5) Connectivity	(PC25) Goals/objectives alignment	[6,12,64,84,97]
	(PC26) Feedback loops and interconnectivity in the task and project networks	[6,65,78,80,84,121]
	(PC27) Relations with permanent organizations	[6,78,80,84,120]
(D6) Emergence	(PC28) Uncertainty of scope	[6,12,14,96,115,131]
	(PC29) Uncertainty of objectives and methods	[6,75,79,93,103,120,132]
	(PC30) Information uncertainty	[6,12,66,92,99,104,133]
(D7) Belonging	(PC31) Technological newness of the project	[5,6,14,118,134]
	(PC32) Strict quality requirement	[6,10,12,64,66,85,87,108]
	(PC33) Unknown/poorly defined requirements	[6,79,93,135,136]

2.3. Hypothesis Development

Numerous investigations have demonstrated that project complexity influences project success and that conventional approaches to project management are insufficient in dealing with such complexity. For construction industry projects, researchers have found a negative association between project complexity and project success [5]. Increasing complexity in construction projects has been found to be a result of various factors, including a lack of complexity management being a major cause of project failure [108,137,138]. To improve the chances of successful project delivery, scholars and practitioners are focusing on the management of project complexity [5,6]. Complexity is a major issue in construction projects, causing low success rates in project delivery [6,139]. The proposed study aims to carefully examine how project complexity, its dimensions, and project success relate to one another, by conducting an extensive examination of engineering projects spanning multiple industries.

As part of this, the following hypotheses have been proposed:

Hypothesis 1 (H1). *Project complexity has a negative impact on project success for complex engineering projects.*

Hypothesis 2 (H2). *Context has a negative impact on project success for complex engineering projects.*

Hypothesis 3 (H3). *Size has a negative impact on project success for complex engineering projects.*

Hypothesis 4 (H4). *Diversity has a negative impact on project success for complex engineering projects.*

Hypothesis 5 (H5). *Autonomy has a negative impact on project success for complex engineering projects.*

Hypothesis 6 (H6). *Connectivity has a negative impact on project success for complex engineering projects.*

Hypothesis 7 (H7). *Emergence has a negative impact on project success for complex engineering projects.*

Hypothesis 8 (H8). *Belonging has a negative impact on project success for complex engineering projects.*

3. Research Methodology

The data collected through a questionnaire using the methods explained in this section were analyzed using structural equation modeling (SEM) in AMOS.

3.1. Development of Questionnaire

Thirty-three critical factors for seven dimensions of project complexity, namely, context, size, diversity, autonomy, connectivity, emergence, and belonging, were proposed on the basis of the literature review and definition provided in a previous study [6] and eleven factors for project success were selected. Before conducting the survey, a panel of six project management experts from industry was selected to gather their opinions and evaluate the questionnaire's contents. To enhance the respondents' comprehension and minimize response bias, certain questions were modified, and the survey tool was further refined based on their feedback. The survey instrument was composed of three distinct parts: the first section was specifically crafted to gather demographic data from respondents (Table 1 shows the details of the questions of Section 1), the second section asked questions related to the seven dimensions and critical project complexity factors (Table 2 shows the details of the questions of Section 2), and the third section consisted of questions related to project success (Table 3 shows the details of the questions of Section 3). A measurement scale based on a five-point Likert scale was used to develop the questionnaire, where "1" stood for "strongly disagree", and "5" for "strongly agree".

Table 3. Demographics information of the respondents.

Attribute	Classification	Frequency (N = 281)	Percentage
Industry	Aerospace	97	35%
	Design	43	15%
	Manufacturing	41	15%
	Oil and Gas	32	11%
	IT	27	10%
	Automotive	26	9%
	Construction	15	5%
Country	Pakistan	144	51%
	China	53	19%
	UAE	15	5%
	UK	13	5%
	USA	12	4%
	Germany	11	4%
	France	10	4%
	South Africa	10	4%
	Australia	5	2%
	Others	8	3%
Experience	5–10 (years)	75	27%
	10–15 (years)	74	26%
	15–20 (years)	94	33%
	Over 20 years	38	14%
Qualification	Bachelors	39	14%
	Masters	206	73%
	PhD	36	13%
Designation	Project Director	40	14%
	Project Manager	114	41%
	Project Management Practitioner	127	45%
Gender	Female	18	6%
	Male	263	94%

3.2. Sampling Procedure and Bias

The objective of this work was to gather data on project success and project complexity and thus a thorough understanding related to practices of project management employed in complex engineering projects was a key selection criterion for the respondents. The respondents were chosen with this requirement in mind based on their relevant professional experience, current job title, and educational background. Table 3 indicates that the survey received responses primarily from practitioners with over 15 years of experience, while also having a strong educational background. Specifically, 73% of respondents held a master's degree in engineering and 41% were project managers. In the survey, the most represented industry was aerospace industry, followed by design, manufacturing, and other industries. Additional demographic information on the participants can be found in Table 3.

Although it is widely accepted that managers can offer unbiased and reliable information through self-reports [140,141], we acknowledge that there may be associated biases. Self-reported data can be particularly problematic for subjects that trigger strong emotional responses, such as attitudes [65,140]. Nevertheless, it was noted that project complexity and success were relatively less emotional topics and therefore the likelihood of being distorted by self-report was reduced. An additional concern was the social desirability bias, which can often result in distorted findings [141]. However, with regard to the design of the current study, no evidence was found to suggest that social desirability has influenced the results.

