Heliyon 10 (2024) e28908

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Modeling of success factors of using PU coats in concrete construction projects

Ahsan Waqar[a], Nasir Shafiq[a], Naraindas Bheel[a], Omrane Benjeddou[b], Nadhim Hamah Sor[c,d,*], Jong Wan Hu[e,f,**], Hadee Mohammed Najm[g], Hamad R. Almujibah[h]

[a] *Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh, Perak, 32610, Malaysia*
[b] *Department of Civil Engineering, College of Engineering, Prince Sattam Bin Abdulaziz University, Alkharj, 16273, Saudi Arabia*
[c] *Civil Engineering Department, University of Garmian, Kalar 46021, Kurdistan Region, Iraq*
[d] *Department of Civil Engineering, Harran University, Sanlıurfa 63510, Turkey*
[e] *Department of Civil and Environmental Engineering, Incheon National University, Incheon 22012, South Korea*
[f] *Incheon Disaster Prevention Research Center, Incheon National University, Incheon 22012, South Korea*
[g] *New Era and Development in Civil Engineering Research Group, Scientific Research Center, Al-Ayen University, Thi-Qar, Nasiriyah, 64001, Iraq*
[h] *Department of Civil Engineering, College of Engineering, Taif University, P.O. Box 11099, Taif City 21974, Saudi Arabia*

ARTICLE INFO

Keywords:
Polyurea coatings
Concrete construction projects
Success factors

ABSTRACT

Polyurea coatings are well recognized for their remarkable protective properties, making them highly appropriate for practical use in the field of concrete building. The use of polyurea coatings in the concrete building business is currently constrained, despite its prevalent application in industrialized nations. The limited use may be ascribed to ambiguities about the determinants of effective implementation in this particular setting, as well as the dearth of extensive study in the realm of new building materials. The primary objective of this research is to assess and conceptualize the key determinants linked to the use of polyurea coatings in concrete building endeavors. Utilizing a quantitative research approach, a comprehensive literature analysis was conducted to identify a total of 21 probable success variables. The reliability of the questionnaire was established by the administration of a pilot survey, and afterwards, an exploratory factor analysis (EFA) was performed to enhance the clarity and precision of the underlying components. The researchers used structural modeling (SEM) approaches to develop a robust model using the primary data obtained from the questionnaire survey. The EFA revealed the presence of five unique constructs that have an impact on the effectiveness of polyurea coatings in concrete building projects. These constructions comprise several characteristics, including environmental considerations, functional requirements, protective properties, execution processes, and creative elements. The significance and relevance of this research are shown by the validation of the study's results using SEM. The study makes a valuable contribution towards the progression of polyurea coating use within the concrete building sector.

---

* Corresponding author. Civil Engineering Department, University of Garmian, Kalar 46021, Kurdistan Region, Iraq.
** Corresponding author. Department of Civil and Environmental Engineering, Incheon National University, Incheon 22012, South Korea.
E-mail addresses: nadhim.abdulwahid@garmian.edu.krd (N. Hamah Sor), jongp24@inu.ac.kr (J.W. Hu).

https://doi.org/10.1016/j.heliyon.2024.e28908
Received 27 April 2023; Received in revised form 2 March 2024; Accepted 26 March 2024

1. Introduction

Concrete is an extensively employed building material with strength characteristics, durability, and cost-effectiveness. However, environmental elements such as moisture, chemicals, and ultraviolet radiation can cause concrete to degrade, crack, and deteriorate over time [1]. Protective coatings are frequently applied to concrete structures to prevent and reduce these problems [2,3]. It is always essential to employ protective coatings on concrete structures to maintain their durability and lifespan. In recent times, polyurea coatings have become an increasingly popular method for preserving concrete buildings from the environment and improving their performance [4]. Layers of polyurea are put as a liquid and then rapidly cured to form a smooth, waterproof, and highly resistant covering [5,6]. The tensile strength, elasticity, and rapid curing period of polyurea coatings have made them the layer of choice for concrete building projects in numerous industries, including infrastructural, oil and gas, industrial, and commercial construction [7].

As a very efficient and effective solution for maintaining and improving the durability of concrete structures, polyurea coatings have gained appeal [8,9]. Since they are resistant to abrasion, solvents, and electromagnetic heat, polyurea coatings are appropriate for industrial flooring, container linings, bridge coating, and waterproofing. It has also been demonstrated that the application of polyurea coatings extends the existence of concrete structures by providing durable protection against harsh climatic conditions [10].

In recent years, polyurea coatings have become increasingly popular in the construction sector, with many builders and engineers preferring them for concrete preservation and restoration [11,12]. Several case studies have shown the effectiveness and advantages of employing polyurea coatings on substantial projects [13,14]. Polyurea coatings offer a diverse range of applications in concrete construction. Pure polyurea coatings provide exceptional abrasion and chemical resistance, making them ideal for heavy-duty environments like industrial floors and high-traffic areas [5,6]. Hybrid polyurea coatings, blended with other materials, offer increased flexibility and adhesion, suitable for areas prone to movement [4,14]. Aliphatic polyurea coatings, with UV stability and color retention properties, are perfect for outdoor concrete applications. Aromatic polyurea coatings, while not UV-stable, find utility in indoor settings [15,16]. Spray-on polyurea coatings are popular for seamless and uniform application on complex shapes, roofs, or flooring. Joint filling polyurea coatings guard against water penetration and potential cracking [13,17]. Waterproofing polyurea coatings protect against water damage and corrosion in basements and tunnels. Chemical-resistant polyurea coatings withstand harsh industrial environments. Decorative polyurea coatings enhance the aesthetic appeal of concrete surfaces [2,3]. High-build polyurea coatings reinforce structures and boost resilience in harsh environments, making them invaluable for concrete protection [18,19].

This study is focused on the success factors of all important types of polyurea coatings, such as, Pure Polyurea Coatings, Hybrid Polyurea Coatings, Aliphatic Polyurea Coatings, Aromatic Polyurea Coatings, Spray-on Polyurea Coatings, Joint Filling Polyurea Coatings, Waterproofing Polyurea Coatings, Chemical-resistant Polyurea Coatings, Decorative Polyurea Coatings and High-build Polyurea Coatings. The literature needs an examination of the underlying links between the various aspects that influence the effectiveness of these coatings. Structural equation modeling (SEM) is a statistical technique that enables the investigation of complicated interactions between variables. It can provide valuable insights into the aspects that influence the effectiveness of employing polyurea coatings [20].

This study's purpose is to examine the effectiveness of polyurea coatings over concrete infrastructure projects utilizing a SEM. Specifically, this study aims to identify the significant parameters that determine the successful use of polyurea coating and to investigate their relationships [21]. This study will create a more nuanced knowledge of the variables that make up the success of utilizing polyurea coating for concrete building projects by providing a more comprehensive insight into the intricate interactions between diverse variables [19].

Moreover, this study will be the first to use SEM to investigate the overall success of employing polyurea coating for concrete building projects. While prior studies have evaluated the efficacy of polyurea coatings, fewer have used SEM to study the microstructure of the surface layer or to analyze the intricate interactions between the various aspects that contribute to their success [22].

According to our knowledge, this is the first study that uses a quantitative research approach to identify and rank the most crucial advantages of polyurea coating by adopting various SEM tools like SPSS, Smart PLS 4 The principal output of this study will be to highlight the core success factors and give a framework to the stakeholder who can be adopted while protecting concrete from unforeseen environmental conditions [23]. The novel approach of just using SEM to examine the accomplishment of using polyurea coating for concrete building projects will contribute to a more extensive and in-depth knowledge of the factors which influence the achievement of such coating materials and will have significant implications for the planning and application of future concrete building projects.

