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Integrating PLS-SEM and ANN to explore major resilience factors of construction Projects: The Case of Ethiopia

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ABSTRACT

The aim of this research is to identify and analyse the key resilience factors contributing towards construction project success in Ethiopia using an integrated approach of Artificial Neural Networks(ANN) and Partial Least Squares Structural Equation Modelling(PLS-SEM).As with elsewhere in the world, the Ethiopian construction industry has faced socio-political instability, resource scarcity and institutional challenges related to the success of construction projects within the country, and resilience is essential to being able to absorb disturbances, adapt to changing conditions, or to facilitate quick recovery from adverse events. Resilience is required to assess the unknown and be able to respond to uncertainty. In this research the integrated methods of PLS-SEM and ANN applied. This integration provides a valuable understanding of this issue, as PLS-SEM inherently supports modelling linear relationships, while ANN's representation can model the non-linear repercussions of relationships under multiple factors of societal construction projects. The outlook from the analysis was that the resilience factors ultimately impact project resilience, and then project success was realised. The two primary resilient factors identified as contributions to project resilience from the integrated research were project team culture and external environment, and the ANN analysis also realised the non-linear relative effects of the external environment and team culture on project resilience and consequently project success. The study proposes developing a resilient organisational culture and external environment that are consistently monitored. This integrated methodological approach has provided new perspectives upon the construction industry for researchers, practitioners, and policymakers aiming toward enhancing resilience and sustainability within the construction industry in Ethiopia and can lead to important policy improvements and theoretical evolvement of resilient project management in the context of Ethiopia.

L'obiettivo di questa ricerca è quello di identificare e analizzare i fattori chiave di resilienza che contribuiscono al successo dei progetti di costruzione in Etiopia utilizzando un approccio integrato di reti neurali artificiali (ANN) e modelli di equazioni strutturali ai minimi quadrati parziali (PLS-SEM). Come in altre parti del mondo, l'industria edile etiope ha affrontato l'instabilità socio-politica, la scarsità di risorse e le sfide istituzionali legate al successo dei progetti di costruzione all'interno del paese, essendo la resilienza essenziale per essere in grado di assorbire le perturbazioni, adattarsi alle mutevoli condizioni o per facilitare una rapida ripresa da eventi avversi. La resilienza è necessaria per valutare l'ignoto ed essere in grado di rispondere all'incertezza. In questa ricerca sono stati applicati i metodi integrati di PLS-SEM e ANN. Questa integrazione fornisce una preziosa comprensione di questo problema, poiché PLS-SEM supporta intrinsecamente la modellazione delle relazioni lineari, mentre la rappresentazione di ANN può modellare le ripercussioni non lineari delle relazioni sotto molteplici fattori dei progetti di costruzione sociale. La prospettiva dell'analisi è stata che i fattori di resilienza in ultima analisi influiscono sulla resilienza del progetto, e quindi consentono la realizzazione con successo del progetto. I due principali fattori resilienti identificati come contributi alla resilienza del progetto dalla ricerca integrata sono stati la cultura del team di progetto e l'ambiente esterno; l'analisi ANN ha anche realizzato gli effetti relativi non lineari dell'ambiente esterno e della cultura del team sulla resilienza del progetto e di conseguenza sul successo del progetto. Lo studio propone di sviluppare una cultura organizzativa resiliente e un ambiente esterno costantemente monitorato. Questo approccio metodologico integrato ha fornito nuove prospettive sull'industria delle costruzioni per ricercatori, professionisti e responsabili politici con l'obiettivo di migliorare la resilienza e la sostenibilità all'interno dell'industria delle costruzioni in Etiopia e può portare a importanti miglioramenti politici e all'evoluzione teorica della gestione dei progetti resilienti nel contesto dell'Etiopia.

Keywords: Foreign Resilience, Project Success, PLS-SEM, ANN, Ethiopia.

1 – Introduction

The Ethiopian construction industry has undergone rapid growth in response to ongoing urbanisation and infrastructure developments. However, the industry still faces considerable risks and challenges. Risks include various political factors (i.e. government funding, political policies, regulation and corruption), unnecessary bureaucracies and socio-economic factors (i.e., economic stability, access to finance, gaps in infrastructure, a lack of construction-skilled labour, and inconsistent market demand) (Tekla Bedada, 2023). In Ethiopia, problems that could affect the resilience nature and the project success of the construction projects are the social, political, and economic instability, resource scarcity, and institutional inadequacies. Understanding these factors enables building project resilience and project success. This could minimise the negative consequences such as project delays, financial losses, and lost opportunities. Undermining them leads to holding Ethiopia's construction project progress and increasing challenges (Lv et al., 2023; Demissew & Abiy, 2023; UNDP, 2022; He et al., 2022).

Resilience is an important component of Ethiopian construction project management because it helps mitigate uncertainty and enhance project success. In construction project management, resilience refers to the capacity or capability to absorb, adapt and recover following a disturbance. It is dependent on leadership, team culture, organisational structure, risk management, and external environment. Project leadership is critical to enhance the resilience of project outcomes (Whyte et al., 2022). Experienced teams are more effective in making informed decisions that enhance positive outcomes and organisational structures that allow flexibility to respond to uncertainties (Wang et al., 2022). Recognising the significance of establishing and cultivating a risk culture is necessary for resilience in regard to the capability of overcoming problems and improves the operational performance of an organisation (Kumar and Anbanandam, 2020). Adapting to the environment is also crucial, as external factors determine the resilience and success of a project (Rahi, 2019). The construction systems are complex and need to be interpreted with a more complex approach because simplistic approaches can overlook some critical uncertainties that come with projects of these types (Eitel, 2023 & Santoro et al., 2020).

In order to address the improvement requirements, through this study the authors are proposing the inclusion of a hybrid assessment approach utilising Partial Least Squares Structural Equation Modelling (PLS-SEM) and Artificial Neural Networks (ANN). PLS-SEM would allow for imperfect models of cause-effect relationships between latent variables. This enables to provide insights into the locations of most resilience factors and the strengths and importance of each factor. Artificial Neural Networks (ANN) are designed on the way the brain operates, they are extremely accurate at predicting and can extract useful information from a data set without the requirement of exact statistical rules (Choudhuri et al., 2020). The goal of the hybrid methods is to provide a more in-depth understanding of the resilience factors and how they relate to project resilience and, in turn, project success. The hybrid methods discuss the advantage of a two-stage model that is appropriate for the construction industry specific to Ethiopia (Santoro et al., 2020).

The research has both theoretical and practical implications. It has highlighted the function of resilience as an element of project success in uncertain conditions. It has provided suitably for practitioners and decision-makers to better their practice in the construction environment. And finally, it has methodologically provided a rich contribution to applied quantitative methods like PLS-SEM and ANN. The hybrid methodologies of PLS-SEM and ANN have provided evidence on the complexities of interrelated relationships in construction systems while adding to the body of knowledge about resilience in Ethiopia and developing countries.

This research has identified the *main resilient factors* and provided practical guidance on the way to realise resilience in the construction sector in Ethiopia. The research made a theoretical contribution to knowledge in an academic setting and a practical contribution for those interested in knowledge from conducting actual construction projects in Ethiopia.

2 – Literature review

2.1 – *Construction Project Success factors and resilience in Developing countries Contexts*

The success of construction projects is an important subject of focus in project management and has it been considered in terms of cost, time, quality, satisfaction and sustainability (PMI, 2017). Project success in a developing country like Ethiopia is impacted by political, social, economic and institutional aspects.

This has made project planning through execution in challenging situations. Project success definition is still disputed and there is no specific criteria for success. Measures of success differ from project to project (Sinesilassie et al., 2019). Although cost, time and quality remain part of the traditional project management (Dalcher, 2017).

Resilience linked to improved performance at work, project adaptability and effective project outcomes (Meneghel et al., 2016; Kanjanasomkid & Cartagena, 2021). The ability of resilient teams to absorb setbacks and create opportunities is critical to the construction industry, where organisational resilience directly impacts project performance in terms of financial, operating and supply chains (Fey and Kock, 2022; Yang & Cheng, 2020). Resilience in engineered systems enhances efficiency, reduces cost, and longer service life. Understanding the construction needs and uncertainties is important for resilience based construction project management.

2.2 – *Resilience in Project Management*

In project management resilience is the ability of a project's system to anticipate, absorb, respond to, and recover from organisational disruptions. It has found a growing relevance in organisational and within the construction industry. The concept originally drawing from principles in ecological and systems theories. In this research the identified resilient factors are leadership, team culture, risk management, organisational structure, and external environments. Leadership enables to guide the project through its complexity and project team culture to enable collaboration and problem solving. Similarly organisational structure to have support flexible decision-making, external environment to allow incidents to respond and finally risk management to determine potential disruptions a head of time .Overall these factors provide a project to have the capability to adapt and to proceed during adverse environmental conditions ..

Research has shown that resilient projects have increased success rates during volatile business environment and where constrained resource environments exist. This has made resilience as both a protective mechanism from their influence on project success (Ghufran et al., 2022 & Oguntona et al., 2022). In the aspect of developing countries, resilience allows project managers to manage complexity and uncertainty for project success (Ofori, 2015). However, there is a lack of African-based studies that focus on project resilience in construction. Existing studies from South Africa, Ethiopia, Kenya, Ghana, and Cameroon, for example, are largely missing articulations of definitions or theoretical bases with regards to the resilience and the use of the term in studies (Chirisa et al., 2016). The implication is that construction industries, need to be supported to develop their resilience and the ability to adapt to changes in economic circumstances. But research related to construction project resilience is largely focused in South and West Africa, with little underexplored elsewhere in Africa. There is a limited research work in the area of resilience. Which suggests that there is a need for research on project resilience in the construction sector of Africa.

2.3 – *Resilience in developing countries*

Resiliency is crucial in construction projects in a developing country context since these projects are usually characterized by complexities and uncertainties, requiring adaptive management to balance risks and project success (Naderpajouh et al., 2020 & He et al., 2022). Most developing countries typically have poor infrastructures links, skills shortages, and fragmented regulatory frameworks presenting obstacles to project sustainability. However, limited research also exists in relation to the implementation of resilience in practice (Esaiyas and Kahssay, 2020 & Zhao et al., 2023).

In Africa the construction sector is still in a relative infancy stage. Local contractors face limited access to technologies, poor labour relations, and very ambiguous standards that limit resilience (Esaiyas et al., 2020 & Seriki, 2020). The systemic problems that arise from poor infrastructure connections and inconsistent regulation are also restricting project resilience, and there remains exceptionally limited and fragmented research in this area (Esaiyas et al., 2020 & Ghufran et al., 2022).

Resilience in Ethiopian construction projects is under-researched, as most of them emphasise organisational resilience, not a specific project (Belay et al., 2021). This demands empirical research by integrating the concept of resilience into construction practices and then into project success.

2.4 – *AI application in construction project management*

The field of Artificial Intelligence (AI) is transforming construction project management practice by improving efficiency, accuracy and decision-making throughout project implementation. According to Victor (2023), AI technologies such as machine learning, natural language processing and computer vision may play a vital role in improving project planning by optimizing resource allocation, scheduling and predicting risk. Likewise, Obiuto et al. (2024) examined the importance of AI technologies to overcome challenges such as project delays, and ineffective communication between stakeholders. Shamim (2024) discusses AI applications to improve stakeholder communication, resource management and risk management as primary areas of improvement through the utilization of AI. She also indicates that ethical consideration is important in AI implementation. Mogharbel et al. (2023) described the important themes of productivity, safety, quality, and site planning, that have practical significance.

Practitioners can identify general practical benefits from their suggestions of multiple applications of AI (Timilsena et al., 2024). Artificial intelligence can take the labour and time-lag and provide an actionable recommendation founded on automated planning and real-time data analysis.This can reduce waste and increase the speed of project delivery (Nwosu et al., 2023).The challenges of data security, resistance to workforce acceptance of automated decisions, and AI implementation costs (Obiuto et al., 2024; Timilsena et al., 2024) are limitations to consider in the growth of the construction project management technology. In conclusion, it appears that AI can improve productivity, efficiency, decision- making and outcomes of the construction project management.