3.3. Sample Size and Response Rate

The distribution of the survey was carried out through email, as internet surveys enable for the transfer of more comprehensive information and enhance communication between the respondents and the researcher. This approach helps ensure higher-quality information, faster response time, and reduced research expenses [142]. As individuals working in various geographical locations and different fields of engineering may have diverse experiences, our interest lies in gathering perspectives from professionals operating in different countries and industries. Project management professionals from different countries (Pakistan, China, UAE, UK, USA, and others) working in different fields (aerospace, design, manufacturing, oil and gas, IT, construction etc.) were sought for their feedback. Despite extensive research, scholars have yet to reach a consensus on an optimal sample size. Hox recommended a sample of 200 for normally distributed data [143], while Marsh et al. argue that a larger sample size leads to more accurate results based on convergence and fitting indices [144]. On the other hand, Hair et al. contend that an optimal sample size is above 200, while also cautioning against an excessive amount of data, which can result in poor fitness indices for datasets with more than 400 samples [145]. The study sent out 530 questionnaires, of which 369 were returned. Of these, 281 responses were deemed suitable for analysis, yielding a response rate of 53%. The acquired response rate was considered reasonable when compared to similar previously published work [146,147].

3.4. Reliability and Validity

The measurement model's strength and adequacy were evaluated using Cronbach's reliability test [145]. An internal consistency of an acceptable level is indicated by a Cronbach's alpha coefficient of at least 0.70, which was used as a cutoff value. In Table 4, the indicators for the eight latent constructs (for the final structure equation model) are shown, along with their corresponding measurements. These constructs exhibit values exceeding 0.70, indicating a high level of reliability and suitability for analysis.

Table 4. Final model's reliability testing.

Latent Variables	Measured Variables	Cronbach's Alpha Value (α)
(D1) Context	(PC1) Cultural configuration (PC2) Environment complexity (PC3) Level of competition (PC4) Geological condition (PC5) Political issues	0.719
(D2) Size	(PC7) Largeness of capital investment (PC8) Number of investors/financial resources (PC10) Number of activities (PC11) Number of objectives/goals (PC13) Project duration	0.717
(D3) Diversity	(PC15) Variety of information systems to be combined (PC16) Geographic location of the stakeholders (PC17) Variety of organizational interdependencies (PC18) Variety of the interests of the stakeholders (PC19) Variety of technologies	0.702
(D4) Autonomy	(PC20) Process interdependencies (PC21) Availability of resources (PC22) Dependencies with the environment (PC23) Interdependencies between actors (PC24) Dependencies between schedules	0.708

Table 4. *Cont.*

Latent Variables	Measured Variables	Cronbach's Alpha Value (α)
(D5) Connectivity	(PC25) Goals/objectives alignment (PC26) Feedback loops and interconnectivity in the task and project networks (PC27) Relations with permanent organizations	0.729
(D6) Emergence	(PC28) Uncertainty of scope (PC29) Uncertainty of objectives and methods (PC30) Information uncertainty	0.910
(D7) Belonging	(PC31) Technological newness of the project (PC32) Strict quality requirement (PC33) Unknown/poorly defined requirements	0.710
(PS) Project Success	(PS4) Top management support (PS5) Environment (PS8) Planning (PS9) Control (PS10) Technology/Technical Tasks (PS11) Clear and realistic goals/objectives/mission	0.727

The final model achieved was validated using Pearson correlation analysis [148]. Table 5 shows the resulting correlations, which demonstrate significant correlations among the latent variables and provide evidence for the final model's convergent validity.

Table 5. Construct correlations.

	Context (D1)	Size (D2)	Diversity (D3)	Autonomy (D4)	Connectivity (D5)	Emergence (D6)	Belonging (D7)	Project Success (PS)
Context (D1)	1							
Size (D2)	0.289 **	1						
Diversity (D3)	0.328 **	0.422 **	1					
Autonomy (D4)	0.227 **	0.442 **	0.482 **	1				
Connectivity (D5)	0.176 **	0.415 **	0.313 **	0.531 **	1			
Emergence (D6)	0.157 **	0.068	0.225 **	0.377 **	0.152 *	1		
Belonging (D7)	0.223 **	0.367 **	0.327 **	0.415 **	0.207 **	0.354 **	1	
Project Success (PS)	−0.386 **	−0.416 **	−0.433 **	−0.424 **	−0.363 **	−0.259 **	−0.414 **	1

** Significant correlation has been determined at the 2-tailed 0.01 level. * Significant correlation has been determined at the 2-tailed 0.05 level.

4. Results and Discussions

4.1. Relationship between Project Complexity and Project Success

SEM was utilized to investigate the association between project complexity and the success of complex engineering projects. This study employed a two-stage method to conduct the SEM [147]. The initial phase of Confirmatory Factor Analysis (CFA) reveals an acceptable goodness of fit (GOF). Several iterations were performed and loadings below 0.5 were removed [145] to reach the final SEM model shown in Figure 1. Results of the final SEM are presented in Tables 6–8.