2. Success identification

Coatings made of polyurea have been widely utilized in concrete infrastructure projects, including the building of bridges, pipelines, and wastewater treatment facilities. Their superior mechanical qualities, including high strength, elongation, with abrasion resistance, contributed to the success of adopting polyurea coating in these projects. SEM was utilized to examine the effect of polyurea coatings on the fracture toughness of concrete [24,25]. The study indicated that polyurea coatings considerably enhanced the concrete's fracture toughness, hence boosting its resistance to crack propagation. Che et al. (2019) and B. Li et al. (2019) examined the effect of polyurea coatings on the fire resistance of concrete in their study [26,27]. Benmokrane & Ali (2018) and J. Zhang et al. (2019) revealed that using polyurea coatings considerably enhanced the fire resistance of the concrete, hence boosting its overall longevity. SEM was utilized to examine the effect of polyurea coatings on the flexural behavior of reinforced concrete [3,28]. The study discovered that polyurea coatings considerably enhanced the flexural behavior of reinforced concrete, hence improving its overall performance [29,30]. SEM was used to determine the effect of polyurea coatings on the adhesion between concrete and epoxy coatings.

According to Bijanzad et al. (2022) and Qiao et al. (2020), using polyurea coatings considerably increased the adhesion between concrete and epoxy coatings, hence increasing the coatings' endurance. Bijanzad et al. (2022) and Qiao et al. (2020) examined the effect of polyurea coatings on the sulfate resistance of concrete [31,32].

The study discovered that polyurea coatings considerably enhanced the resistance of concrete against sulfate attack, hence increasing its overall durability and service life. Polyurea coatings were placed on the surface of concrete specimens, and their performance under various stress circumstances was tested. Caiyun et al. (2019) and Hou et al. (2019) discovered that polyurea coatings greatly enhanced concrete samples' tensile and compressive strengths [12,33]. Somarathna et al. (2015) and Sustersic et al. (2018) discovered that using polyurea coatings significantly decreased the rate of chloride ion penetration, enhancing the durability and service life of concrete structures [34,35]. Using SEM, the impact of polyurea coatings on the performance of concrete structures has been analyzed. SEM was used to model the link between polyurea coating thickness and concrete compressive strength [36,37]. The study discovered that the thickness of the polyurea coating greatly affected the concrete's compressive strength.

The study indicated that using polyurea coatings considerably improved the bonding strength between steel and concrete, therefore boosting the overall performance of the concrete construction. In a study by J. Liu et al. (2022) and Y. xiang Sun et al. (2021), SEM was utilized to examine the influence of various polyurea coating types on the corrosion resistance of concrete [6,38]. Q. Liu, Guo et al. (2021) and Hao Wang et al. (2019) discovered that polyurea coatings with particular compounds enhanced the corrosion resistance of concrete. SEM was utilized to predict the effect of polyurea coatings on the fatigue behavior of reinforced concrete beams [39,40]. The study discovered that polyurea coatings enhanced the fatigue performance of reinforced concrete beams, hence increasing their overall longevity. The impact of polyurea coatings on the freeze-thaw resistance of concrete was explored by Gu et al. (2020) and X. Wang (2020) [41,42].

The study indicated that adding polyurea coatings considerably increased the concrete's resilience to freezing and thawing, increasing its durability. SEM was used to examine the effect of polyurea coatings on the corrosion behavior of reinforced concrete in a marine environment [15,43]. The study indicated that polyurea coatings considerably enhanced the corrosion resistance of reinforced concrete, hence extending its service life [44]. SEM was utilized to examine the effect of polyurea coatings on the crack resistance of concrete. Greene & Myers (2013) and L. Zhang et al. (2022) discovered that polyurea coatings considerably enhanced the concrete's cracking resistance, boosting its overall performance [18,45]. The application of SEM has provided a potent analytical tool for evaluating the influence of polyurea coatings on various properties of concrete, such as corrosion resistance, fatigue behavior, freeze-thaw resistance, fire resistance, fracture toughness, and adhesion to other coatings [11,46]. This literature study demonstrates

Table 1
Identified success factors.

Code	Success Factors	References
F1	Polyurea coatings are devoid of free volatile organic compounds (VOC), giving them an environmentally friendly choice for protecting concrete.	[49,50]
F2	Polyurea coatings are simple to maintain and clean.	[51,52]
F3	Polyurea could be applied rapidly and effectively, saving time and money on large-scale projects	[17,53]
F4	Polyurea coatings may enhance the insulation qualities of concrete surfaces, reducing heat transfer and improving building energy efficiency.	[54,55]
F5	Polyurea is offered in various colors and finishes, enabling it to be customized to meet particular design specifications.	[56,57]
F6	Polyurea may be used on various concrete surfaces but sprayed using spray equipment. This makes it an adaptable alternative for a variety of jobs.	[58,59]
F7	Polyurea coatings dry rapidly, often within a few minutes, allowing for quick turnaround times on significant projects.	[5,60]
F8	Polyurea coatings are fire-resistant, offering additional protection in a fire.	[61,62]
F9	Polyurea coatings are resistant to ultraviolet radiation, making them a viable option for concrete surfaces exposed to direct sunshine and located outside.	[17,53]
F10	Polyurea is a highly durable polymer resilient to impact, abrasion, and chemicals. This makes it perfect for usage in places with heavy foot traffic and severe surroundings.	[54,55]
F11	Polyurea coatings are highly resistant to mold formation and other hazardous germs, making them an excellent option for usage in areas where cleanliness is a concern.	[63,64]
F12	Polyurea coatings may increase the overall aesthetic appeal of concrete surfaces by giving them a smooth, polished appearance. This may increase the value and marketability of structures and buildings by enhancing their visual appeal.	[8,16]
F13	Polyurea is a flexible polymer that can sustain a broad temperature range without cracking or fracturing. This makes it suitable for concrete surfaces susceptible to movement or moving over time.	[65,66]
F14	Polyurea coatings may reflect light and prevent heat absorption, making them an excellent option for sun-exposed outdoor concrete surfaces. This reduces the quantity of cooling necessary for buildings, lowering energy expenses.	[67,68]
F15	Polyurea coatings generally have a lifetime of 20 years or over, making them an economical solution for concrete protection.	[9,69]
F16	Polyurea provides resistance to a wide variety of chemicals, mainly acids and fuels, making it suitable for commercial and industrial use.	[2,70]
F17	Polyurea is impervious and resistant to humidity, making it perfect for water-containing concrete, including swimming pools and water tanks.	[71,72]
F18	The great impact resistance of polyurea coatings makes them an excellent option for concrete that may be vulnerable to impacts and collisions, including such walls and parking lots.	[51,73]
F19	Polyurea coatings offer a smooth and airtight covering over concrete, which may enhance interior air quality by minimizing air exchange with the outside environment.	[74,75]
F20	polyurea coatings are an excellent solution for concrete surfaces for public locations where graffiti is an issue.	[49,76]
F21	Polyurea coatings may be textured to offer a non-slip surface, which makes them an excellent option on concrete surfaces that might become wet, such as pool decks and pathways.	[50,77]

that the application of polyurea coatings can greatly enhance the quality and service life of concrete structures [47,48]. Following the literature findings 21 success factors of utilizing Polyurea in concrete are presented in Table 1. These success factors are the core variables of this research as they indicate the possible outcomes in context with scope of this research.