2.5 – *Post pandemic resilience*

The COVID-19 pandemic has affected the construction and health sectors .Which lead them to develop new resilience strategies. Grant Nwaogbe et al. (2025) have discussed some workforce challenges within construction by outlining the importance of digital technologies, flexible work, and policy development to strengthen productivity. Ewert et al. (2023) noted the limited health system resilience and suggested the need for improved systems thinking and change. Gongtao et al. (2024) offered a very practical opportunistic adaptation for remote work and new safety standards in China, which is a reasonable example of resilience for the construction companies. Malik and Bustami (2024) stated that company experience and preparation/planning leading to better project delivery is a positive sign. In line with it, they point out that some aspects of project management, like planning and control, prepare firms not only for Covid-19 disruption but also to instill resilience. In general, it is suggested that technological development, governance issues, and individual organisation quality (i.e., of their capabilities and capacities) are key in developing or using resilience resulting from Covid-19.

2.6 – *Key enablers*

Various studies indicate that enablers of resilience can make projects to be resilient. As discussed by Ali et al. (2017), important enablers of strategic and operational resilience may include redundancy, mobility, collaboration, trust and flexibility. Ghufran et al. (2022) identified resilience enablers such as senior management support (and settings), s'eystematic risk management, adaptability, purpose (or communication), and cooperation. Geambasu (2011) offered a three-level or paradigm framework comprising shared vision, organisational culture and structure. Resources, competitiveness and organisational learning are considered by Pillay (2020) and Ranasinghe et al. (2020). Thakur (2016), Vargo (2011), and Seville (2011) conceptualized resilience as a combination of external responsive identity capacity, leadership, and environmental identity from a team identification perspective. Pavez et al. (2021) identified trust and West-Olatunji et al. (2018) empowerment as resilient enablers.

The PMI PMBOK supports many of these items in the project management context. However, the latest version of PMI PMBOK focused on construction projects do not mention about external adaptive capacity. As discussed by Meneghel et al. (2016) and West, Patera, & Carsten (2009), resilient project teams demonstrate good organisational structures and risk monitoring (Kanjanasomkid et al., 2021); top-management commitment (Ranasinghe et al., 2020); and effective leadership (Ghufran et al., 2022). All of these items together enhance adaptability, flexibility and the overall project's success.

Based on the above-mentioned studies, poor management and insufficient consideration of risk management, external control, social influence, organisational structure, leadership and team culture affect project resilience. As the Ethiopian context is unique, addressing these factors is an important driver in improving the project's resilience and then project success.

One of the observed research gaps is giving little attention to the resilience of Ethiopian construction projects (Belay et al., 2021). However, there are studies about resilience in urban construction contexts in Africa as a whole. It is still critical to do context-specific studies to understand what Ethiopia's particular socio-economic, political, and environmental factors act as barriers to enabling project resilience.

2.7 – *Analytical Techniques in Resilience Research*

PLS-SEM and artificial neural networks are useful tools for analysing hidden factors of the complex relationships. Partial Least Squares Structural Equation Modelling (PLS-SEM) has gained considerable acceptance in project management research, as it is a suitable method of analysing complex connections between latent variables as it does not require strong assumptions such as normality of the data and sample size (Sarstedt et al., 2022). PLS-SEM is helpful in exploratory studies and theory development, as the researcher is able to do both the assessment of measurement models (validity and reliability) and structural models (the hypothesised relationships) in one model (Henseler et al., 2015). However, PLS-SEM is inherently limited by its linearity, meaning that the ability to study the nonlinear dynamic interactions that are present a priori in the construction environment is also limited. PLS-SEM considers linear relationships, thus limiting the complexity that can be modelled in the nonlinear interactions that occur in environments of uncertainty and dynamism (Ringle et al., 2022). As a remedy, recent studies have included some machine learning approaches like ANN. Because a neural network operates, ANN can produce better predictions in complicated systems that perhaps rudimentary non-linear models overlook (Valence and Intention, 2023, and Rehman and Arabia, 2020). Artificial Neural Networks (ANN) are biological neural systems attempting to replicate human behaviour by automatically observing and identifying non-linear patterns and mappings within complex layers of interactions among variables without making any a priori assumptions of the distribution of the data (Rehman et al., 2020). This illustrates ANN as a viable complement for analysis to enhance predictive accuracy and identify concealed or encrypted relationships in project management research (Wang et al., 2023). ANN's capabilities are immensely valuable for predicting outcomes, where different causes are often complicated and interrelated, in unpredictable construction contexts.

The integration of PLS-SEM and ANN enables to get the strength of the two approaches. PLS-SEM is used first to evaluate the relationships in the structural model and identify relevant predictors, and then ANN provides a degree of certainty in the ranking of predictors and improves predictive power accuracy (Duc, M.L. et al., 2022). Hybrid PLS-SEM and ANN methods have been used in research on construction project resilience to develop theoretical understanding about how internal and external factors interact and impact project success in uncertain environments (Valence & Intention, 2023).It is important to use the analyses capabilities of PLS-SEM and ANN to capture the complexities of resilience mechanisms (Hidayat-ur-Rehman and Alsolamy, 2023).

There is minimal research that bridges PLS-SEM and ANN in Ethiopia's construction field, based on the searches made via Google Scholar and Google. Most of the published research is either singularly focused on PLS-SEM or ANN, and there is a gap to exploit combined research to build the capacity in the industry and bring about change in practice.

3 – Conceptual framework and hypotheses

3.1 – *Introduction*

The development of the conceptual framework described in this research was to study how resilience is related to success in construction projects in Ethiopia. The resilience framework is an elaboration of existing empirical and theoretical frameworks, which provide general resilience dimensions and describe resilience's relationship to project success. A hypothesis is formed based on the resilience conceptual framework that supports an empirical test of the hypothesis using the PLS-SEM and ANN methodology.

3.2 – *Conceptual Framework*

This research theorises that resilience is an important antecedent of success in construction projects, especially given the current challenges of socio-political instability, limited supply of materials, limited resources, and regulatory uncertainty in Ethiopia. The resilience framework assumes that resilience dimensions like leadership, team culture, organisational structure, external environment factors, and risk management are important antecedents to expand the ability of a project to absorb shocks, adapt to changing environments, and recover from disruptions.

Figure 1 provides the conceptual model that shows the resilience factors as independent variables and the dependent variable of project success. The independent variables are "leadership", "project team culture", "organisational structure" , "external environment factors" and "risk management". The dependent variable is project resilience. The other dependent variable is "Success". The research conceptual model asserts that demonstrated strong "leadership" results in better project decisions; a resilient "team culture" creates trust and collaborative problem solving; "external environment" prepares for external shocks and "risk management" minimises disruption to the project efforts, and a flexible organisational structure enables quickly adapting to projects. In this way, all the proposed variables are hypothesised to interact positively with project performance measures such as cost, time, quality, satisfaction and safety of stakeholders.

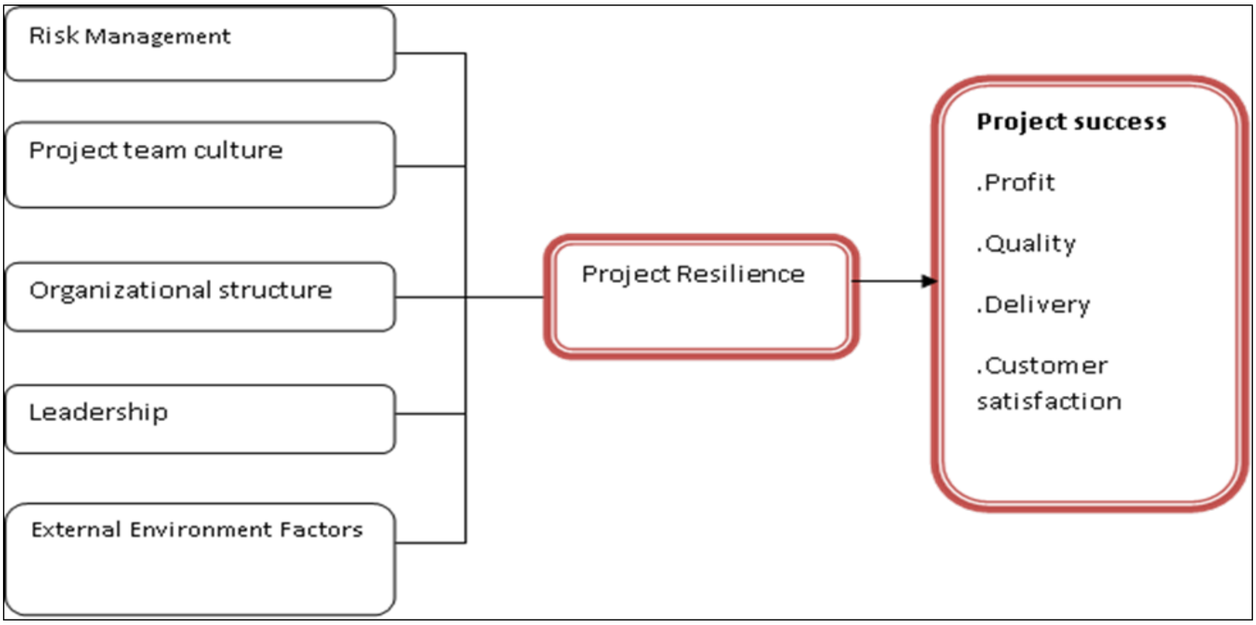


Fig.1– Research Conceptual model

3.3 – *Theoretical Foundations*

The framework is informed by principles of resilience theory. Complex construction projects operate as a dynamic system where many factors are interdependent and affect their chance of success. Resilience represents a systemic capacity which contributes to the ability of a project to sustain and change so that uncertainty can be navigated. The dimensions of resilience discussed in this research are based on literature explaining their role in enabling project resilience in complex and turbulent contexts.

3.4 – *Hypotheses Development*

After the conceptual model and literature review were presented, the hypotheses are the following:

- **H1:** Leadership positively impacts project success through the resiliency of the project team and stakeholders.
- **H2:** Organisational culture of the project team has a positive experience on project success in communication, collaboration, and adaptability.
- **H3:** Flexible, decentralised organisational structure positively impacts project success through the speed of decision- making.
- **H4:** Adapting to the external context has a positive impact on project success by enabling proactive responses to external disturbances (political shocks, economic shocks).
- **H5:** Effective risk management has a positive impact on project success through the early identification of risks and issues and identifying ways to minimise or eliminate potential issues through plans.
- **H6:** All resiliencies' factors alone or in combination have a significant impact on determining project success by their combined impact.

3.5 – *Application in Analytical Models*

The proposed hypotheses are tested within the PLS-SEM framework to determine strong and significant relationships between the factors of resilience and project success. PLS-SEM is useful when investigating complex cause-effect relationships between latent constructs, especially when the sample size is a moderate level. The test of the hypotheses is conducted within the framework of PLS-SEM to assess strong and significant links between factors of resilience and project success. After validating the measurement model and examining the strength of structural relationships, measures derived from SEM become input into an ANN model (Rehman et al., 2020).

In the ANN approach, the data is further analysed to find non-linear relationships among the resilience factors. Thus, the present study aims to provide explanatory data (i.e., relationship between resilient factors and success) and predictive data (i.e., project success factors) about project success in Ethiopia.

4 – Research methodology

4.1 – *Overview*

The study describes the research design and data collection methods, the sampling strategy or procedure where applicable, and the methods of data analysis that are purposeful for this study. The aim is to describe the methods that were used to satisfy the aims of the research while indicating the reliability and validity of the findings.

4.2 – *Research Design*

The study adopted a descriptive correlational design, which is used to determine a relationship between independent variables and a dependent variable. A descriptive correlational study gathers information about data from the same time period using a cross-sectional method. Data collection was based on quantitative methods, such as statistical analysis and hypothesis testing.