The SEM model represents the seven project complexity dimensions as latent variables, while the critical project complexity factors serve as dominant variables. According to the analysis's results, a negative correlation is found between project complexity and success of −0.754, which has a statistical significance level of $p < 0.001$. The findings support hypothesis H1.

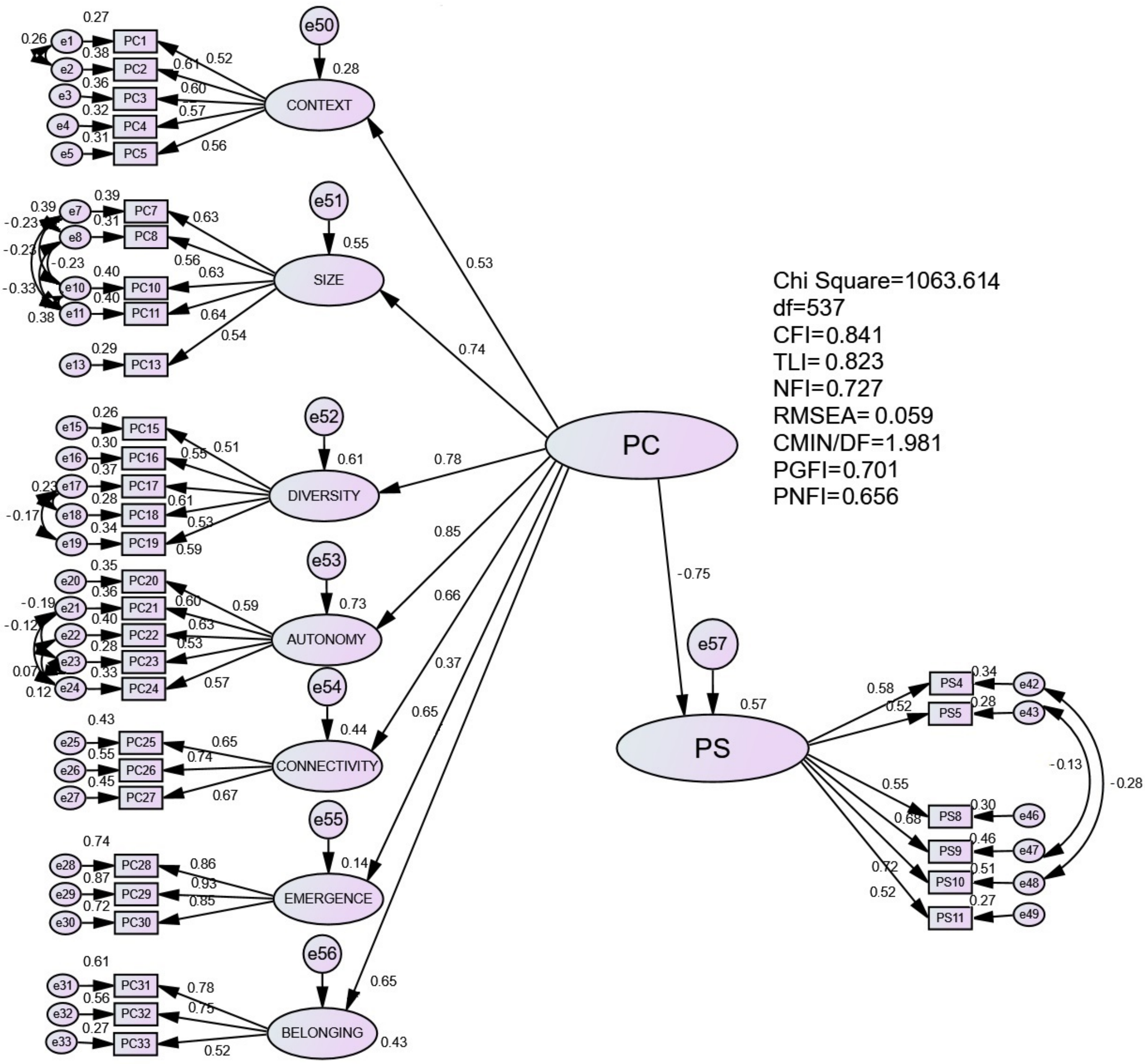

Figure 1. The finalized SEM model for project complexity (PC) and project success (PS).

Table 6. Results for goodness of fit (GOF) measures.

GOF Measure	Levels of GOF Measure (Recommended) [65,149]	PC and PS	D1 and PS	D2 and PS	D3 and PS	D4 and PS	D5 and PS	D6 and PS	D7 and PS
χ^2/df	<5	1.98	1.5	1.37	1.92	1.42	1.34	2.25	1.37
Absolute fit measure									
Root mean square error of approximation (RMESA)	<0.10	0.06	0.04	0.04	0.06	0.04	0.04	0.07	0.04
Incremental fit measure									
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0.84	0.97	0.98	0.94	0.98	0.99	0.97	0.98
Tucker–Lewis index (TLI)	0 (no fit) to 1 (perfect fit)	0.82	0.96	0.97	0.92	0.96	0.98	0.95	0.98
Parsimonious fit measure									
Parsimonious goodness of fit index (PGFI)	>0.5	0.7	0.58	0.52	0.56	0.53	0.52	0.51	0.52
Parsimonious normal-fit index (PNFI)	>0.5	0.66	0.66	0.6	0.63	0.62	0.63	0.63	0.63

Table 7. Summary of standardized regression weights of paths (final SEM model).