3. Methodology

SEM is a commonly used statistical approach in several sectors of study, such as business, social sciences, and engineering. For our SEM analysis in this research, we employed Smart PLS 4 software. Smart PLS 4 is a potent tool that is capable of handling both reflecting and formative models and estimating complicated models with many latent variables and indicators. The methodology is indicated in Fig. 1. The two primary components of our SEM strategy were the measurement model and the structural model. Exploratory factor analysis (EFA) was used to design the measurement model in order to recover the underlying dimensions of the constructs [52,73]. EFA assisted us in identifying the elements or dimensions that contribute to the formation of the constructs, hence enabling us to establish a trustworthy measuring model. Path analysis was employed to analyze the links between the components in the structural model. Path analysis permits the evaluation of the direct and indirect impacts of independent factors on the dependent variable [78]. This allowed us to comprehend the relationships between the various constructions and to discover the relevant routes in the model. The structural model was calculated using the variance-based SEM technique partial least squares (PLS) [51,71]. The PLS method calculates route coefficients by minimizing the sum of squared differences between the observed and predicted values of the dependent variable [79]. This method is especially advantageous when the sample size is limited or when the data are not regularly distributed [70,72]. The outcome of the Smart PLS 4 analysis offered estimates of the path coefficients, significance levels of the correlations between the constructs, and model-fitting statistics. The goodness-of-fit statistics, such as the PLS SEM Algorithm and Q2 values, let us evaluate the model's overall fit and estimate its predictive capability [2,69]. Overall, the SEM method with Smart PLS 4 provided us with a potent instrument for examining the correlations between the components in our model [80]. We were able to find the relevant routes and evaluate the relative relevance of the various constructs in explaining the variance in the dependent variable by applying this method [75].

3.1. *Exploratory factor analysis and construct development*

EFA was used to determine the underlying components that might explain the success of utilizing polyurea coating in concrete building projects. The first set of variables includes project management, material attributes, and quality control factors based on a thorough literature research and expert opinion. The sample size for the EFA was set using the rule of thumb of five to ten individuals

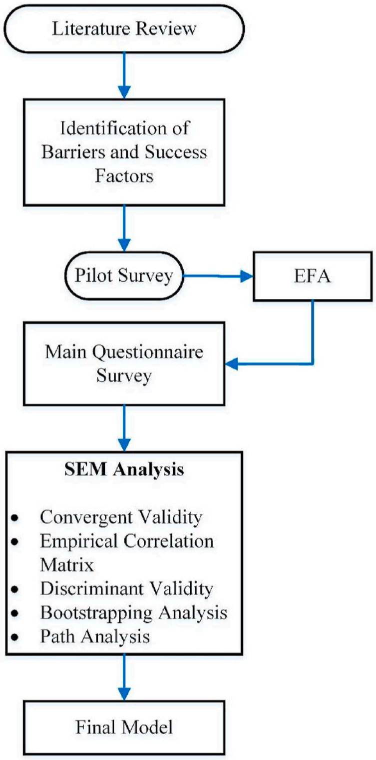

Fig. 1. Research methodology.

per variable [81]. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test for sphericity were used to evaluate the sample size and the data's factorability [2,53,60,69]. The KMO value of 0.7 should be set as minimum goal so that the data was appropriate for EFA, and the Bartlett's test of sphericity was statistically significant ($p < 0.001$), indicating that the correlations between variables were adequate to continue with EFA. Principal Component Analysis (PCA) was used as the extraction approach for the EFA, and the Varimax rotation method was utilized to generate factor structures that were easier to read. Using Kaiser's criteria (eigenvalue > 1) and scree plot analysis, the number of variables to extract was calculated. The first EFA performed on 21 variables [17,62]. Following an examination of the factor loadings and item-total correlations. Material Durability, Surface Preparation, Application Process, Quality Control, Project Management, Environmental Conditions, Material Compatibility, Contractor Experience, and Training and Education were the recognized criteria. These characteristics demonstrate the multifaceted nature of polyurea coating's performance in concrete building projects Normally it is expected that EFA show the underlying constructs that potentially explain the effectiveness of polyurea coating use in concrete building projects and offered a foundation for additional construct development and hypothesis testing.

3.2. *Common method bias*

Common technique bias refers to the possible bias that might develop in research when the independent and dependent variables are measured using the same method or data source. In the present research, a single survey questionnaire was used to gather data, which might contribute to common method bias. Several actions were done to remedy this problem [54]. First, the survey questionnaire was created to eliminate the possibility of common method bias. For example, the questions were designed to limit the likelihood that participants would provide socially acceptable replies or provide the same response to all topics. In addition, the poll contained both favorably and negatively phrased questions to reduce response bias [82]. Harman's single-factor test was used to determine the existence of common method bias. It is expected that component accounted for less than fifty percent of the variation, indicating that common technique bias should not a major problem in the research. The use of partial least squares structural equation modeling (PLS-SEM) to decrease the impacts of common method bias has been proposed in data analysis. PLS-SEM is less susceptible to common method bias than other SEM approaches since it emphasizes the connections between the latent variables rather than the observable variables [83]. In conclusion, despite the fact that common method bias is a possible concern in this research, numerous steps were taken to mitigate its impacts [54,64]. Harman's single-factor test findings reveal that the bias is not statistically significant, and the inclusion of PLS-SEM in data analysis further mitigates the impacts of common method bias.

3.3. *Model development*

SmartPLS 4.0 software was used for data analysis and SEM. The primary phases of the model development procedure were measurement model development and structural model development.

3.3.1. *Measurement model*

The convergent and discriminant validity of the constructs were evaluated in the first step via the development of a measuring model. Based on the average variance extracted (AVE), composite reliability (CR) (Eq. (2)), and Cronbach's alpha (Eq. (3)), convergent validity was examined [55]. Acceptable were AVE values above 0.5, CR values above 0.7, and Cronbach's alpha values above 0.7 [84]. Using the Fornell-Larcker criteria, which compares the square root of the AVE (Eq. (1)) for each construct to its correlations with other constructs in the model, discriminant validity was determined. If the square root of the AVE for a concept is larger than its correlation with other constructs, discriminant validity is regarded to have been established.

Following calculations used for convergent validity exploration:

$$\text{Average Variance Extracted} = \text{AVE} = \frac{\sum \lambda^2}{\sum \lambda^2 + \sum \varepsilon} \tag{1}$$

$$\text{Composite Reliability} = \text{CR} = \frac{\left(\sum \lambda\right)^2}{\left(\sum \lambda\right)^2 + \sum \varepsilon} \tag{2}$$

$$\text{Cronbach Alpha} = \text{CA} = \alpha = \left[\frac{k}{(k-1)} \times \left(1 - \frac{\sum \varepsilon}{\sum x^2}\right)\right] \tag{3}$$

where: λ = the factor loading of each indicator on its corresponding construct; ε = the indicator's unique error variance; where: k = the number of indicators in the construct; ε = the indicator's unique error variance; ΣX^2 = the total variance of the construct, which is equal to the sum of the squared factor loadings and error variances of the indicators.

The Fornell-Larcker criteria compares the square root of the AVE for each construct, as indicated in Eq. (4), to the construct's correlations with other constructs in the model [54]. When the square root of the AVE for a particular construct is larger than its correlation (Eq. (5)) with other constructs in the model, it is argued that the construct has discriminant validity. The AVE for each structure is computed as follows:

$$\text{AVE for each structure} = \frac{\sum \lambda^2}{\sum \theta} \tag{4}$$

where λ^2 is the factor loading squared and θ is the construct's error variance.