4.3 – *Population and sample*

Construction professionals in Ethiopia were the target population. The population consists of the construction company representatives, consulting firms and the government representatives. Given that most of the construction professionals work on construction projects at the national construction project level, it is believed respondents can indicate the state of the country's construction projects. Obtaining project type, project size, and project region information from the survey was difficult in finding the data due to the political instability and security problems of the regions, as well as the unwillingness and misinterpretation of what you are trying to do by the stakeholders. However, a good representation of the overall knowledge and experience of the professionals and an overall picture of the construction sector were captured.

The study utilised data collected from an online survey tool, "Google Forms", providing cross-sectional data collected between March 8 and May 13, 2024. The main section had constructs with 41 questions /items. A total of 192 survey responses were used for analyses. PLS-SEM can utilise a small sample size to generate quality output. Although Artificial Neural

Network (ANN) has a role with small numbers of cases (Elareshi et al., 2022), the data had enough to optimise in PLS-SEM and ANN analysis.

4.4 –*Data collection methods*

The primary data was collected electronically, through the distribution of structured questionnaires using Google Forms. The survey instrument attempted to utilise pertinent variables like project team culture, leadership, organisational structure, risk management, and external environment factors. For each variable, a 4- point Likert scale was utilised. The survey instrument and questions were pre-tested for validation and reliability issues. In terms of the survey instrument development, multiple online channels (email, WhatsApp, and Telegram) were used to disseminate the survey instrument and to improve participation.

4.5 – *Data pre-processing*

Data cleaning is an important step in identifying and addressing missing data and identifying outliers. Tom et al. (2020) define data cleaning as the process of verifying the correction of errors. When the survey instrument is designed, the chance for incomplete responses is avoided by inserting a button that avoids responding to the next question without responding the previous question. Outliers were defined and removed using Z-score analysis. Z-scores were calculated and compared using an acceptable cut-off of +/- 3.29 and found there is no outlier issue.

Data normality was evaluated by skewness, kurtosis measures of central tendency, Z-Score analysis and the Cramér-von Mises test. Results indicated that except for the Cramer –von Mises test (i.e., showing non-normally distributed data distribution), the data collected are normally distributed. The PLS-SEM is designed to manage both the normally and non-normally distributed data, and this shows that it is the right tool to analyse data for this research.

4.6 – *Data analysis techniques*

The study addressed associations among variables using both partial least squares structural equation modelling (PLS-SEM) and artificial neural networks (ANN) analytics. PLS-SEM is a suggested analytic tool to evaluate relationships between the measurement and structural models while considering reliability, validity and hypothesised paths, ANN provides paths towards predictive analysis by evaluating possible non-linear relationships in the data.

PLS-SEM analysis was conducted using Smart PLS software (version 4.0). Smart PLS allowed for conducting PLS-SEM analysis and assisting in evaluating both measurement models and structural relationships among the latent variables. SPSS (version 28) was employed to conduct ANN analysis using the Artificial Neural Networks module, for the identification of non-linear patterns and the interaction among the constructs. Conducting PLS-SEM and ANN provides variations of results, discussion, and conclusions, providing clarity for future studies using similar constructs but different methodological approaches.

4.7 – *Ethical consideration*

The students who participated in the study participated on a voluntary basis, and the students were requested to give informed consent prior to participating in the study. Access protocols were considered to uphold the respondent’s confidentiality and anonymity. Ethical consideration protocols were adhered to in developing ethical consideration protocols with regard to data, processes, and instruments using the research ethical consideration protocols undertaken by the "UNISA" research ethics review committee.

5 – Data analysis

5.1 – *Pretesting of questionnaire*

Reliability of the instrument was determined using the Cronbach's alpha test. For some questionnaires, Sun et al. (2018) suggest an acceptable Cronbach's alpha value should not be less than 0.7 in order to provide "adequate" internal consistency.

The result of the Cronbach's alpha test showed a reliability coefficient equal to 0.95, thus, allowing a decision of reliability, or internal consistency, to be made regarding items in this questionnaire.

5.2 – *Demographic information of the respondents*

Demographic questions were the first set of questions in the questionnaire. They included type of organisation, position in company, highest educational qualification, awareness of project resilience in construction projects, experience with implementation and years of experience within the Ethiopian construction sector as well as company experience. Below is a summary of respondents' demographic data.

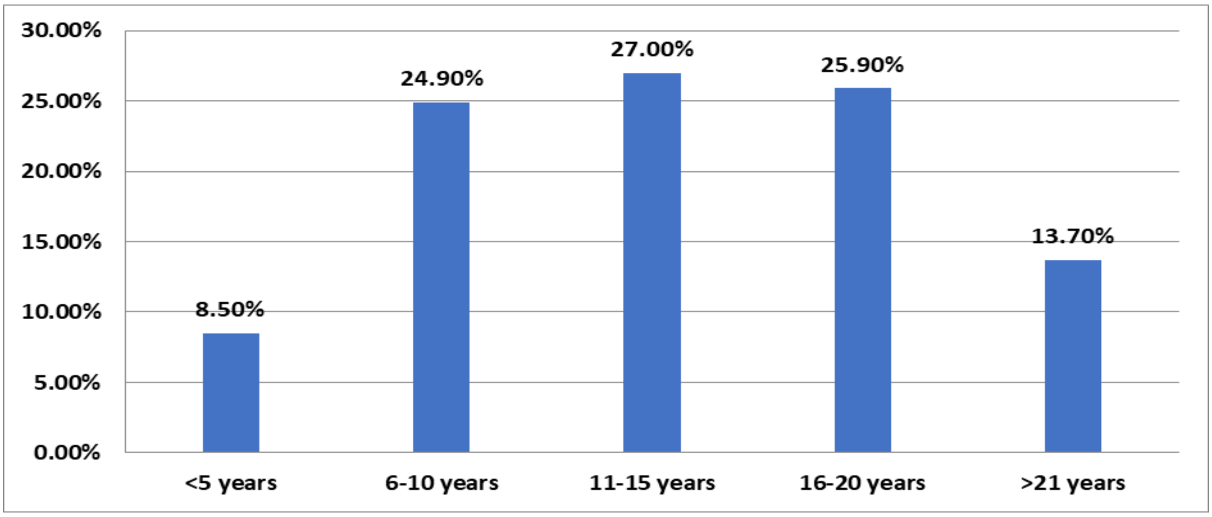


Fig. 2 – Respondent's years of work experience

Figure 2 denotes participants careers or work experience in years; 8.50% had less than 5 years of professional experience, 24.90% had 6 to 10 years, 27.00% had 11 to 15 years, 25.90% had 16 to 20 years and lastly, 13.70% had over 20 years of professional experience. The respondent's data of years of experience corroborates their capacity to answer survey questions to be analysed in subsequent questionnaire data analysis sections, with %age distribution indicating more than 11 years of experience in constructed building experience (66.70%).

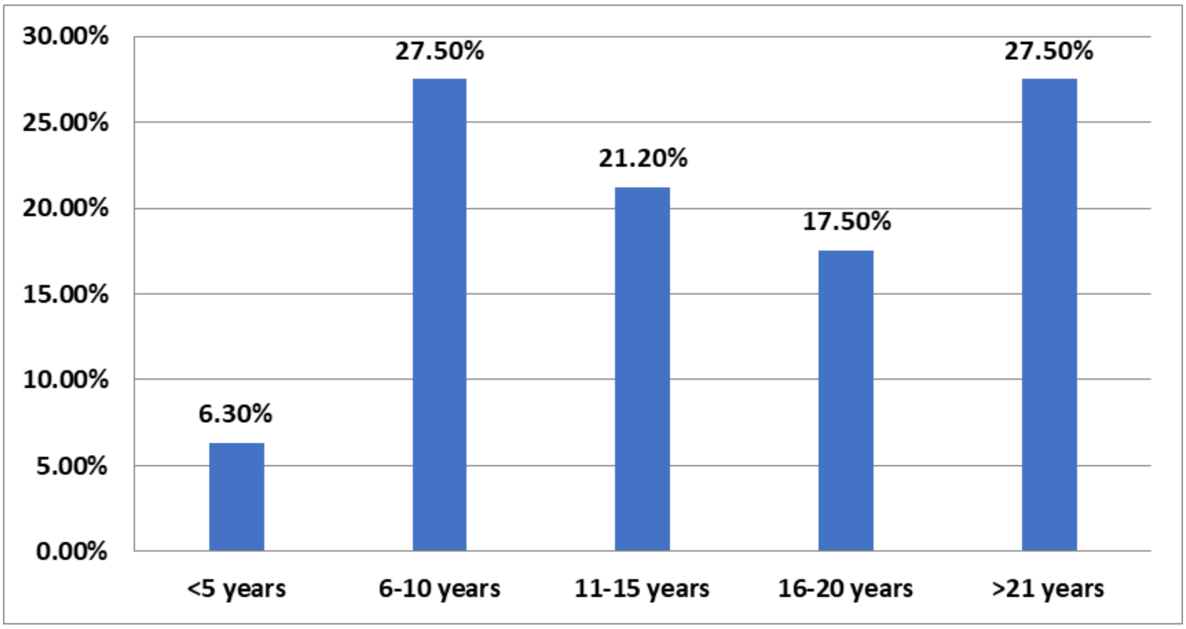


Fig. 3 – Organisations years of work experience

The companies that were contacted for employees' participation in this study are shown in the figure: 5.2. 50% of the companies have more than 21 years of experience, 17.50% have between 16 and 20 years, and 21.20% have between 11 and 15 years of experience. The remaining percentages are accounted for by those with six through ten (27.50%) and less than five (6.30%) years' worth of experience. Most firms (66.2%) have more than eleven years' worth of construction experience, which is the same as the percentage representing professionals who possess over eleven years' worth of experience themselves (66.7%),(see Figure 3).

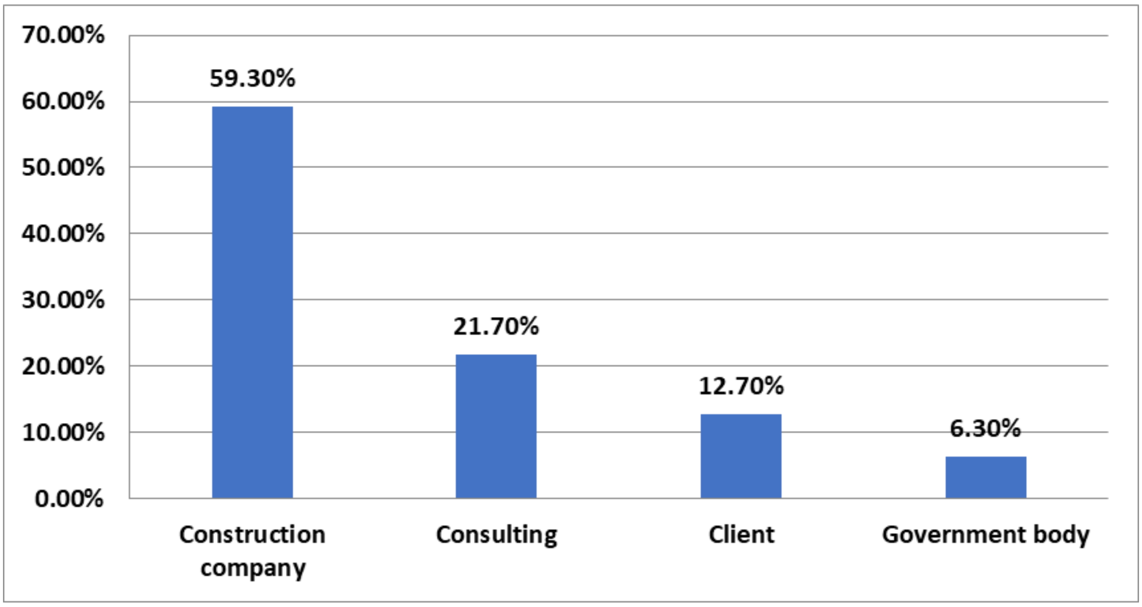


Fig. 4 – Respondent's construction sectors area

According to Figure 4, respondents worked within construction-related industries; however, this was already known, as they were all contacted through construction companies.