Path			Estimate
Project Success	←	Project Complexity	−0.754
Context	←	Project Complexity	0.529
Size	←	Project Complexity	0.739
Diversity	←	Project Complexity	0.784
Autonomy	←	Project Complexity	0.853
Connectivity	←	Project Complexity	0.662
Emergence	←	Project Complexity	0.371
Belonging	←	Project Complexity	0.652
PC1	←	Context	0.517
PC2	←	Context	0.614
PC3	←	Context	0.598
PC4	←	Context	0.565
PC5	←	Context	0.556
PC7	←	Size	0.626
PC8	←	Size	0.559
PC10	←	Size	0.63
PC11	←	Size	0.635
PC13	←	Size	0.535
PC15	←	Diversity	0.505
PC16	←	Diversity	0.545
PC17	←	Diversity	0.607
PC18	←	Diversity	0.531
PC19	←	Diversity	0.587
PC20	←	Autonomy	0.594
PC21	←	Autonomy	0.597
PC22	←	Autonomy	0.631
PC23	←	Autonomy	0.534
PC24	←	Autonomy	0.575
PC25	←	Connectivity	0.653
PC26	←	Connectivity	0.742
PC27	←	Connectivity	0.672
PC28	←	Emergence	0.859
PC29	←	Emergence	0.931
PC30	←	Emergence	0.846
PC31	←	Belonging	0.783
PC32	←	Belonging	0.751
PC33	←	Belonging	0.523
PS4	←	Project Success	0.583
PS5	←	Project Success	0.525
PS8	←	Project Success	0.548
PS9	←	Project Success	0.677
PS10	←	Project Success	0.716
PS11	←	Project Success	0.521

A statistical significance at a level of $p < 0.001$ is observed for all standardized coefficients in the model.

Table 8. Summary of direct effects of project complexity and its dimensions on project success.

Path			Estimate	S.E.	*t*-Value	Hypothesis Status
Project Complexity (PC)	→	Project Success (PS)	−0.754	0.292	−2.582	H1 is supported.
Context (D1)	→	Project Success (PS)	−0.522	0.101	−5.168	H2 is supported.
Size (D2)	→	Project Success (PS)	−0.527	0.088	−5.989	H3 is supported.
Diversity (D3)	→	Project Success (PS)	−0.580	0.124	−4.677	H4 is supported.
Autonomy (D4)	→	Project Success (PS)	−0.555	0.085	−6.529	H5 is supported.
Connectivity (D5)	→	Project Success (PS)	−0.472	0.073	−6.466	H6 is supported.
Emergence (D6)	→	Project Success (PS)	−0.294	0.032	−9.188	H7 is supported.
Belonging (D7)	→	Project Success (PS)	−0.580	0.059	−9.831	H8 is supported.

All values are significant at $p < 0.001$.

Table 6 presents the final SEM model substantiated by the appropriate GOF measures. The χ^2/degree of freedom of 1.981 demonstrates that the data have a satisfactory fit. An absolute fit parameter, the root mean square error of approximation (RMSEA), has been calculated to be 0.059, indicating that it falls below the recommended threshold of 0.10. Incremental fit parameters, the comparative fit index (CFI) and the Tucker–Lewis index (TLI), have values of 0.841 and 0.823, respectively, indicating an acceptable model fit. Both the parsimonious normal-fit index (PNFI) and the parsimonious goodness of fit index (PGFI) have values greater than 0.5, indicating ample evidence of the satisfactory fit of the measurement model with the data.

Table 7 provides the standardized regression weights' summary for the final model. All of the model's path coefficients exhibit statistical significance at a level of $p < 0.001$, indicating their strong association with the model. Project complexity was categorized into seven dimensions in the final SEM model: (D1) context, (D2) size, (D3) diversity, (D4) autonomy, (D5) connectivity, (D6) emergence, and (D7) belonging. Project success was directly influenced by six factors, specifically (PS4) top management support, (PS5) environment, (PS8) planning, (PS9) control, (PS10) technology/technical tasks, and (PS11) clear and realistic goals/objectives/mission.

4.2. Relationship between Dimensions of Project Complexity and Project Success

Using structural equation modeling (SEM), the effects of different dimensions of project complexity on project success were examined. This analysis included (D1) context, (D2) size, (D3) diversity, (D4) autonomy, (D5) connectivity, (D6) emergence, and (D7) belonging. Figures 2–8 illustrate the final SEMs.