The correlation between two constructs i and j is calculated as:

$$\text{Correlation}(i,j) = \frac{\sum \lambda i \times \lambda j}{\sqrt{\sum \lambda i^2} \times \sqrt{\sum \lambda j^2}} \tag{5}$$

The square root of the AVE for each construct is then compared to the construct's correlation with other model constructs. The discriminant validity is established if the square root of the AVE is larger than the correlation with any other concept [17,61]. The Heterotrait-Monotrait (HTMT) ratio of correlations, as indicated by Eq. (6), is determined by dividing the correlation between two constructs (heterotrait) by the average correlation of each construct with itself (monotrait). Following is the algorithm for calculating HTMT:

$$\text{HTMT} = \sqrt{\frac{r_{ij}{}^2}{\text{AVE}(r_i, r_j)}} \tag{6}$$

where r_ij is the correlation between constructs i and j, and ave (r_i,r_j) is the average of the correlations of constructs i and j with themselves. In general, the HTMT threshold value is set at 0.9 or less, suggesting that the constructs are sufficiently dissimilar from one another to have discriminant validity [26,39]. The cross-loading of an item on a structure may be described mathematically as follows: For construct j, the loading of item i is given by λ_ij and the residual variance of item i is given by ξ_i (Eq. (7)). Then, the cross-loading of item i on construct k ($k \neq j$) is given by:

$$\lambda_{ik} = \frac{\text{COV}(i,k)}{\sqrt{\text{var}(i)}} \tag{7}$$

where cov (i, k) is the covariance between item i and construct k; var(i) is the variance of item i.

3.3.2. Bootstrapping analysis

Using the SmartPLS 4.0 software, a SEM study was undertaken to explore the links between the research model's components. The bootstrap approach was used to assess the relevance and robustness of the parameter estimations of the model. Bootstrapping entails obtaining random subsamples from the data set and creating a distribution of parameter estimates for each model route [11,18]. The significance and strength of the association between the constructs are shown by the t-value and p-value for each path coefficient, which are provided as the results of the bootstrap analysis [85]. A p-value of less than 0.05 was statistically significant. In addition, the coefficient of determination (R-squared) was used to assess how much variation the model explained. R-squared values over 0.3 were regarded as acceptable.

Table 2
EFA rotated component matrix.

	Component					Cronbach Alpha
	1	2	3	4	5	
F1	0.812					0.862
F8	0.780					
F9	0.768					
F14	0.753					
F17	0.742					
F7		0.730				0.825
F13		0.726				
F11		0.717				
F4		0.678				
F2		0.648				
F10			0.846			0.872
F16			0.814			
F21			0.736			
F20						
F3				0.728		0.805
F5				0.720		
F12				0.683		
F18						
F6					0.782	0.776
F15					0.717	
F19					0.699	
Eigen Value	3.285	2.973	2.645	2.572	2.176	
% Variance	13.621	12.238	11.012	10.212	7.999	
Extracted Variables	F18 and F20 Extracted due to factor loading less than 0.6.					

3.3.3. Predictive relevance analysis

After assessing the significance of the route coefficients, the predictive capacity of the structural model was assessed. Using the cross-validated R-squared (Q2) value, the predictive potential of the model was examined. The Q2 number indicates the amount of variation in the dependent variable that the model predicts [86]. A Q2 number more than 0.25 indicates high predictive ability, while a Q2 value less than 0.1 indicates poor predictive ability [13,14]. Overall, SmartPLS 4.0's structural model analysis offers a full evaluation of the links between the model's elements. The structural model is both trustworthy and valid due to the use of sophisticated statistical procedures, such as bootstrapping, and the assessment of its prediction potential.

4. Results

4.1. EFA analysis

The EFA was conducted on the pilot survey results, and it was found that the five components can be constructed, including all the success factors. It was important that all the components have eigenvalues greater than 1 [4,7]. Further, it is observed that all the components have a combined variance of greater than 50%. That was the acceptance criteria of the test, and ultimately, it provided an appropriate view of all the success factors, divided into five components. F20 and F18 were both excluded from components 3 and 5 [10,13]. It is because all the factors with factor loading greater than 0.6 are included in the final rotated component matrix presented in Table 2. A scree plot is presented in Fig. 2, indicating the components having satisfactory eigenvalues. Table 3 presents the overall success factors of polyurea coatings along with their success stages, or components, renamed as environment, functionality, protection, creativity, and execution.

4.2. Demographics

The demographic profile in Fig. 3 is constructed for the participants involved in the main questionnaire, and it is critical in terms of justifying the validity of the data produced in the main questionnaire that is further critical for the development of the model. The four different demographic perspectives are evaluated in the main questionnaire, such as age, education, profession, and experience. From an age perspective, it is observed that most of the participants involved in the survey are between 31 and 35 years old, which is adequate in terms of the size of the industry. Furthermore, including the most important component of the working class is critical for the study's efficient results, and thus the age group effectively indicates the significance of the results. From an educational standpoint, most people have at least a master's degree, which is required in the current working environment to fully understand the new technology used in the construction industry. It is for this reason that the overall educational perspective is completely appropriate to relate to the effectiveness of the main questionnaire findings. From the profession's perspective, it is observed that a higher percentage of civil engineers are involved as compared to other professions such as safety managers and project managers. Including more civil engineers is crucial in terms of justifying the unbiased approach to data collection and also the relativity of the demographic sample to the nature of the questions. From the experience perspective, it is observed that people with more than 11–15 years of experience are significant in this demographic category, which critically shows the understanding of new technology and also gives a better response in terms of fully understanding the requirements of the questionnaire.

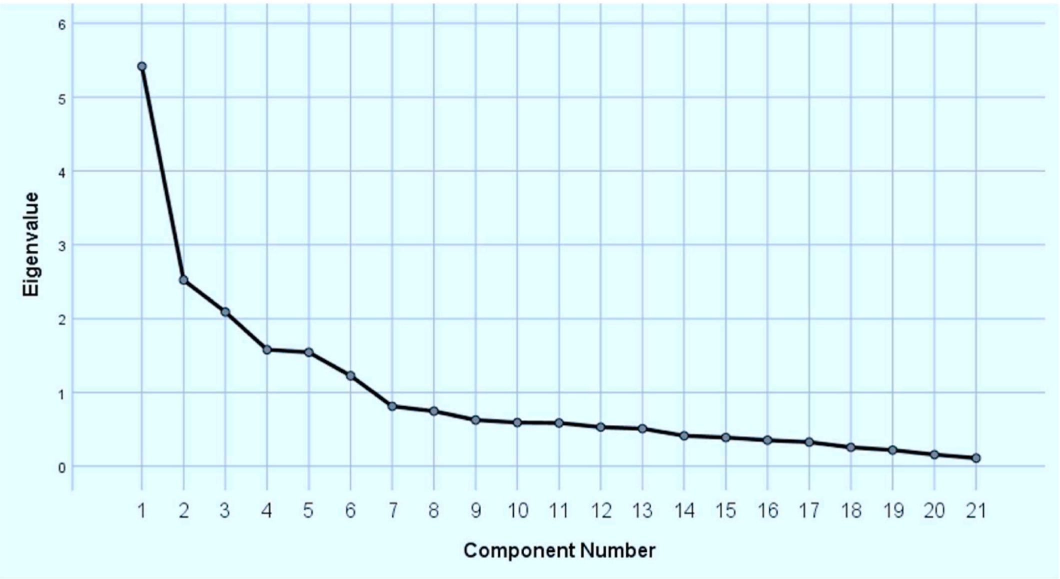

Fig. 2. Scree plot.