The "Government body" made up only 6.3%, while consultants represented 21.7%. "Client entities" constituted another 12.7 %. Those who are working directly at construction companies share 59.3% of the respondents. Therefore, it can be said that most participants indeed do work within construction itself. Seeing as how these numbers match perfectly with what was expected based on who took part in answering questions about their field-related experiences during the research data collection phase.

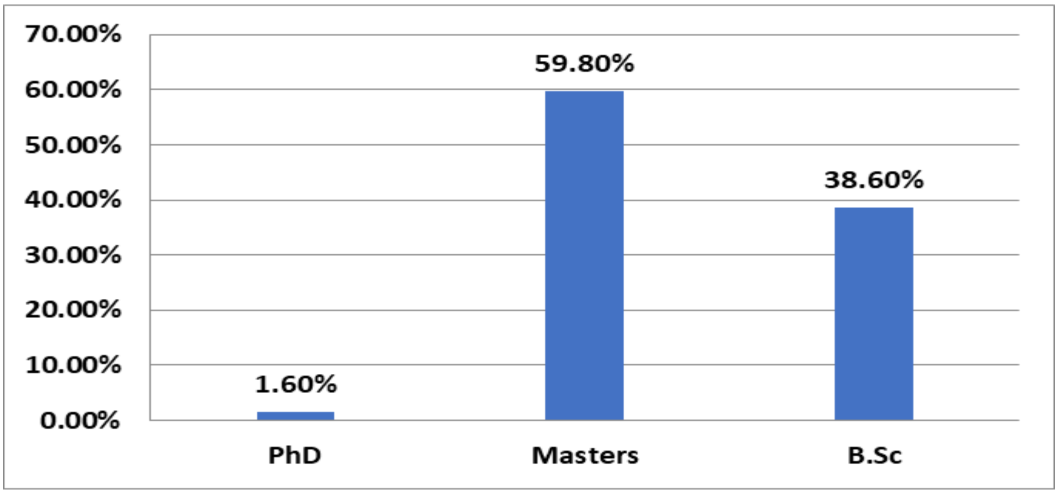


Fig. 5 – Respondent's educational level

Figure 5 illustrates respondents' education levels: Sixty % achieved master's degrees, followed closely behind by 38.6 %, who earned bachelor's degrees in science fields, leaving only 1.6 % having obtained PhD credentials, showing adequate qualifications for undertaking this particular investigation.

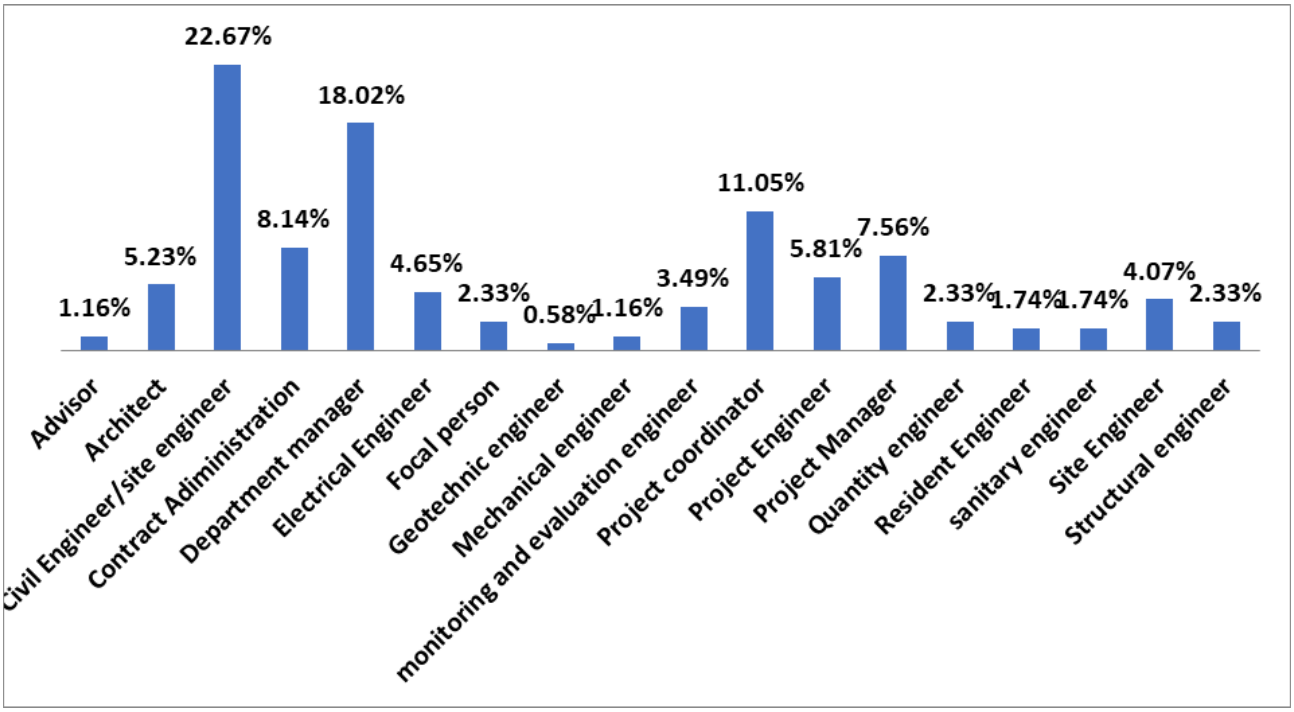


Fig. 6 – Respondent's professional qualifications

Figure 6 presents results from surveys completed by those who identified as being employed in various roles (project coordinator, project engineer and project manager) related to projects in the industry.

The results indicate that 24.42 % claimed direct involvement with project management activity. 18.20% of points indicated departmental managerial positions were held among them, while 5.23% referred to themselves simply as architects. Most respondents were engineers, as they represented 94.73 %.

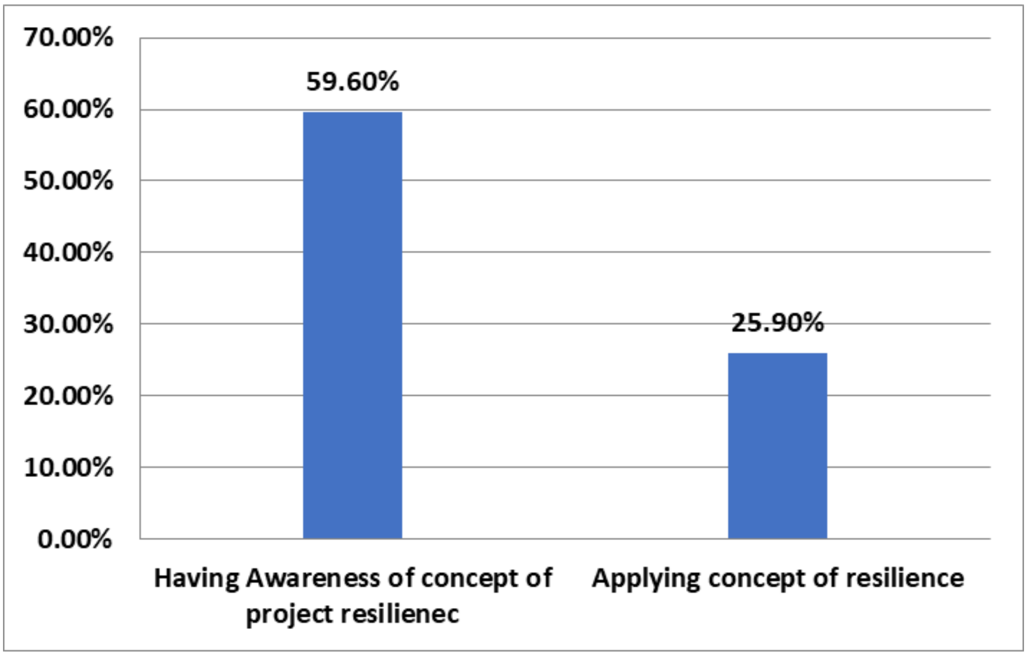


Fig. 7 – Awareness level of respondents on resilience concept

Specifically, Figure 7 shows how the participants understood resilience and how they used resilience levels, which is different from the study expectations in terms of both understanding (59.6 %) and use of the concept (about 25.9 %). This study was indeed a survey and used to identify understanding of resilience as interpreted by the practitioners of services related to resilience, who were the experts on resilience.

5.3 – *Data Preprocessing*

Tom et al. (2020) define data cleaning as the process of discovering and correcting mistakes and discrepancies in data. This study relied on data collected via an online survey, using Google Forms, between March 8, 2024, and May 13, 2024. All participants had to fill every question in a sequential questionnaire, thus there was no missing data. Data cleanliness is strong, as the means and medians of the scores across the respective categories aligned well, and there was a narrow range and limited outliers. Z-score analysis was used to identify outliers once again, and we identified one response to remove with a Z-score of 3.87 within the category. Normality tests identified that most of the variables had moderate skewness and kurtosis, and the majority of test values were reasonably acceptable. As none of the collected data falls perfectly into a normal distribution and none were ruled perfect, this was confirmed by significant Cramér-von Mises p-values below 0.05.

5.4 – *Measurement of Constructs*

This research examined resilience factors of leadership, team culture, organisational structure, external environmental factors, risk management, and project success factors such as cost, time, quality, stakeholder satisfaction and safety.

All constructs are operationalised by multiple indicators to provide details, measurement and analysis.

5.4.1 – PLS-SEM Analysis

This research embraced PLS-SEM as the methodology to assess first the measurement model and then validate the theoretical relationships between the resilience factors and project success. First, we evaluated the reliability and validity of the measurement model and PLS-SEM using a bundle of criteria.

We confirmed that indicator reliability was above 0.7, demonstrating loadings above 0.7; internal consistency reliability was assessed using Cronbach's alpha and composite reliability—in both instances, it was expected to be above 0.7; convergent validity is established when the average variance extracted (AVE) is greater than 0.5, and discriminant validity was assessed with the Fornell-Larcker criterion and the cross-loadings assessment.

To assess the significance of the structural model path coefficient, the significance of the model assessed using bootstrap resampling of 5000 samples as per Hair et al. (2019). Coefficients of determination (R^2) reveal the strength of the model. We assess effect sizes (f^2) and predictive relevance (Q^2) for every relationship or model outcome. The data was analysed using SmartPLS4 software.

5.4.2 – ANN Analysis

The ANN was designed to complement the PLS-SEM results to model non-linear relationships between resilience factors and project success, incorporating predictive capability and signalling the importance of each predictor in relation to the others. The input for the ANN model was the latent variable scores from the PLS-SEM model. A method of ten-fold cross-validation was used to mitigate overfitting (Duc, M.L. et al., 2022). The data set was segregated into training and test subsets for modelling, with both subsets divided into 90% for training the model and 10% for test purposes to mitigate overfitting of the training model (Rehman et al., 2020).

For the ANN, a multilayer feed-forward model with one hidden layer with 10 neurons was defined based on grid search results. That indicated the model complexity was matched to the model performance (Duc, M.L. et al., 2022). The training method included back-propagation with gradient descent algorithms for training the network, and performance measures were saved and maximised including root mean square error (RMSE) and R^2 for the back-propagation optimisation of the network (Rehman et al., 2020).

The 10-fold cross-validation process indicated an average RMSE of 0.15 and R^2 of 0.85, which indicates a reasonable level of predictive accuracy. After model training, the model weights were retrieved and analysed to position the relative importance of resilience factors presented to the ANN.For the analysis, the SPSS Artificial Neural Networks module was used. To the baseline linear model review, the ANN model showed a significant improvement in accuracy. This validates that the ANN is an appropriate modelling technique in this instance to model complex relationships.