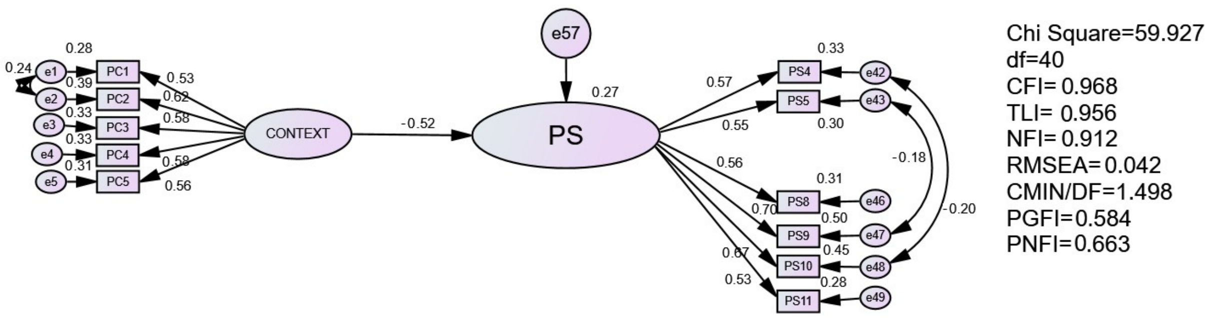

Figure 2. SEM model for context (D1) and project success (PS).

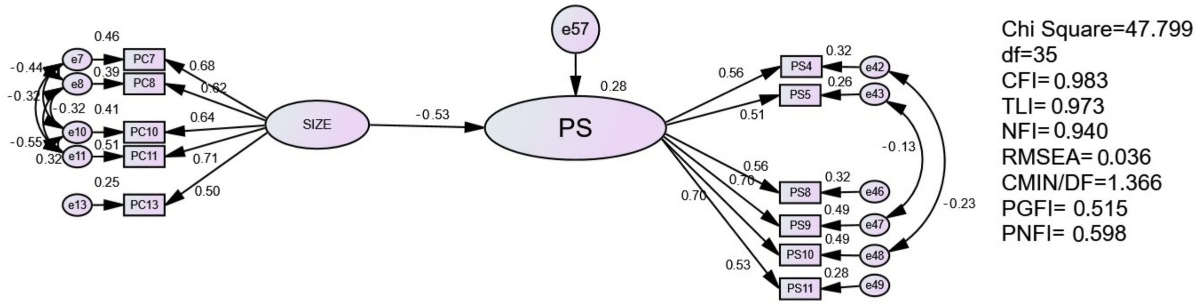

Figure 3. SEM model for size (D2) and project success (PS).

Table 6 shows that the χ^2/degree of freedom for all dimensions of project complexity is less than 3, indicating a satisfactory fit to the data. The values of the absolute fit parameter, the root mean square error of approximation (RMSEA), are below the recommended threshold of 0.10. The Tucker–Lewis index (TLI) and comparative fit index (CFI) exhibit values exceeding 0.90, which indicates that the model exhibits an acceptable level of fit. In addition, the parsimonious normal-fit index (PNFI) and the parsimonious goodness of fit index (PGFI) have values greater than 0.5, which indicates sufficient supporting evidence of an acceptable model fit. Table 7 provides a summary of the standardized regression weights of the final SEM model, whereas Table 8 presents a summary of the direct effects of project complexity and its dimensions on project success.

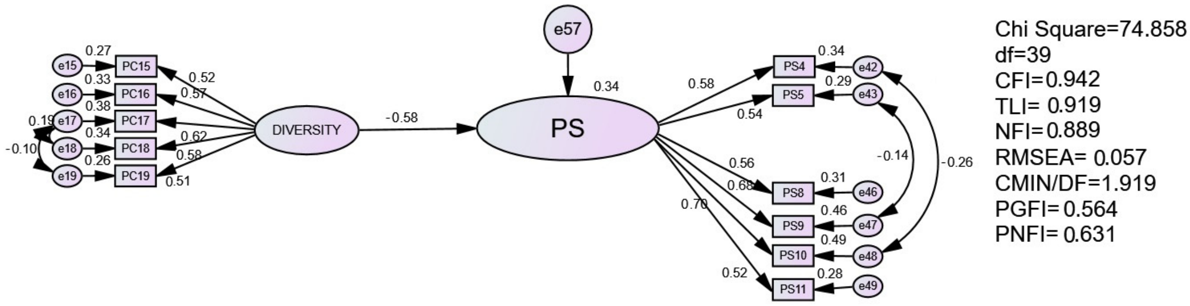

Figure 4. SEM model for diversity (D3) and project success (PS).

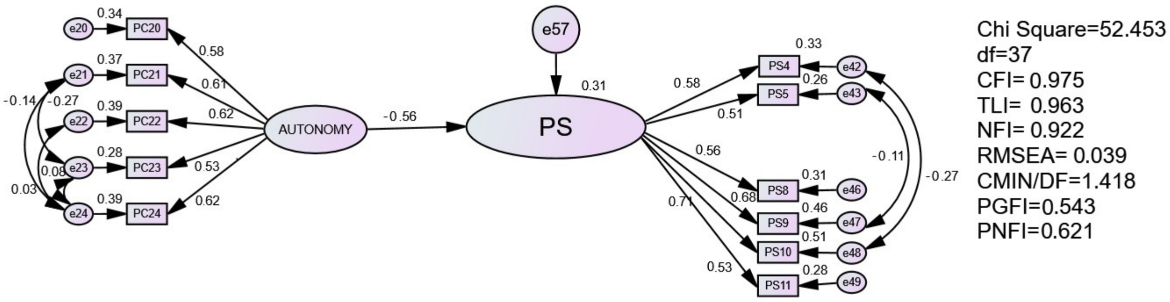

Figure 5. SEM model for autonomy (D4) and project success (PS).