Table 3
Success factors along with constructed categories from EFA analysis.

Success Stages	Assigned Code	Activities
Environment	F1	Polyurea coatings are devoid of free volatile organic compounds (VOC), giving them an environmentally friendly choice for protecting concrete.
	F8	Polyurea coatings are fire-resistant, offering additional protection in a fire.
	F9	Polyurea coatings are resistant to ultraviolet radiation, making them a viable option for concrete surfaces exposed to direct sunshine and located outside.
	F14	Polyurea coatings may reflect light and prevent heat absorption, making them an excellent option for exposed outdoor concrete surfaces. This reduces the quantity of cooling necessary for buildings, lowering energy expenses.
	F17	Polyurea is impervious and resistant to humidity, making it perfect for water-containing concrete, including swimming pools and water tanks.
Functional	F7	Polyurea coatings dry rapidly, often within a few minutes, allowing for quick turnaround times on significant projects.
	F13	Polyurea is a flexible polymer that can sustain a broad temperature range without cracking or fracturing. This makes it suitable for concrete surfaces susceptible to movement or moving over time.
	F11	Polyurea coatings are highly resistant to mold formation and other hazardous germs, making them an excellent option for usage in areas where cleanliness is a concern.
	F4	Polyurea coatings may enhance the insulation qualities of concrete surfaces, reducing heat transfer and improving building energy efficiency.
	F2	Polyurea coatings are simple to maintain and clean.
Protection	F10	Polyurea is a highly durable polymer resilient to impact, abrasion, and chemicals. This makes it perfect for usage in places with heavy foot traffic and severe surroundings.
	F16	Polyurea provides resistance to a wide variety of chemicals, mainly acids and fuels, making it suitable for commercial and industrial use.
	F21	Polyurea coatings may be textured to offer a non-slip surface, which makes them an excellent option on concrete surfaces that might become wet, such as pool decks and pathways.
	F20	Polyurea coatings are resistant to deterioration and tear, making them an excellent option for concrete surfaces subjected to extensive usage or severe circumstances
Creativity	F3	Polyurea could be applied rapidly and effectively, saving time and money on large-scale projects
	F5	Polyurea is offered in various colors and finishes, enabling it to be customized to meet design specifications.
	F12	Polyurea coatings may increase the overall aesthetic appeal of concrete surfaces by giving them a smooth, polished appearance. This may increase the value and marketability of structures and buildings by enhancing their visual appeal.
Execution	F6	Polyurea may be used on various concrete surfaces but sprayed using spray equipment. This makes it an adaptable alternative for a variety of jobs.
	F15	Polyurea coatings generally have a lifetime of 20 years or over, making them an economical solution for concrete protection.
	F19	Polyurea coatings offer a smooth and airtight covering over concrete, which may enhance interior air quality by minimizing air exchange with the outside environment.

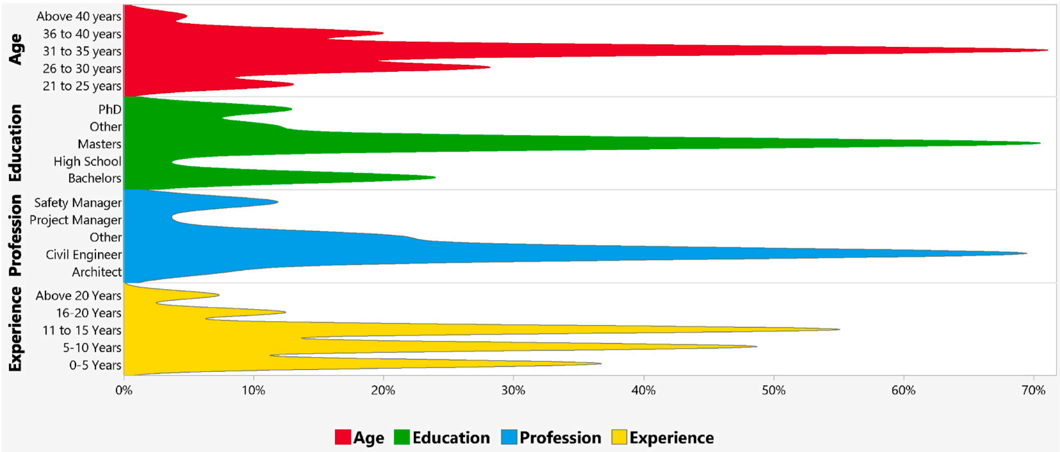

Fig. 3. Demographics.

4.3. Structure equation modeling (SEM) and analysis

The structure modeling is done in accordance with the initial measurement model development, and the item loadings are evaluated for all of the success factors involved in the analysis. It is observed that a total of two factors are further deleted because of law item loadings of less than 0.7. These are F17 and F20. Further, the group impact rank is also calculated as presented in Table 4. It is critical to remember that the environment is the most important factor influencing the model, while execution is the least important factor. As a result, a significant portion of the success factors relate to the environmental impact of using coatings.

Table 4
Item loadings and group impact rank.

Success Stages	Assigned Code	Loadings	Group Impact Rank
Environment	F1	0.867	Rank 1
	F8	0.852	
	F9	0.806	
	F14	0.808	
	F17	Deleted	
Functional	F7	0.711	Rank 3
	F13	0.779	
	F11	0.712	
	F4	0.786	
	F2	0.742	
Protection	F10	0.920	Rank 4
	F16	0.842	
	F21	0.915	
	F20	Deleted	
Creativity	F3	0.859	Rank 2
	F5	0.864	
	F12	0.821	
Execution	F6	0.718	Rank 5
	F15	0.845	
	F19	0.848	

Further, the model's reliability is also determined, and the findings are presented in Table 5. The Cronbach alpha values for all of the constructs are greater than 0.7, which is the minimum acceptance criteria of the reliability constant [10]. Further, it is appropriate because the entire reliability perspective of the formative contracts is being justified from analysis, which is further proved by the composite reliability constants indicating greater than 0.7 for all of the constructs. AVE was also found to be greater than 0.5, which is the minimum acceptance criteria in terms of the 50% average variance explanation given by all of the constructs in the measurement model [14]. This can be justified by utilizing the best perspective of construct reliability and overall validity in terms of the measurement model. Figs. 4–6 present the variation of item loading with AVE, composite reliability, and Cronbach's alpha. The variation in item loading can be critically observed from the figures, which is consistent with the change in reliability statistics. Obtaining high reliability has resulted in indicating the greater atom loading for all of the items and effectively justifying the significance of the constructs involved in the model.

The empirical correlation matrix is presented in Table 6, where a pairwise comparison is done between all the items. It is indicated that the accepted significance exists between the majority of the items because the empirical correlation leads to the acceptability of the items in the model and further justifies their presence in the formative side of the model. That is important to consider because most of the coordination observed from the analysis is greater than 0.2, which is the minimum criteria for accepting a correlation [26]. Minor deviations also exist from the accepted value of correlation, but they are still acceptable because all the constructs are contributing well to explaining the change in the model and equally justifying their involvement in the structure model.

It can be justified that the environmental construct has the highest impact on the latent variable, with a path impact of 0.403. The least impact is observed in cases of execution, with an impact of 0.182 on the latent variable, such as the success using polyurea coating for concrete construction projects [27].