6 – Results

6.1– *PLS-SEM Results*

6.1.1 – Introduction to Structural Model Evaluation

In summary, the goal of the PLS-SEM evaluation was to assess the measurement model and the hypothesised relationships between resilience constructs and construction project success in Ethiopia. The analysis was completed using Smart PLS4 with 192 responses. The analysed sample provided sufficient statistical power for the complexity of the model.

6.1.2 – Measurement Model Evaluation

Prior to concluding the hypothesis testing process, a detailed review of measurement model reliability and validity was conducted utilising the following dimensions:

A – Indicator Reliability: All outer loadings of the indicators that were greater than 0.40 (Hair et al., 2017) were retained, and those that were lower than 0.40 were discarded. The reliability and internal consistency were acceptable, as established by the Cronbach's alpha and composite reliability values, which were all between 0.718 and 0.853 (Table 1).

Table 1– Cronabch’s alpha. composite reliability and AVE

Construct	Cronbach's alpha(α)	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
EF (External Environment Factor)	0.815	0.824	0.870	0.575
LD (Leadership)	0.773	0.778	0.868	0.688
OS (Organisational Structure)	0.718	0.728	0.826	0.544
RM(Risk Management)	0.853	0.860	0.901	0.694
Success	0.761	0.811	0.833	0.512
PC (Project Culture)	0.839	0.849	0.886	0.610

B – Convergent Validity: Using Average Variance Extracted (AVE), all constructs above 0.5 (HAYAM QASEM ALNAKHLI, 2019) were taken for the next analysis. This shows that the constructs meet convergent validity criteria. The observed AVE values were between 0.544 and 0.694.

C – Discriminant Validity: In this research, all HTMT values were below 0.9. The Fornell-Larcker criterion was achieved with the square root of AVE for each construct being greater than its correlations with other constructs.

D – Assessment of Significance and Relevance of Indicators: The confidence intervals of outer weights and outer loadings show the true value lies within a range of 95% confidence level.

6.1.3 – Structural Model Analysis

The collinearity test showed that all predictor variables have VIF values below 3. The VIF values are ranging from 1.693 to 2.552, which shows that there is no multicollinearity problem between predictors. This means that the independent variables (i.e., external factors (EF), resilient leadership (LD), organisational structure (OS), risk management (RM), and project resilience (PC)) are independent from one another. This presumes the stability and reliability of regression estimates in the model.

In terms of assessing the hypothesised relationships in the structural model, the summarised key results are shown in Table 2.

Table 2 – Hypothesis Testing

Hypothesis	Path coefficient(β)	T-statistics	P-Values	Confidence interval		Hypotheis supported ?
				2.5%	97.5%	
Hypothesis H1: Project resilience has significant impact on project success.	0.631	12.695	0.000	0.516	0.714	**yes**
Hypothesis H2: High performance culture has positive impact on project resilience.	0.324	8.294	0.000	0.249	0.401	**Yes**
Hypothesis H3: Resilient leadership behaviour has a positive impact on project resilience.	0.274	10.567	0.000	0.227	0.231	**Yes**
Hypothesis H4: Resilient organisational structure has significant impact on project resilience.	0.227	7.666	0.000	0.174	0.290	**Yes**
Hypothesis H5: External environmental factors have significant impact on project resilience.	0.292	8.179	0.000	0.217	0.357	**Yes**
Hypothesis H6: Risk management practice has direct effect on project resilience performance	0.230	6.813	0.000	0.169	0.301	**yes**

The analysis has provided evidence that all of the proposed hypotheses have support based on the obtained values of T statistics, P values and confidence intervals (Table 2).All the hypothesised factors contributed positively and significantly to project resilience and to success. In order of influence, project resilience has the strongest influence on project success first (path coefficient β = 0.631,P=0.000), then external environmental factors (β = 0.292,P=0.000), high - performance project team culture (β = 0.324,P<005), resilient leadership behaviour (β = 0.274,P=0.000), resilient organisational structure (β = 0.227,P=0.000) and risk management practices (β = 0.230,P=0.000). The t-statistics for all hypotheses are well above the threshold of 1.96, and the confidence intervals (in between 2.5% and 97.5%) do not include zero, which adds certainty to the significance of these relations.

6.1.4 – Model Fit and Variance Explained

The model demonstrates fairly excellent explanatory power overall:

A – R-squared (R^2): The model shows good explanatory power, and resilience had a very high R^2 value of 0.972, which indicates 97.2% of the variance in resilience is explained by the predictors. The data demonstrated that the model explains about 37.9% of the variance in project success, with a moderate R^2 of 0.379. The adjusted R^2 values are nearly identical and show that these findings have excellent stability. The high R^2 =0.972 for resilience was analysed to ensure, over fitting and measurement bias did not occur. VIF values below 5 indicate no problem of multicollinearity, and the closeness of the adjusted R^2 to R^2 indicates a well-specified model. With respect to the residual statistics, the standard residual is in between -2.614 and 3.064. This evidence supports that the high R^2 translates to true explanatory power rather than overfitting and measurement bias.

B – Effect Size (f^2): The effect size of the constructs varies from 0.4778 to 1.29.According to Cohen's guide line, the effect is from medium to high. Whereas for the resilience to success, the effect size is 0.611, which is a high effect. Which infers that there are no exogenous constructs in the model that have no effects on endogenous constructs that correspond to those exogenous constructs. Overall, this shows completeness of the research model.

C – This research uses the Importance-Performance Map Analysis (IPMA) as a novel approach in PLS-SEM to evaluate the importance and the performance of each construct in the research model (Elareshi et al., 2022). This map provides insights to see insightful factors of successful objectives. IPMA is a graphical tool where, on the x-axis, there is "Importance" ("Total Effect") of business drivers for success represented using a scale of 0 to 1. The "Performance" is plotted against the y-axis using a scale of 0-100 (Figure 8).

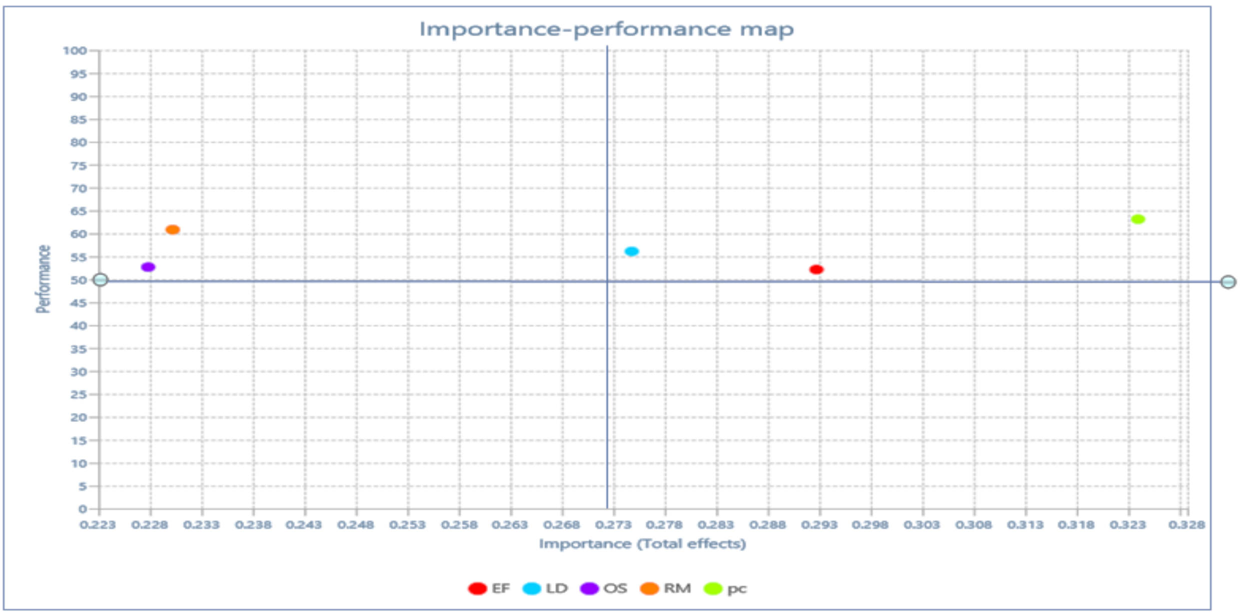


Fig. 8 – IPMA Graph

Researchers are able to identify structures that exhibit high /low "performance" and high/low "importance. According to WONGNG (2019), IPMA requires equidistant scales with balanced positive & negative categories on either side of a neutral category in the middle.

The IPMA performance scores indicate a moderate overall performance from the perspectives of Horizon 2030, with a concentration in project culture (63.24%) and managing risk management (60.85%) (Table 3). Thus, both project culture and managing risk management can be interpreted as strengths in cultivating a favourable project environment and managing risk.56.16% performance by leadership and 52.64% performance by external environment have moderate scores. Finally, organisation structure with a performance of 52.61% has the lowest score related to project resilience.

Table 3 - -IPMA performance

Constructs	Performance(%)	Rank
External Environment (EF)	52.64	4
Leadership (LD)	56.16	3
Organisation Structure (OS)	52.613	5
Project Culture (pc)	63.243	1
Risk Management (RM)	60.849	2

6.1.5 –- Summary of SEM Results

Overall, the PLS-SEM results confirm the hypothesis that resilience factors significantly contribute to construction project success and that of the five resilience- contributing constructs, they have also contributed to project success. The most significant contributor to project resilience and then to success is project culture, as it is supported by the PLS-SEM path analysis and the IPMA analysis. These analysis results suggest project team culture and risk management enhance project resilience in the Ethiopian construction project environment.

However, socio-political instability, diversity of regions, maturity level of organisations, cultural aspects are not fully captured in the model and have an impact on the above factors and on shaping the outcome of resilience. Therefore, their interpretation should be taken in the context of the Ethiopian construction sector.

6.2 – *ANN Results*

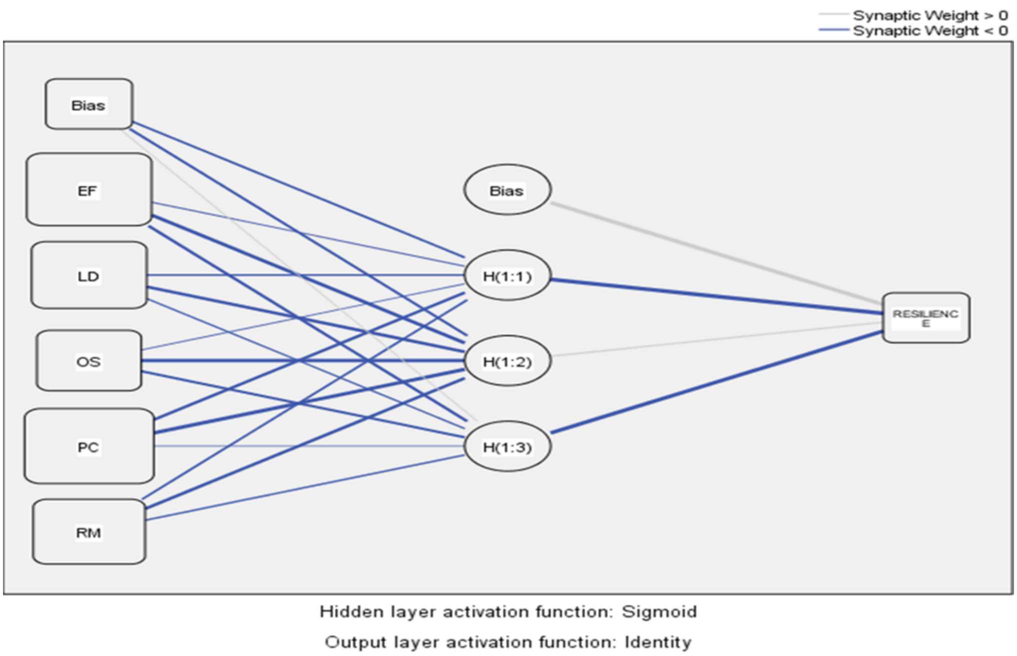
6.2.1– Purpose and Model Construction

The second method of analysis is an Artificial Neural Network (ANN) to assess the overall project success score based on the same five resilience constructs from the SEM. The aim of exploring ANN modelling for this study is to assess the nonlinear predictive capacity of each resilience factor based on the relative importance of its contribution to project success.