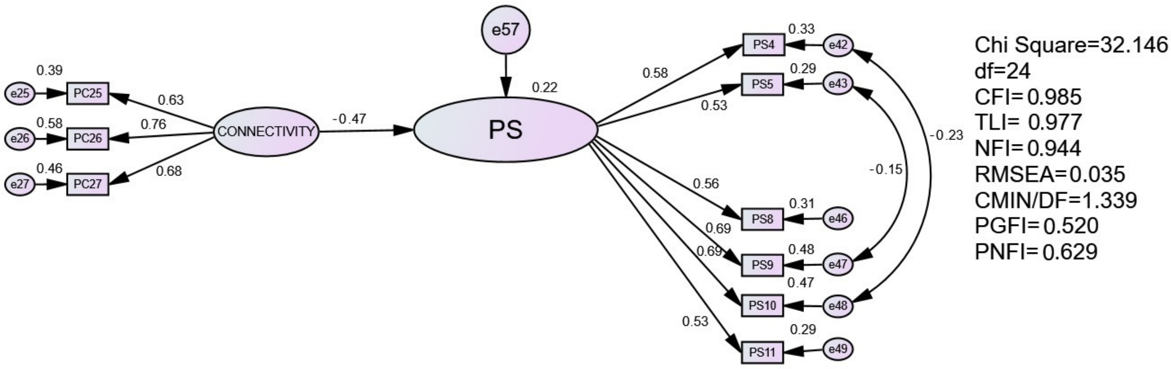

Figure 6. SEM model for connectivity (D5) and project success (PS).

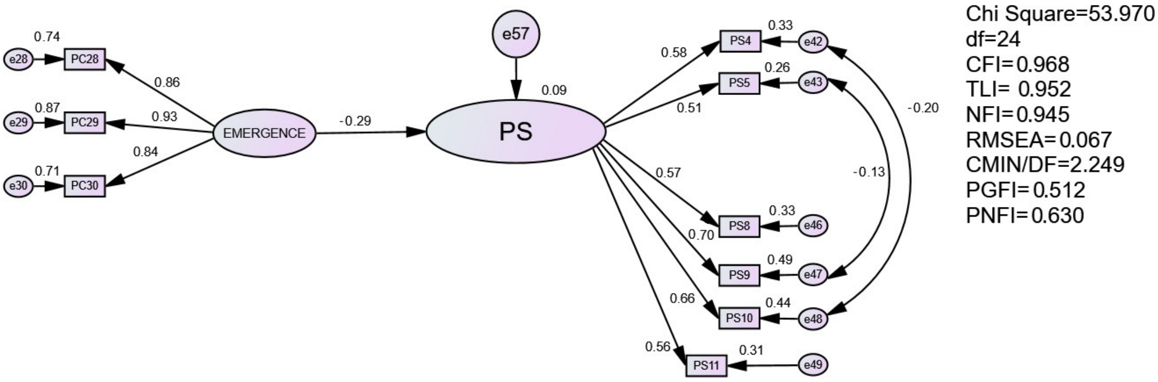

Figure 7. SEM model for emergence (D6) and project success (PS).

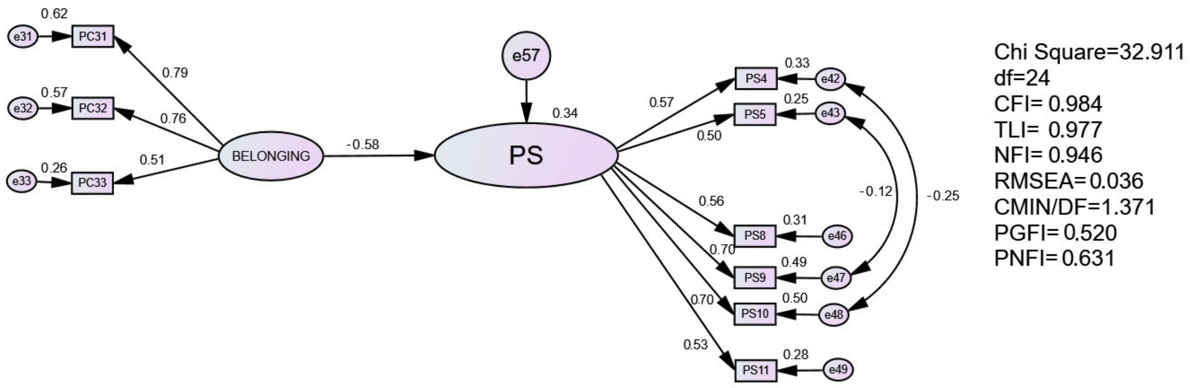

Figure 8. SEM model for belonging (D7) and project success (PS).