4.3.1. Second order analysis

From the discriminant validity perspective, it was important to establish the construct significance in the model, and Fornell and Larcker statistics indicated that the AVE should be greater than the variance observed in the different constructs of the model. This is significant because it helps to justify the constructs' discriminate validity while also providing valuable information for further model refinement [50]. Table 7 is indicating that the different correlations observed between the contracts are less than the overall AVE observed in the previous section, which is critical for providing register vacation of discriminate validity of the model and also confirming that the constructs have an appropriate impact on the latent variable. HTMT statistics are also providing appropriate justification for discriminant validity because all the values observed in Table 8 are less than 1. Therefore, in the second-order analysis, it is critically important that the variance explanation provided by the constructs is completely appropriate, and further, that it does not create any inappropriate behavior in the model that could have a negative impact on the latent variables [76]. No further exclusion

Table 5
Model reliability statistics.

Constructs	Cronbach's alpha	Composite reliability (rho-a)	Composite reliability (rho-c)	AVE
Creativity	0.806	0.807	0.885	0.72
Environmental	0.853	0.858	0.901	0.695
Execution	0.736	0.774	0.847	0.65
Functional	0.802	0.808	0.863	0.557
Protection	0.873	0.883	0.922	0.798

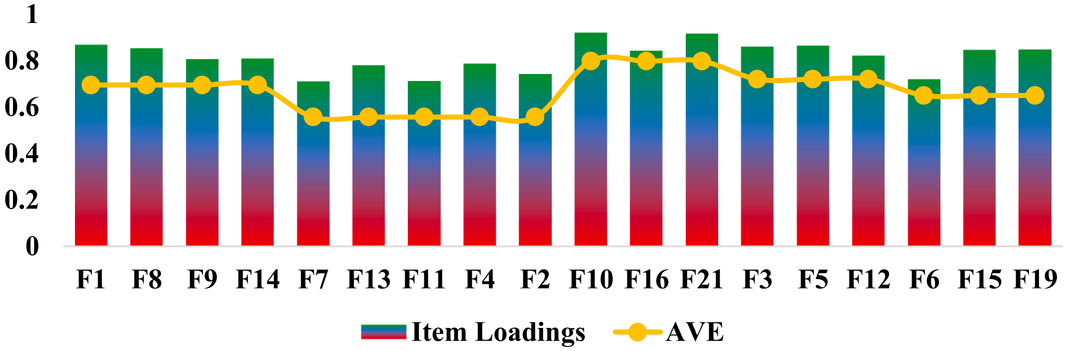

Fig. 4. Item loadings and AVE.

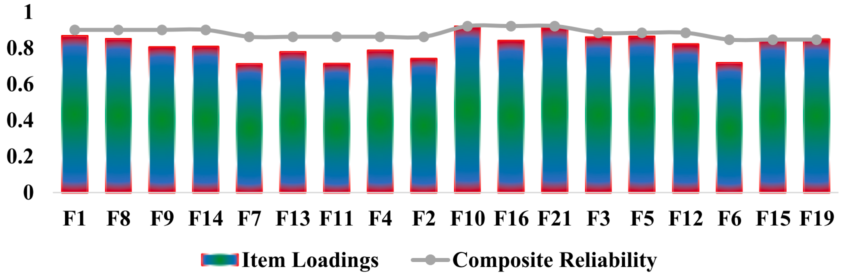

Fig. 5. Item loadings and Composite reliability.

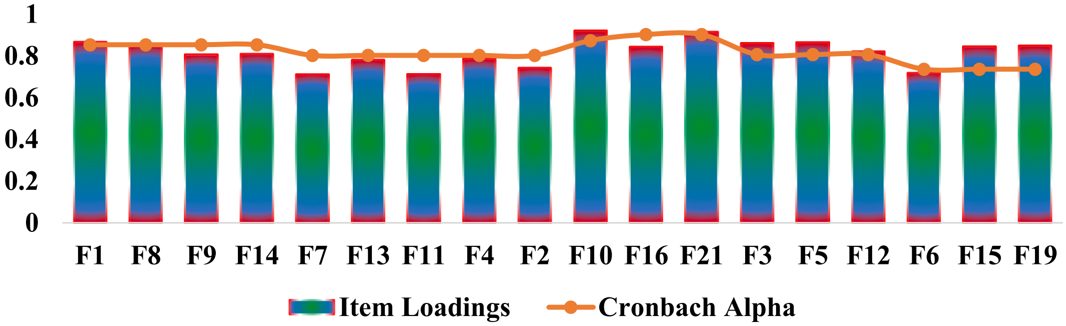

Fig. 6. Item loadings and Cronbach alpha.

of items is necessary in the model because it is equally justified in terms of all the critical elements of the model [64]. Table 9 depicts the item cross-loadings, where it is clear that all of the cross loadings are greater than 0.7, indicating that each of the items in the model and their respective constructs has a significant impact. That is an important element of the overall findings, where the cross-roads contribution in the model is effectively evaluated at the basic level, and further, it has justified the importance of all the constructs in the model.

4.3.2. Path analysis

The path analysis of all formative contracts is complete and presented in Table 10. The path coefficient is the most important component of the path analysis; it is highest in the case of environment construct and lowest in the case of execution. The model's validity is being demonstrated further because a greater impact will be produced if the polyurea coating is implemented in concrete construction projects. SE values are also less than 1, which justifies the overall path analysis of the formative construct and further gives evidence of the justification of hypotheses relative to each of the constructs [87]. t values also indicate acceptable statistics because they are not much greater but still greater than 1, while giving further evidence of validation of all the alternate hypotheses and indicating that the constructs are creating an impact on the latent variable. VIF values must be less than 3.5, as seen in the results, which is critical to not only finding the path analysis but also providing useful insights into the model to see where it can be strengthened further and have an impact on the latent variable. Figs. 7–11 are present in the frequency isotope programs of path analysis, where it can be easily observed that the density histogram and the normal distribution do not have a significant difference

Table 6
Empirical correlation matrix.

Var	F1	F10	F11	F12	F13	F14	F15	F16	F19	F2	F21	F3	F4	F5	F6	F7	F8	F9
F1	1	0.367	0.282	0.268	0.284	0.477	0.123	0.392	0.239	0.271	0.262	0.28	0.388	0.349	0.205	0.347	0.423	0.434
F10	0.367	1	0.134	0.297	0.28	0.263	0.162	0.692	0.097	0.266	0.265	0.311	0.151	0.103	0.277	0.031	0.264	0.194
F11	0.282	0.134	1	0.228	0.215	0.192	0.125	0.055	0.2	0.205	0.203	0.239	0.467	0.033	0.182	0.437	0.133	0.189
F12	0.268	0.297	0.228	1	0.148	0.385	0.14	0.317	0.193	0.141	0.188	0.706	0.314	0.282	0.166	0.28	0.342	0.35
F13	0.284	0.28	0.215	0.148	1	0.363	0.121	0.298	0.182	0.578	0.133	0.154	0.295	0.266	0.156	0.264	0.322	0.33
F14	0.477	0.263	0.192	0.385	0.363	1	0.211	0.272	0.176	0.346	0.344	0.403	0.264	0.289	0.083	0.237	0.573	0.588
F15	0.123	0.162	0.125	0.14	0.121	0.211	1	0.173	0.105	0.115	−0.059	0.146	0.171	0.154	0.091	0.153	0.187	0.192
F16	0.392	0.692	0.055	0.317	0.298	0.272	0.173	1	0.175	0.284	0.283	0.331	0.221	0.189	0.047	0.055	0.245	0.195
F19	0.239	0.097	0.2	0.193	0.182	0.176	0.105	0.175	1	0.173	0.172	0.202	0.098	−0.102	0.525	0.19	0.099	0.134
F2	0.271	0.266	0.205	0.141	0.578	0.346	0.115	0.284	0.173	1	0.127	0.147	0.282	0.253	0.149	0.251	0.307	0.315
F21	0.262	0.265	0.203	0.188	0.133	0.344	−0.059	0.283	0.172	0.127	1	0.197	0.28	0.252	0.148	0.25	0.305	0.313
F3	0.28	0.311	0.239	0.706	0.154	0.403	0.146	0.331	0.202	0.147	0.197	1	0.328	0.295	0.173	0.293	0.358	0.367
F4	0.388	0.151	0.467	0.314	0.295	0.264	0.171	0.221	0.098	0.282	0.28	0.328	1	0.199	0.213	0.524	0.214	0.272
F5	0.349	0.103	0.033	0.282	0.266	0.289	0.154	0.189	−0.102	0.253	0.252	0.295	0.199	1	−0.083	0.251	0.255	0.263
F6	0.205	0.277	0.182	0.166	0.156	0.083	0.091	0.047	0.525	0.149	0.148	0.173	0.213	−0.083	1	0.094	0.004	0.043
F7	0.347	0.031	0.437	0.28	0.264	0.237	0.153	0.055	0.19	0.251	0.25	0.293	0.524	0.251	0.094	1	0.182	0.229
F8	0.423	0.264	0.133	0.342	0.322	0.573	0.187	0.245	0.099	0.307	0.305	0.358	0.214	0.255	0.004	0.182	1	0.537
F9	0.434	0.194	0.189	0.35	0.33	0.588	0.192	0.195	0.134	0.315	0.313	0.367	0.272	0.263	0.043	0.229	0.537	1