The PLS-SEM model in this study is based on a higher-order construct. A common method of analysing a higher-order construct is to break it down into two or more first-order constructs. In view of this, the analysis was divided into three separate models. Model A examined the resilience factors on the resilience. Model B investigated resilience as a higher-order construct that insulates construction projects from augmenting project success. Model C investigated the direct applicability of resilience factors on project success. Each construction model was subjected to Artificial Neural Network (ANN) analysis. This was to determine which model exhibited the best nonlinear constructs and structure between the variables and a model that would enable the best predictive accuracy and is the most robust. The predictive accuracy can improve, and the errors reduce after multiple rounds of processing. To assess predictive accuracy, Rahim and Munshi (2023) recommend using 90% of the sample in the training process and 10% on a sample for testing to eliminate the risk of overfitting and implemented a ten-fold cross-validation method to derive the RMSE (root mean square of errors). To implement the ANN analysis, the data set (192 responses) was separated into training and testing, where 90% of the responses (173 responses) were put into training and 10% of the responses (19 responses) were allocated to a test. The ANN design is a multi-layer perceptron, which consists of the input layer that contains 5 nodes for each contributing resilience factor, a hidden layer, and a single output layer that consists of outputting the project success score.

6.2.2 – Model Performance

The PLS-SEM model is of Higher Order Construct (HOC) of second degree order. In order to analyse such constructs in ANN, the mother model has to be separated to make it a single-order construct. For the ANN analysis, three models with first-order constructs are developed. Model A is referring to the direct relationship between the five resilient factors and resilience. Model B is a direct relationship between resilience and success. Model C is about the direct relationship between the five resilient factors and project success. The codes used to show the resilient factors considered in the three models are EF (External Environment factors), LD (Leadership),OS (Organisational structure),PC (Project team culture) and RM (Risk Management).



Fig, 9 – ANN Model A-factors to resilience (R^2=0.997)

Table 4- MODEL A-RMSE values

Network	Sum of squares error (Training)	Sum of squares error (Testing)	Sample Size (Training)	Sample Size (Testing)	RMSE (Training)	RMSE (Testing)	RMSE (Training) - RMSE (Testing)
1	0.192	0.024	163	29	0.034320753	0.028767798	0.005552955
2	0.342	0.026	173	19	0.044462103	0.036992176	0.007469928
3	2.297	0.053	174	18	0.114896255	0.054262735	0.06063352
4	0.24	0.007	171	21	0.037463432	0.018257419	0.019206014
5	0.389	0.027	174	18	0.047282472	0.038729833	0.008552639
6	0.143	0.275	169	23	0.029088724	0.109345881	-0.080257158
7	0.351	0.024	174	18	0.04491371	0.036514837	0.008398873
8	0.289	0.016	172	20	0.04099064	0.028284271	0.012706369
9	2.891	0.091	173	19	0.129270966	0.069206023	0.060064943
10	2.494	0.229	173	19	0.120067418	0.109784478	0.010282941
Mean	**0.9628**	**0.0772**			**0.064275647**	**0.053014545**	
SD	**1.114261469**	**0.095696047**			**0.039933681**	**0.032998864**	

Table 5- Model A- Normalized Importance (%)

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Normalized Importance (%)
EF-RES	0.295	0.293	0.045	6.592	0.000	90.5
LD-RES	0.262	0.259	0.018	14.221	0.000	86.49
OS-RES	0.201	0.199	0.02	10.053	0.000	65.07
PC-RES	0.351	0.351	0.032	10.802	0.000	94.23
RM-RS	0.265	0.263	0.028	9.463	0.000	77.14

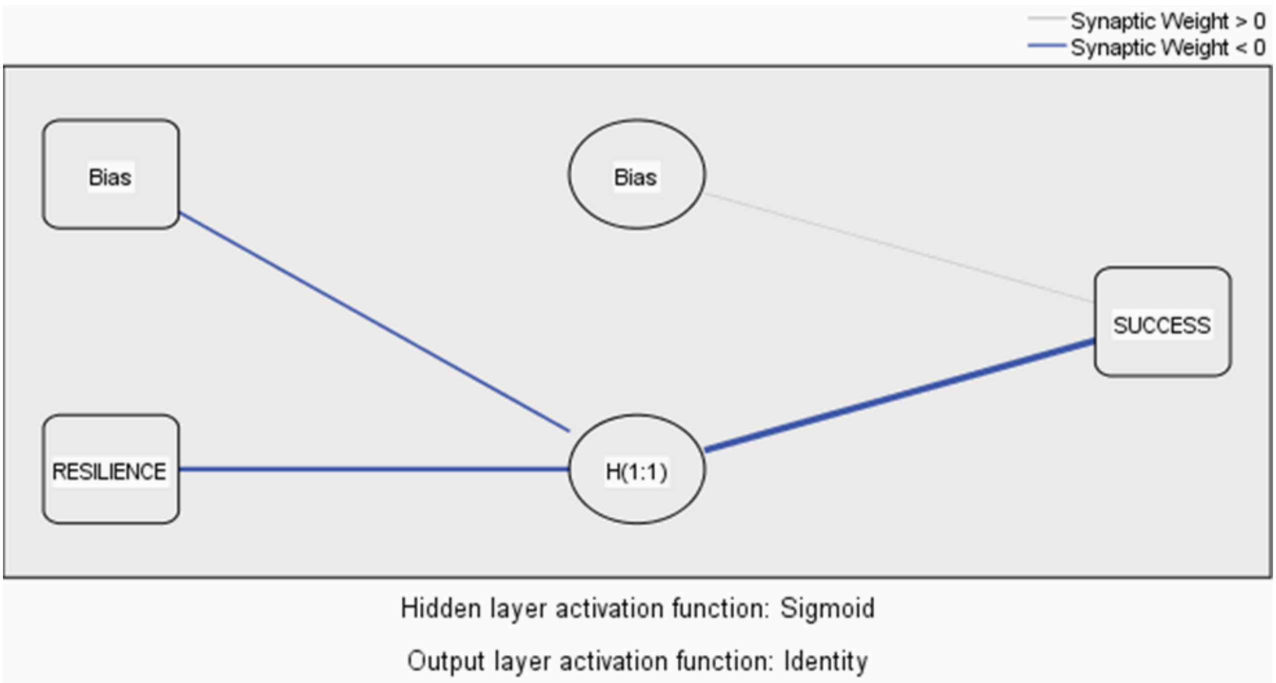


Fig.10 –ANN MODEL B- resilience to success(R^2=0.408)

Table 6- MODEL B-RMSE Values

Network	Sum of squares error (Training)	Sum of squares error (Testing)	Sample Size (Training)	Sample Size (Testing)	RMSE (Training)	RMSE (Testing)	RMSE (Training) - RMSE (Testing)
1	52.72	9.96	171	21	0.555251379	0.688684045	-0.133432667
2	48.74	8.83	174	18	0.529258862	0.700396713	-0.171137851
3	49.87	5.64	169	23	0.543220726	0.495194297	0.04802643
4	58.54	5.25	174	18	0.580031707	0.540061725	0.039969983
5	51.07	6.76	172	20	0.544902381	0.581377674	-0.036475293
6	51.39	7.36	173	19	0.545024791	0.622389284	-0.077364493
7	55.12	3.89	173	19	0.564457896	0.452478554	0.111979342
8	63.58	9.91	163	29	0.624548917	0.584571756	0.039977161
9	50.93	4.53	171	21	0.545743765	0.46445052	0.081293245
10	65.66	13.87	168	24	0.625166644	0.760208305	-0.13504166
Mean	**54.762**	**7.6**			**0.565760707**	**0.588981287**	
SD	**5.915857785**	**3.074045471**			**0.034005041**	**0.104454197**	

Table 7- Model B Normalized Importance (%)

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Normalized Importance (%)
RESILIENCE -SUCCESS	0.616	0.624	0,053	11.032	0.000	100

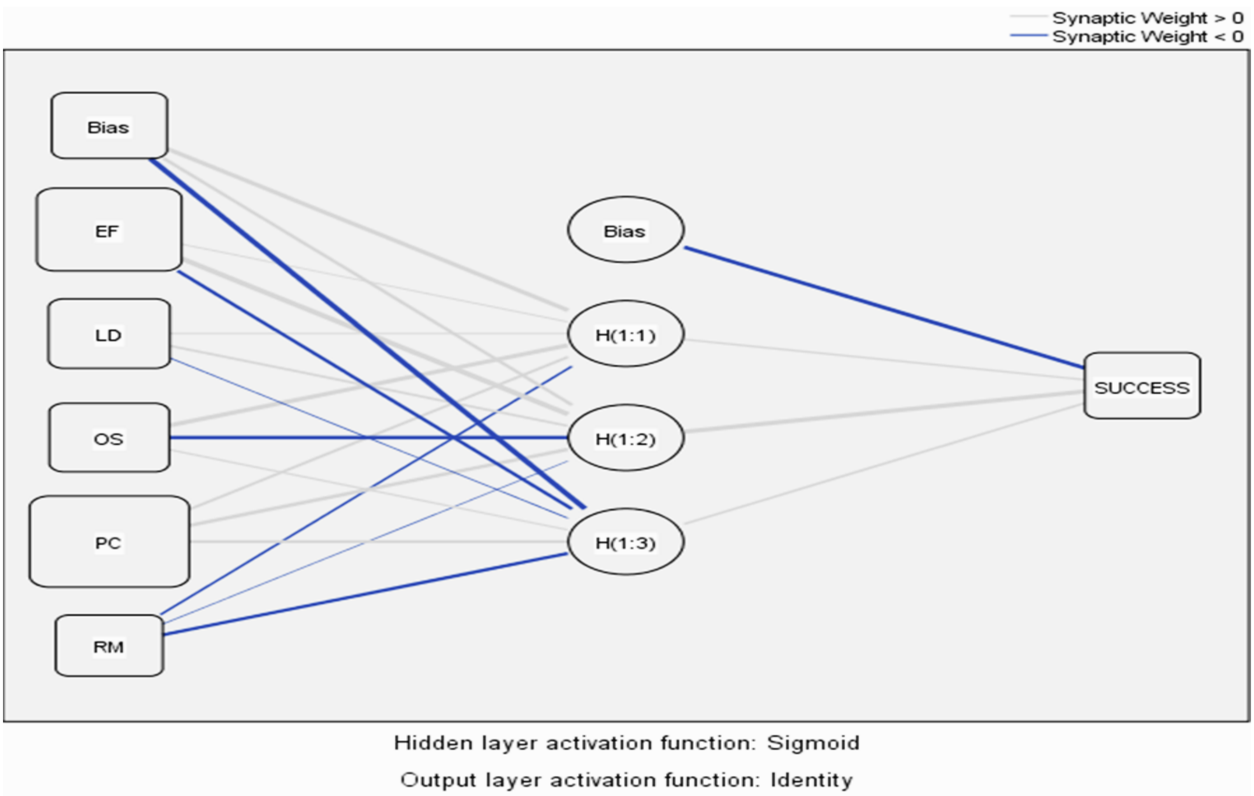


Fig.11-ANN Model C-factors to success(R^2=0.579)

Table 8- Model C:RMSE values

Network	Sum of squares error (Training)	Sum of squares error (Testing)	Sample Size (Training)	Sample Size (Testing)	RMSE (Training)	RMSE (Testing)	RMSE (Training) - RMSE (Testing)
1	36.09	3.31	179	13	0.449021282	0.504594277	-0.055572995
2	37.42	2.12	169	23	0.470552992	0.30360157	0.166951423
3	37.56	5.12	174	18	0.464609588	0.533333333	-0.068723746
4	36.07	3.75	171	21	0.459277337	0.422577127	0.03670021
5	41.08	2.27	174	18	0.485892945	0.355121263	0.130771682
6	38.4	1.96	169	23	0.476674873	0.29192018	0.184754694
7	37.64	3.65	174	18	0.465104116	0.450308536	0.01479558
8	49.95	1.82	172	20	0.538894217	0.301662063	0.237232154
9	45.42	1.87	173	19	0.512389844	0.313721298	0.198668547
10	39.8	2.24	173	19	0.479643413	0.34335803	0.136285383
Mean	**39.943**	**2.811**			**0.480206061**	**0.382019768**	
SD	**4.484856123**	**1.098184866**			**0.026874656**	**0.089340927**	

Table 9- Model C Normalized Importance (%)

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Normalized Importance (%)
EF-RES	0.295	0.293	0.045	6.592	0.000	98.17
LD-RES	0.262	0.259	0.018	14.221	0.000	53.36
OS-RES	0.201	0.199	0.02	10.053	0.000	41.21
PC-RES	0.351	0.351	0.032	10.802	0.000	63.33
RM-RS	0.265	0.263	0.028	9.463	0.000	19.79

To evaluate the predictive accuracy, root mean squares of errors (RMSE) were calculated for the training and testing based on the sum of squares error (SSE). The RMSE values noted in Table 8 show that the RMSE values are low, and all the ANN models indicate greater predictive accuracy (Rehman et al., 2020).