4.3. Discussion

In this study, structural equation modeling (SEM) was used to analyze the relationship between project complexity, its seven dimensions and project success. Table 6 presents the fit statistics for the project complexity and its dimensions, showing a satisfactory fit to the data with an χ^2/degree of freedom of less than 3, RMSEA values below 0.10, TLI and CFI values exceeding 0.8, and PNFI and PGFI values greater than 0.5, supporting an acceptable model fit. The final SEM model categorized project complexity into seven dimensions: (D1) context, (D2) size, (D3) diversity, (D4) autonomy, (D5) connectivity, (D6) emergence, and (D7) belonging. According to Table 7, autonomy had the highest influence in characterizing project complexity (coefficient: 0.85) followed by diversity (coefficient: 0.784), size (coefficient: 0.739), connectivity (coefficient: 0.662), belonging (coefficient: 0.652), and context (coefficient: 0.529). Emergence (coefficient: 0.371) had the least influence in characterizing project complexity. In the final SEM model, project success is measured by (PS4) top management support, (PS5) environment, (PS8) planning, (PS9) control, (PS10) technology/technical tasks, and (PS11) clear and realistic goals/objectives/mission. Table 7 shows that technology/technical tasks had the highest influence in characterizing project success (coefficient: 0.716) followed by control (coefficient: 0.677), top management support (coefficient: 0.583), planning (coefficient: 0.548), and environment (coefficient: 0.525). Clear and realistic goals/objectives/mission (coefficient: 0.521) had the least influence on project success. Table 8 shows the direct effects of project complexity and its dimensions on project success and all the standardized coefficient values are significant at $p < 0.001$. Project complexity has a negative impact on project success (coefficient: −0.754). Therefore, H1 is supported, i.e., project complexity has a negative impact on project success for complex engineering projects. The results of the study are aligned with earlier research conducted on the subject. Lebcir and Choudrie conducted simulations to evaluate the impact of project complexity on the completion times of construction projects and obtained similar outcomes [150]. Additionally, Bosch-Rekveldt validated that project complexity generally results in reduced project performance [12], Williamson established a detrimental association between project complexity and IT projects' success [151], and Luo et al. also presented a significant negative correlation between project complexity and construction projects' success [5,15]. Context, being an important dimension of project complexity with a standardized coefficient of 0.529, shows a significant correlation with five factors: (PC1) cultural configuration, (PC2) environment complexity, (PC3) level of competition, (PC4) geological condition, and (PC5) political issues. Environmental complexity (coefficient: 0.614) had the highest influence in characterizing context followed by level of competition (coefficient: 0.598), geological condition (coefficient: 0.565) and political issues (coefficient: 0.556). Cultural configuration (coefficient: 0.517) had the least influence in characterizing the context. It can be seen that context, with a standardized coefficient of −0.52, demonstrates a substantial negative impact on project success. Thus, H2 is supported, i.e., context has a negative impact on project success for complex engineering projects.

Size, as a fundamental dimension of project complexity with a standardized coefficient of 0.739, is significantly related with five factors: (PC7) largeness of capital investment, (PC8) number of investors/financial resources, (PC10) number of activities, (PC11) number of objectives/goals, and (PC13) project duration. The number of objectives/goals (coefficient: 0.635) had the highest influence in characterizing the size followed by the number of activities (coefficient: 0.630), largeness of capital investment (coefficient: 0.626), and number of investors/financial resources (coefficient: 0.559). Project duration (coefficient: 0.535) had the least influence in characterizing the size. Project size significantly influences project success in a negative manner, as evidenced by a standardized coefficient of −0.53. Hence, H3 is supported, i.e., size has a negative impact on project success for complex engineering projects. Diversity, as a significant dimension of project complexity with a standardized coefficient of 0.784, is defined by five factors: (PC15) variety of information systems to be combined, (PC16) geographic location of the stakeholders, (PC17) variety of organizational interdependencies, (PC18) variety of the interests of the stakeholders, and (PC19) variety of technologies. The variety of organizational interdependencies (coefficient: 0.607) had the highest influence in characterizing the diversity followed by variety of technologies (coefficient: 0.587), geographic location of the stakeholders (coefficient: 0.545), and variety of the interests of the stakeholders (coefficient: 0.531). The variety of information systems to be combined (coefficient: 0.505) had the least influence in characterizing diversity. Diversity, with a standardized coefficient of −0.58, plays a crucial role in influencing project success. Therefore, H4 is supported, i.e., diversity has a negative impact on project success for complex engineering projects. Autonomy, being an important dimension of project complexity with a standardized coefficient of 0.853, is characterized by five attributes: (PC20) process interdependencies, (PC21) availability of resources, (PC22) dependencies with the environment, (PC23) interdependencies between actors, and (PC24) dependencies between schedules. Dependencies with the environment (coefficient: 0.631) had the highest influence in characterizing autonomy followed by availability of resources (coefficient: 0.597), process interdependencies (coefficient: 0.594), and dependencies between schedules (coefficient: 0.575). Interdependencies between actors (coefficient: 0.534) had the least influence in characterizing autonomy. Autonomy, with a standardized coefficient of −0.56, exhibits a negative impact on project success. Thus, H5 is supported, i.e., autonomy has a negative impact on project success for complex engineering projects. The project complexity dimension connectivity, with a standardized coefficient of 0.662, is defined by three factors: (PC25) goals/objectives alignment, (PC26) feedback loops and interconnectivity in the task and project networks, and (PC27) relations with permanent organizations. Feedback loops and interconnectivity in the task and project networks (coefficient: 0.742) had the highest influence in characterizing connectivity followed by relations with permanent organizations (coefficient: 0.672) and goals/objectives alignment (coefficient: 0.653). Connectivity plays an important role in project success (standardized coefficient = −0.47) by exerting a negative influence. Hence, H6 is supported, i.e., connectivity has a negative impact on project success for complex engineering projects. Another project complexity dimension known as emergence, with a standardized coefficient of 0.371, is directly reflected by three attributes: (PC28) uncertainty of scope, (PC29) uncertainty of objectives and methods, and (PC30) information uncertainty. Uncertainty of objectives and methods (coefficient: 0.931) had the highest influence in characterizing emergence followed by uncertainty of scope (coefficient: 0.859) and information uncertainty (coefficient: 0.846). Emergence demonstrates a negative impact on project success, as evidenced by its standardized coefficient of −0.29. Therefore, H7 is supported, i.e., emergence has a negative impact on project success for complex engineering projects. Belonging, one of the dimension of project complexity, with a standardized coefficient of 0.652, is defined by three factors: (PC31) technological newness of the project, (PC32) strict quality requirement, and (PC33) unknown/poorly defined requirements. Technological newness of the project (coefficient: 0.783) had the highest influence in characterizing belonging followed by strict quality requirement (coefficient: 0.751) and unknown/poorly defined requirements (coefficient: 0.523). A significant negative correlation was found between belonging and project success, having a standardized coefficient of −0.58. Thus, H8 is supported, i.e., belonging has a negative impact on project success for complex engineering projects.