Table 7
Fornell larker criteria results.

Constructs	Creativity	Environmental	Execution	Functional	Protection
Creativity					
Environmental	0.447				
Execution	0.248	0.21			
Functional	0.281	0.5	0.271		
Protection	0.298	0.373	0.09	0.243	

Table 8
HTMT analysis results.

Constructs	Creativity	Environmental	Execution	Functional	Protection
Creativity	0.848				
Environmental	0.376	0.833			
Execution	0.202	0.168	0.806		
Functional	0.231	0.421	0.183	0.747	
Protection	0.251	0.331	0.076	0.187	0.893

Table 9
Cross loadings of items.

Variables	Creativity	Environmental	Execution	Functional	Protection
F3	**0.859**	0.274	0.181	0.143	0.162
F12	**0.821**	0.382	0.199	0.243	0.237
F5	**0.864**	0.291	0.131	0.193	0.233
F1	0.328	**0.867**	0.214	0.369	0.335
F8	0.354	**0.852**	0.15	0.363	0.272
F9	0.271	**0.808**	0.094	0.36	0.255
F14	0.354	**0.852**	0.15	0.363	0.272
F6	0.208	0.071	**0.718**	0.187	−0.078
F19	0.208	0.071	**0.848**	0.187	−0.078
F15	0.174	0.177	**0.845**	0.241	−0.078
F7	0.144	0.274	0.126	**0.742**	0.238
F11	0.197	0.313	0.161	**0.712**	0.056
F13	0.115	0.439	0.115	**0.779**	0.15
F4	0.253	0.315	0.134	**0.786**	0.204
F2	0.144	0.274	0.126	**0.742**	0.238
F10	0.259	0.274	0.181	0.143	**0.920**
F16	0.264	0.291	0.131	0.193	**0.842**
F21	0.021	0.382	0.199	0.243	**0.915**

Table 10
Path analysis results of formative constructs.

Path	β	SE	t-values	p-values	VIF
Creativity > Success of using Polyurea Coating for Concrete Construction Projects	0.343	0.017	15.546	<0.001	1.232
Environmental > Success of using Polyurea Coating for Concrete Construction Projects	0.403	0.019	18.545	<0.001	1.439
Execution > Success of using Polyurea Coating for Concrete Construction Projects	0.182	0.014	18.660	<0.001	1.100
Functional > Success of using Polyurea Coating for Concrete Construction Projects	0.341	0.022	18.442	<0.001	1.246
Protection > Success of using Polyurea Coating for Concrete Construction Projects	0.275	0.017	17.256	<0.001	1.185

[66]. The trend of the frequency histogram and normal distribution are aligned, which is critical for providing evidence of path validation and confirming the model's significance. Figs. 7–11 depicts the potential outcome of bootstrapping analysis, where the significance values are less than 0.05, indicating that the model is fully validated and in accordance with the study's objectives.

4.3.3. Analysis of model predictive relevance

The predictive relevance of the model is determined by Q-squared statistics, where it should be greater than 0. In Table 11, the predicted relevance of the model is significant because the value is greater than 0.2, indicating that the model has moderate implications on the latent variables.

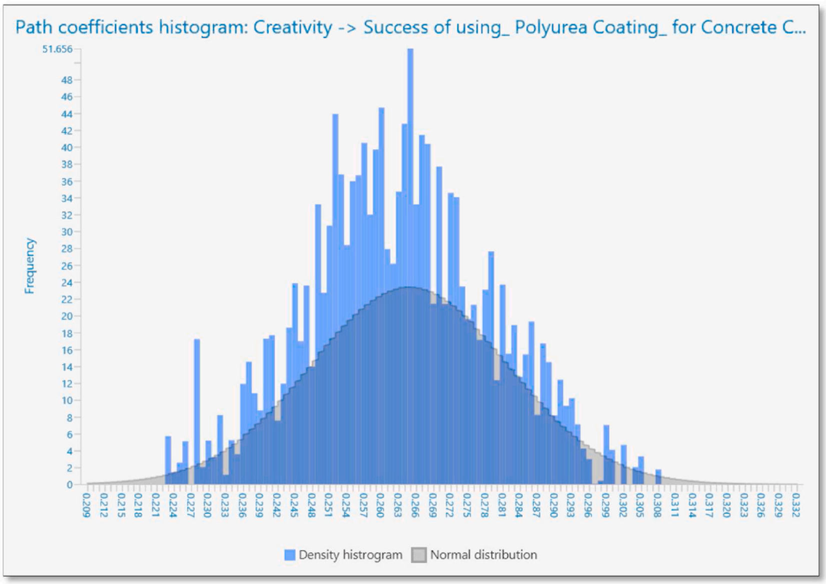

Fig. 7. Path coefficient histogram for creativity construct.

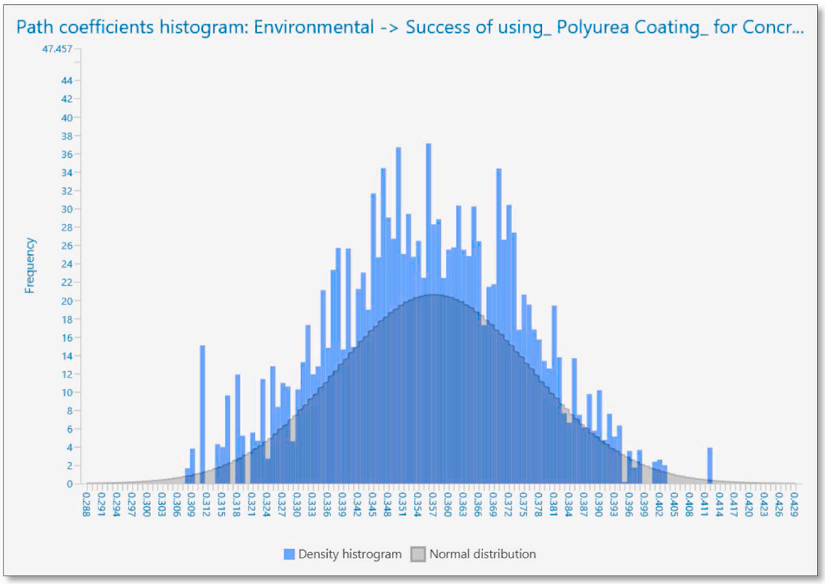

Fig. 8. Path coefficient histogram for environmental construct.