Similarly, the R^2 values produced as part of the PLS-SEM offered information about the explanatory power of each model error. Model A had a very high R^2 (Figure 9) value of 0.997. The result indicates that almost all variance in resilience can be explained by associated factors, which is consistent with the conclusion from the ANN with low RMSE and demonstrates good generalisation. Model B had a lower R^2 (Figure 10) of 0.408, which means that resilience only explains a moderate amount of the differences in project success, and the ANN showed a higher RMSE, indicating it has limited ability to predict outcomes.

Model C resulted in an R^2 (Figure 11) of 0.579, indicating moderate to strong explained variance for project success as a direct outcome of resilience factors. When assessing ANN Model A (Factors to Resilience), it showed very good predictive accuracy, with a training RMSE of 0.064 and a testing RMSE of 0.053 (Table 4). Particularly, the normalised importance scores of Model A (Table 5) identify project team culture (94.23%), external environmental factors (90.5%), and leadership (86.49%) as the top predictors of resilience. In relation to Model B (Resilience to

Success), Model B displayed a slightly higher test RMSE result (0.588) than the training RMSE value (0.566) (Table 6), indicating limited generalisation. The contribution from a resilience perspective to predicting success on Model B was clear, with resilience possessing a 100% normalised importance (Table 7). Model C (Factors to Success) produced the best predictive outcome with a training RMSE of 0.480 and a markedly lower test RMSE value of 0.38 (Table 8), which indicated good generalisation of Model C.

The ranking of the normalised importance for Model C (Table 9) identified external environment factors (98.17%) and project team culture (63.33%) as the key contributions to success. The PLS-SEM approach indicated that all path coefficients were statistically significant ($p = 0.000$) across the models, confirming Model A confirmed the structural element of project team culture, external project environment factors, and leadership to resilience ; Model B confirmed resilience as a significant but not dominant predictor of success; and Model C confirmed a direct and stronger relation in terms of the associated resilience factors contributing to success. Descriptively, across the ANN and PLS-SEM methods of providing statistical analysis, Model C (factors of resilience for project success) is the top model, followed by Model A, and the weakest statistical predictive performance was Model B for statistical significance and computing error.

6.2.3 – Sensitivity Analysis

The sensitivity analysis ranked the predictors' normalised relative importance (NRI) to the dependent variable. The NRI of each predictor for any output neurone was computed by dividing the means of each predictor's importance by that of the most important predictor (Valence and Intention, 2023).

It should be noted that the connection weights method for the model C importance scores for each resilience factor was derived:

Table 10 – Model C-Resilient factors rank

Resilience Factor	Importance Score (Model- C)	NRI	Rank
External Environment Factor (EF)	98.17 %	1.000	1
Leadership (LD)	53.36 %	0.545	3
Organisational Structure (OS)	41.21 %	0.429	4
Project Team culture (PC)	63.33 %	0.645	2
Risk Management (RM)	19.79 %	0.202	5

The NRI ranking indicates that External Environment Factor (EF) (NRI=1.000) is the highest-ranked predictive factor of the artificial neural network model. Project Team Culture (PC) (NRI=0.645) and Leadership (NRI=0.545) are the next predictive factors (Table 10).

6.3 – *Comparison of PLS-SEM, IPMA and ANN Results*

6.3.1 – Model Assessment Power

The R^2=0.972 for resilience indicates the predictors explained 97.2% of the variance in resilience, and the R^2 value of 0.379 for project success was moderate. The findings of the ANN models show that Model A (Resilience factors to Resilience) with R^2 (0.997) can fully explain , resilience and Model B (Resilience to Success) with R^2 (0.579) explains a moderate to strong component of success. Finally, Model C (resilience factors to success) with R^2 (0.408) for resilience explains a moderate component of success.

6.3.2 – Relevance of Predictors

In SEM and IPMA, project team culture had the largest path coefficient (β=0.324, $p < 0.001$) and an importance performance of 63.24%, and in ANN Model C, the external environment factor has the most importance score of 98.17%. Team culture is the second in importance, with a score of 63.33%. Both risk management and organisational structure are low in predictive influence.

6.3.3 – Similarities and differences

The results between PLS-SEM and ANN were compared using the path coefficient and normalised relative importance (Richter and Tudoran, 2024). Ranking of constructs differed across the three approaches (Table 11). In SEM, the highest-valued constructs were project culture (β = 0.324), and the next is external environment (β = 0.292). Then leadership (β = 0.274), risk management (β = 0.230), and organisational structure (β = 0.227) are at the bottom. The IPMA rankings place Project Culture (63.33%) on top and Organisational Structure at the bottom (52.61%). In ANN, the external environment (98.17%) is the most important predictor, and risk management was at the lowest level.

Project culture and external environment constructs have similar rankings. Project team culture is captured in SEM and IPMA (i.e., linear effect), and external environment is at its peak and project culture is second rank in ANN (i.e., nonlinear effects).These constructs capture the influence differently. Organisational structure is the lower-level predictive construct in both SEM and IPMA, and risk management is in ANN.

Table 11-Resilient factors Rank comparison of SEM,IPMA and ANN values

Construct	SEM		IPMA		ANN	
	Path coefficient(β)	Rank	Performance (%)	Rank	Importance score	Rank
Project culture(PC)	0.324	1	63,24	1	63.33	2
Leadership(LD)	0.274	3	56.16	3	53.36	3
Organisational Structure(OS)	0.227	5	52.61	5	41.21	4
External Environment factors(EF)	0.292	2	52.64	4	98.17	1
Risk management(RM)	0.230	4	60.85	2	19.79	5

6.3.4 – Practical Implications

Both PLS-SEM and ANN considered the significance of project team culture and external environment factors as a basis for improved resilience and project success. Since ANN had improved prediction accuracy compared to the SEM analysis, non-linear relationships and complicated interactions should be included when discussing resilience issues in the construction industry. Project managers should concentrate on developing fundamental project team culture qualities and addressing external environmental factors so as to have an impact on project success. However, the findings of this research indicate that in line with the dynamic business environment: socio-political, financing, cultural and labour force changes have the capacity to impact on project resilience and on success. Because they have a significant influence to disrupt or improve these relationships.

6.3.5 – Limitations of Each Method

PLS-SEM is a method that uses a theory-based structure to test theories and understand direct cause-and-effect relationships. While ANN is able to model complex, nonlinear relationships and was able to provide predictive power, the interpretability with respect to specific effects of predictors (Wong et al., 2024). Therefore, the integrated use of SEM for the validation of theoretical relationships (linear relations) and the use of ANN to distinguish complex patterns (Non-linear relations) to describe resilience achieves the best understanding of the resilience factors influencing project success (Rehman et al., 2020). The research highlights the need for more mixed-method research in the future in order to fully understand the complexity involved and provide richer explanations than just quantitative correlations.

6.4 – *Summary*

This research used PLS-SEM and ANN to examine how key resilience factors influence construction management practice in Ethiopia. It established that the two resilience factors, project culture and the external environment are drivers of construction project resilience and success. The PLS-SEM assessment result revealed that project culture has a strong influence on resilience and has high explanatory power for the model, while the ANN analysis showed the external environment to be the most influential predictor but with nonlinear impacts. Overall, SEM and ANN demonstrated the need for a project to develop project team culture and understand external environmental conditions when working on projects. By using both SEM and ANN, a comprehensive understanding of the project resilience model emerges; then the project team can gain further insights on how to enhance resilience in projects through advancing project team culture, leadership, flexible organisational structure, risk management and adaptation to the external environment to improve overall project performance. Research limitations include that results broadly may reflect regional socio-political factors, resource constraints, and the effect of informal leadership influence.

7 – Discussion

7.1 – *Introduction*

In this study the objective is to synthesise the key findings of the empirical analysis and focus on the key resilience factors, project culture and external environment. To discuss how PLS-

SEM and ANN provided different but complementary insights to understand these complex constructs and their relationships.

7.2 – *Summary of Key Findings*

The usefulness of SEM and ANN methods together captures the important distinction of resilience factors as they relate to project success as follows: Based on the SEM results, the resilience factors explained a high proportion of the variance for resilience ($R^2 = 0.972$) and a moderate proportion for project success ($R^2 = 0.379$). Within the SEM results, resilience was found to be a strong predictor of project success. The PLS-SEM assessment result showed that team culture has a strong influence on project resilience. The results of ANN indicated that the external environment was the most important predictor (98.17%), followed by team culture (63.33%). Therefore, both approaches validated the importance of project team culture and external environment factors to enhance resilience in the construction sector in Ethiopia.

7.3 – *Discussing the influence of major resilience factors.*

7.3.1 – Project team culture

The PLS-SEM analysis reveals project culture is associated with project resilience, as a pathway coefficient of 0.324 ($p < 0.001$) indicates that project culture is one indicator (along with project endorsement by top management, project team competence, and project team stakeholder involvement) of how resilient a project can be. IPMA results had project culture receiving the highest importance score, with an importance of 63.24%. Also, based on expectations from ANN, project culture indicates that it determined that project culture contributes 63.33% to the project's success.

The results presented in this study corroborate previous studies that have sought to examine the relationship of organisational culture on resilience. Fietz et al. (2021) examine culture as representing the common beliefs and understanding of a group that prescribe the behaviours of its members and develop adaptive behaviours (Pathiranage et al., 2020). Previously, the literature examined cultural coherence, communication and strategies for effective team development that were more specific to the context of Ethiopia's construction sector (Tedla, 2016 & Debebe and Hanfore, 2018 & Mohammed, 2018) but have remained deprived of empirical evidence on the impact of team culture on project resilience. This study continues to offer quantitative support to the project culture-resilience relationship through hybrid applications of PLS-SEM and ANN analysis that includes further understandings yet still emphasises the need for more advancements in robustness.