5. Conclusions

The conclusion of this study highlights the contributions and implications of research on project complexity in complex engineering projects. By incorporating seven key dimensions—context, size, diversity, autonomy, connectivity, emergence, and belonging—this study offers a holistic perspective on project complexity, acknowledging the multi-dimensional nature of this phenomenon. This novel framework distinguishes itself from earlier research by adopting an integrative and systematic approach to comprehensively understand and evaluate project complexity. This work presents a novel evaluation of project complexity by demonstrating the individual effect of each of the seven key dimensions. This comprehensive approach collectively captures the intricate and interrelated factors that contribute to project complexity in diverse engineering sectors. The empirical validation of measuring project complexity for complex engineering projects was accomplished successfully. The identified measurement items have demonstrated validity and reliability, making them suitable for future research as a reliable instrument to measure project complexity. The objective of this study was not to develop an instrument for understanding complexity in a specific industry. Instead, the results can be applied to various engineering sectors, making them useful for project management practitioners, engineers, and researchers. To analyze the association between project complexity and project success for complex engineering projects, structural equation modeling (SEM) was employed. The SEM results support the hypothesis that project complexity, with a standardized coefficient value of −0.754, has a significantly negative impact on project success. Additionally, the analysis results indicate that all seven dimensions of project complexity, which included context, size, diversity, autonomy, connectivity, emergence and belonging, are negatively correlated with project success, thus supporting all hypotheses from H2 to H8. This information highlights the importance of managing these dimensions effectively in order to increase project success rates. Thus, this analytical study has yielded a number of practical implications.

For project managers, it is essential to recognize and comprehend various types of complexities that can emerge during a project and take appropriate measures to manage those effectively. The SEM's results demonstrate that autonomy had the highest influence in characterizing project complexity followed by diversity, size, connectivity, belonging, context, and emergence. In order to address complexity due to autonomy, project managers should pay special attention to its five factors. Dependencies with the environment had the highest influence in characterizing autonomy followed by availability of resources, process interdependencies, and dependencies between schedules. Interdependencies between actors had the least influence in characterizing autonomy. For diversity-related complexity, project managers should focus on handling five factors. The variety of organizational interdependencies had the highest significance in characterizing diversity followed by variety of technologies, geographic location of the stakeholders, variety of the interests of the stakeholders, and variety of information systems to be combined. Project managers should prioritize the handling of five factors to manage complexity arising from project size. The number of objectives/goals was found to have the most influence in characterizing size followed by number of activities, largeness of capital investment, number of investors/financial resources, and project duration. Managing complexity due to connectivity involves managing three factors. Feedback loops and interconnectivity in the task and project networks had the highest significance for characterizing connectivity followed by relations with permanent organizations and goals/objectives alignment. To manage complexity due to belonging, project managers should take care of three factors. Technological newness of the project had the most influence in characterizing belonging followed by strict quality requirement and unknown/poorly defined requirements. To handle complexity due to context, project managers should focus on five factors. Environmental complexity was found to be the highest influencing factor in characterizing context followed by level of competition, geological condition, and political issues and cultural configuration. Finally, complexity due to emergence may be managed by focusing on three factors. Uncertainty of objectives and methods had the highest influence in characterizing emergence followed by uncertainty of scope and information uncertainty. Further, the results show that project success is characterized by six factors. Technology/technical tasks had the highest influence in characterizing project success followed by control, top management support, planning, environment, and clear and realistic goals/objectives/mission. By addressing these various types of complexity and critical factors of project success, project managers can better navigate the challenges and risks associated with complex projects, and improve the likelihood of project success. Project performance and success rates will increase manifold if project managers take into account these factors as per their highlighted significance.

This study has certain limitations. Since it encompasses various engineering fields from different countries, increasing the sample size by collecting additional data would be beneficial. Furthermore, although the theoretical model provided a tool and framework for investigating the influence pathway, future research could explore other factors such as project team performance, emotional intelligence, leadership, resilience, and more as moderating and mediating variables.

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