Through the PLS-SEM analysis the finally accepted indicators of project team culture are team trust, team passion for contribution, team recognition scheme and assigning the right team for the right job. Based on this, here is the supporting literature in line with them,

Trust between teammates nurtures trustworthiness and subsequently cooperation and crisis management assistance, which produces continuity and constructive performance (Hartwig et al., 2020:184; Imam et al., 2021:3; Bond-Barnard et al., 2018:432). The visibility of passion about contributing meaningfully and how much one's contribution might universally matter, and factoring a job into the equation, their absence of visibility of a passion, erodes the team's ability to function (Salas-Vallina et al., 2022:13; Jetu, 2013:440). Recognition schemes are recognised for a motivational purpose and they generally motivate teams to produce more attachment to the project - resilience (Amaral et al., 2015:1186; Mbukwana et al., 2023; Taylor et al., 2020). Many workers accept jobs they are not capable of doing, leading to either low productivity or a lack of success to achieve the project. Matching capable people to appropriate jobs is still a common problem (Crane et al., 2017; Hussain et al., 2021). So, a resilient and adaptable project team culture can be summed up as overall project resilience.

It is worth pointing out that there may be biases (e.g., social desirability) regarding the cultural valuing identified in self-reports and could have limited generalisability given the multitude of ethnicities and regional contexts in Ethiopia affecting how resilience culture could be applied and valued in projects.

7.3.2 – External Environment as the Most Important Non-linear Predictor

External environment is the most important factor in ANN analysis, with an importance score of 98.17%, showing how crucial it is for project success. External environmental factors such as economic, political, social, and legal conditions are typically not under the control of the organisation but could be important for resilience (Arefieva et al., 2019 & Amoah et al., 2021). Yifru (2019) identified in Ethiopia that a project manager has a responsibility to spot external environmental factors that affect project performance to reduce cost and schedule overruns. This research confirms these findings and also shows the nonlinear and dominant role of the external environment in resilience according to ANN analysis, which indicated a complexity that had not previously been measured in Ethiopian construction research (Hidayat-ur-Rehman & Alsolamy, 2023).This adds depth to the interplay between external shocks and opportunities with project internal factors.

As per the PLS-SEM analysis, the finally accepted indicators under the shelter of external environment are low inflation rate, stable economic conditions and enforcing proper legal certainty. Here are below some supporting these indicators.

Due to increased costs and project delays the purchasing power of money for projects is affected. High inflation negatively affects the overall success of the project (Tessema et al., 2022). Project performance is also affected by the unpredictable economy resulting from the VUCA business environment nature (Funmilayo et al., 2017).Proper legal frameworks that provide legal certainties creates confidence and compliance to have a stable project environment (Popelier, 2008).

7.3.3 – Alignment of the findings with studies of other developing countries

The conclusions generated from the findings of the PLS-SEM and ANN analyses, which note the influence of project team culture and the external environment on project resilience and project success were well supported by empirical evidence that exist from other developing countries or regions.

Team culture has a significant influence and impact on resilience in developing countries because it builds internal adaptability. This is evidenced in Nigeria when both the positive organizational culture and resilience of the employees improved the performance of the hospital through both employee's behavioural (resilience) and hospital working conditions (Akintunde-Adeyi et al., 2023). Reports from a number of African countries note how positive team cultures can build social capital and encourage anticipatory learning. So that social and environmental challenges can be responded to effectively (Tutu & Busingye, 2018). The reports from the Asian countries noted the importance of promoting open lines of communication and transformational leadership to foster strategic resilience through innovation and developing dynamic capabilities when environmental changes emerge (Kittopoomwong et al., 2023). These research shows that strong team culture is a fundamental condition for the development of organized resilience in developing countries.

The external environment has a great deal to do with the development of organizational resilience in developing countries. As noted in East Asia, the COVID-19 pandemic forced people and businesses to adapt to developing their resilience and to determine success when operating in unpredictable markets (Liang et al., 2025).In Nigeria, the changing markets and technology require manufacturing firms to be flexible and responsive so that they can improve their adaptability and strategic position (Iyke & Onuoha, 2023). While in Egypt, the process of environmental scanning promotes organizational learning to support SMEs to adapt to their environmental uncertainty (Marzok, Yasmeen & Jin, Jiafei, 2022). All of these reports outlined later demonstrate external environmental contexts are drivers of resilience through adaptive strategies.

These study specific findings highlight that project resilience in developing countries should be viewed as the complex interaction between a combination of internal team culture and external environmental context.

7.4 – *Theoretical and Practical Implications*

This research enhances resilience theory by recognising the internal (organisational culture) and external (market dynamics) attributes of a systemic framework. It affirms the perspective that resilience is a dynamic, emergent property of complex systems and calls attention to the importance of models that incorporate nonlinear interactions such as a neural network approach.

Organisations need to cultivate resilient, adaptable cultures and monitored environment. The results suggest that this research recommend an actionable resilience implementation framework with actionable steps, such as assessing vulnerabilities of the organisation, developing adaptive culture, ongoing environmental scanning, and creating learning mechanisms to facilitate responsive actions to disruptions. Policymakers, in the case of Ethiopia, should develop regulatory and support mechanisms (such as for legal certainty, for low inflation rate and for having stable economic environment) to enable rapid responses to external shocks. The combined application of PLS-SEM and ANN can produce a useful framework to identify important predictors, contribute towards developing custom resilience pathways, and harness the best of both methods (Rehman et al., 2020).

In the context of Ethiopia's socio-political landscape, these factors suggest that resilience building and resilience-related operations must be context aware enough such that governance is steady, regulatory transparency is documented, and recognition and inclusion of socio-cultural contexts happen to support effective success. Active engagement with local populations and leadership are key factors in ensuring resilience is on going in construction projects.

Finally, an important consideration to emphasise in implementing resilience in planning as well as post-implementation is for a project-cost benefit analysis of the projects for assessing the economic benefits, financial negative impact of delays, and economic and financial cost overruns of resilience investments. An evident pitfall to overcome, particularly in countries such as Ethiopia, has been sourcing the funding requirements for resilience projects through the traditional and conventionally recognised international development funding sources. But potentially considering the other funding brochures, such as public-private partnership options, resilience bonds, development funding, and/or social impact investment financing, may support in obtaining funding for resilience project capitalisation. Transparent financial planning and accountability support accountability and delivering projects reasonably further to sustainability.

7.5 – *Limitations*

This study has applied a cross-sectional design, which restricts the ability to easily understand the relationships between project team culture and external environment factors with resilience and project success. For capturing changes over time, longitudinal studies are beneficial, and this also provides stronger causal evidence (Ogbu Edeh et al., 2020).

The research data collected relies on the participants individual capacity, knowledge and previous experience. In doing so, their response might be biased by their external and internal situations, such as the personal behaviour of respondents, social bias, stakeholder's bias, etc. Which may finally affect the accuracy of the reported findings from the research. To reduce such impact, future research shall integrate qualitative interviews to have a better understanding of the context and to collect better information that leads to realistic results.

The degree of applying the research findings to the other regions of the country might be affected by the cultural and socio-political context. These are cultural differences, communication skills, openness, political situations, governing laws, etc. Therefore, attention shall be given when applying these research findings in the real world.

8 – Conclusion and recommendations

This research explored the relationships among the main resilience factors that have an impact on the success of construction projects in Ethiopia. Using PLS-SEM and ANN analysis, this study has determined key factors of resilience and how resilience as a factor could influence the success of construction projects in Ethiopia. The findings can enable construction professionals, policymakers, and researchers interested in advancing project performance in the rapidly evolving construction sector of Ethiopia.

8.1– *Summary of Findings*

The study has identified the resilience factors that have an impact on the resilience of the Ethiopian construction project. These are the project team's culture and the project team's external environment. The study has reported resilient construction projects have a constantly evolving or adaptable culture. This culture promotes a level of trust, communication, and sharing of issues within the project team. Ultimately the project team's culture is a factor that contributes towards supporting project resilience and success within the ever-changing business environment.

The external environment has the most nonlinear impact on project success. As the external environment is dynamic, professionals must be able to continuously monitor their external environment to be in a flexible situation.

The integrated statistical analysis of PLS-SEM and ANN demonstrated that resilience determinants are interdependently influenced by one another. By PLS-SEM, resilience key factors (project culture (first) and external (second)) are linear influences on project success.

Whereas, by ANN , the key factors (external environment (first) and project culture (second)) are nonlinear and have same the influence on success. The models demonstrated reasonably large portions of the variance described by these two resilience key factors, suggesting that there is a holistic manner of capacity building for resilience.

8.2 – *Overall Findings*

To sum up, this study supports the assertion that the building of resilience is not only a linear process but also an iterative process that requires the deliberate and strategic holistic consideration of aspects towards cultures and external contexts. In the case of Ethiopia's construction sector obviously has a lot of factors that create a difficult business environment (i.e., socially, economically and politically).

Resilience begins at the point where a project culture is built to synthesise and facilitate adaptability, innovation and participation. It is a dynamic culture that provides leadership with a strategic vision and motivation to continue with resilience in the uncertain environments. The project team can take action if they understand external factors that create abrupt shocks. Systematic environmental systems analysis or scanning also provides protection against vulnerability and allows the project to reconfigure to deliberately plan for certain unavoidable disruptions. The ability to rapidly reconfigure and deploy resources in a new configuration means the agile organisation is adaptive to change. The capability of quickly reconfiguring and deploying resources is highly important for the success of the project in a nonlinear business context. As was the case in Ethiopia.

This research outlined the contribution of new theoretical knowledge on how nonlinear relationships between cultural and environmental aspects shape project resilience. It also reveals Ethiopia - specific socio-political and cultural dynamics in regard to resilience mechanisms and project outcomes.

8.3 – *Practical Recommendations*

To create resilience, cultural building and environmental scanning are very important. Construction companies of Ethiopia should consider existing knowledge of teams and team effectiveness in building teams through training and in improving their leadership capacity (Mohammed et al., 2018). Other recommended practical methods for enabling resilience include having open trust, transparency, accountability, and learning from failure (Zhang et al., 2020), being able to build resilient culture , having the capability to monitor the environment in real time, and having the foresight to plan for contingencies (Forsgren et al., 2022). Closely working with a large number of stakeholders enables the development of strong partnerships and business networks. When implementing aspects of resilient practice, consider the costs and benefits when developed via resilience interventions. Finally, it is recommended that policy makers take the initiative to consider resilience in future policies , embed resilience thinking into regulations, and develop productive policies that offer value in developing related resilience- building initiatives.

8.4 – *Recommendations for Future Research*

This study was intended as an exploratory investigation into resilience, and ideally future studies would use data that would allow for longitudinal studies and assessment by looking at how resilience factors change across the project life. Here are some of the proposed future research works below:

a – Conduct sector-specific research particularly on infrastructure, residential, and commercial projects to, better understand resilience needs per the project type.

b – Develop a hybrid approach to model that by integrating Structural Equation Modelling (SEM) and the predictive capability of Artificial Neural Networks (ANN) in new measures of the constructs.

c – Take a broader geographical scope including other parts of Ethiopia or similar developing countries.

d – Experimental and quasi-experimental designs are advocated for future research, as this methodological approach more adequately addresses causal relationships among leadership, organisational structure, and resilience factors as they relate to providing stronger empirical evidence of interventions and mechanisms.

e – Use longitudinal or mixed-method approaches to be able to investigate what mechanisms connect culture and external environmental factors to project resilience and project success (Blessin et al., 2022 & Chmitorz et al., 2021). Such integration enables to know more about the non-linear relationships that exist between resilience factors and their effect on project success.

f – The likelihood of biases in the identification of the key resilience indicators in consideration of the cultural and political situation in Ethiopia.

g– The necessity for a more rigorous validation and testing of the resilience model created in real construction projects to ensure it fits into practice and is generalisable.

8.5 – *Final Remarks*

To conclude, resilience is paramount for the success of construction projects in Ethiopia. Thus, associated actors shall be educated to adapt and survive through uncertainty to create and continue to create successful project outcomes through the progressive building and systematic understanding of both cultural and external environmental dynamics. The integrated analytical framework (i.e PLS-SEM and ANN) of resilience analysis is an integrated and rigorous methodology, which conceptualises how the resilience process occurs as well as what is considered the nonlinear mechanisms of that process and how it is practically implemented. When applied, it presents an opportunity to improve project performance in uncertainty and contributes toward the sustainable development of the Ethiopian construction industry.

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