5. Discussion

Environmental formative construct includes, F1 "Polyurea coatings are devoid of free volatile organic compounds (VOC), giving them an environmentally friendly choice for protecting concrete", F8 "Polyurea coatings are fire-resistant, offering additional protection in a fire", F9 "Polyurea coatings are resistant to ultraviolet radiation, making them a viable option for concrete surfaces exposed to direct sunshine and located outside", and F14 "Polyurea coatings may reflect light and prevent heat absorption, making them an excellent option for exposed outdoor concrete surfaces. This reduces the quantity of cooling necessary for buildings, lowering energy expenses. According to Beiki & Mosavi (2020) and Ismail et al. (2018), it is one of the most important features of polyurethane coatings that they are free from volatile organic compounds, which ultimately provide environmental significance, and it is also one of the main reasons why this factor is regarded as the most significant by the study in model [5,61]. When polyurethane coatings are used in concrete, they have the unique property of contributing to excellent environmental sustainability. Further, it is providing evidence of

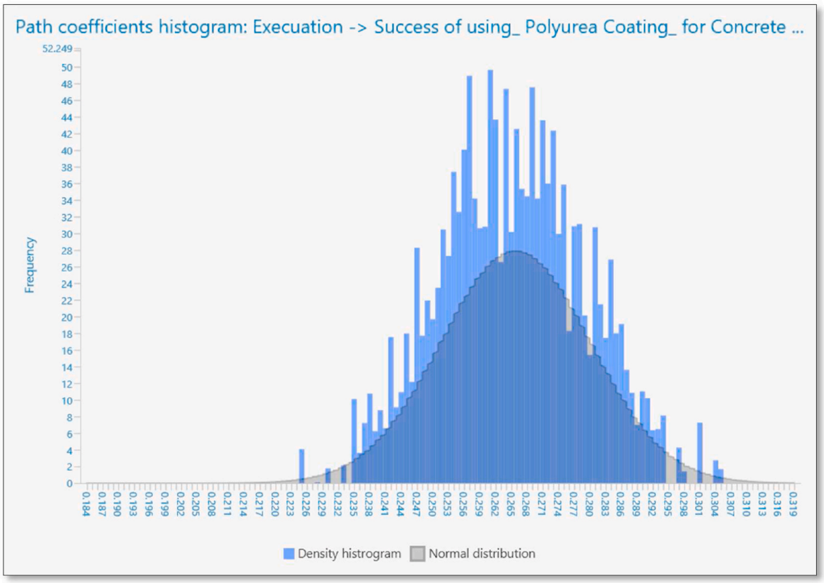

Fig. 9. Path coefficient histogram for execution construct.

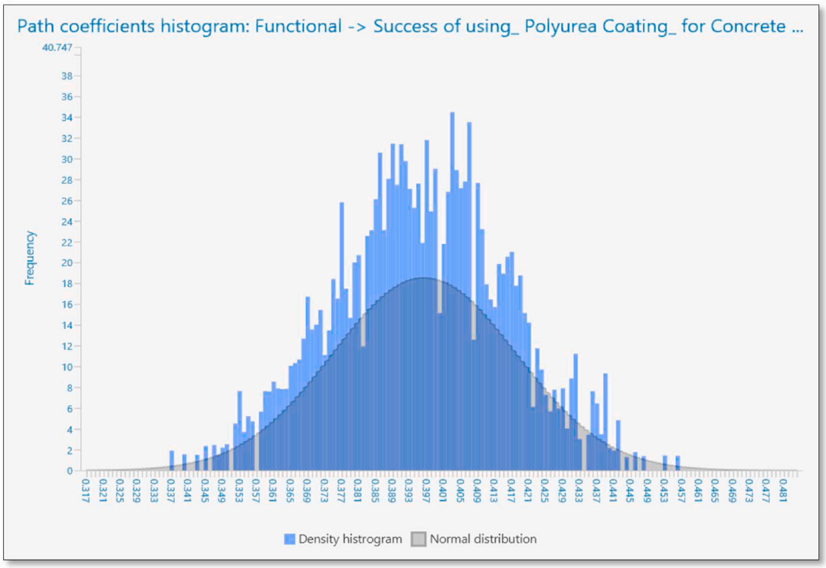

Fig. 10. Path coefficient histogram for functional construct.

different research outcomes with respect to the district studies, which is critical justification of the model constructed in the study [61].

Functional formative construct includes, F7 “Polyurea coatings dry rapidly, often within a few minutes, allowing for quick turnaround times on significant projects”, F13 “Polyurea is a flexible polymer that can sustain a broad temperature range without cracking or fracturing. This makes it suitable for concrete surfaces susceptible to movement or moving over time”, F11 “Polyurea coatings are highly resistant to mold formation and other hazardous germs, making them an excellent option for usage in areas where cleanliness is a concern”, F4 “Polyurea coatings may enhance the insulation qualities of concrete surfaces, reducing heat transfer and improving building energy efficiency”, and F2 “Polyurea coatings are simple to maintain and clean”. From the functional perspective, and in accordance with Duda et al. (2019) and Hao Wang et al. (2019), it is also observed that the polyurea coatings can ultimately increase the insulating capacity of the concrete when applied, and this is the critical finding for modern concrete construction [11,40]. Further, it is observed that other factors have achieved the significant results, which are unique in that they justify the construct within the model while also providing suitable evidence by which polyurea coating can be extended in concrete construction [27,50]. Further, it is equally just to find the cost of validity, as the functional side of polyurea coatings is completely appropriate and moderately different

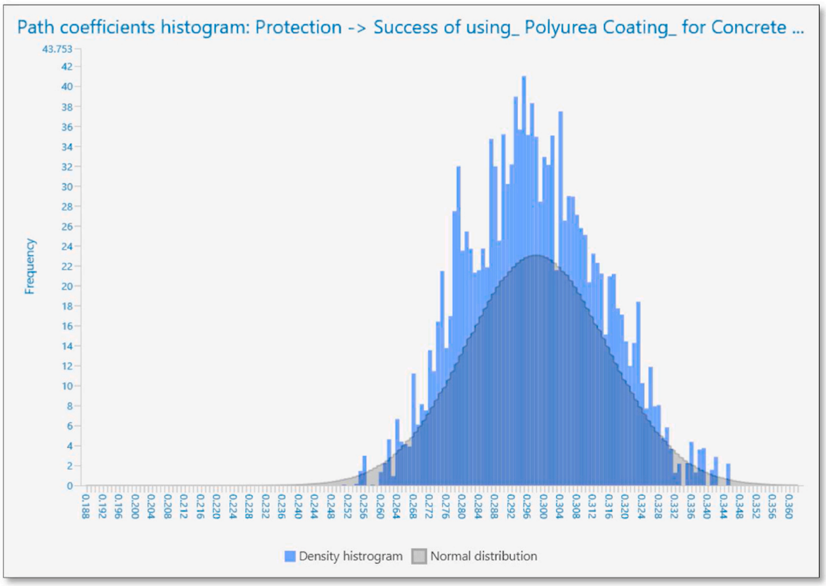

Fig. 11. Path coefficient histogram for protection construct.

Table 11
Endogenous latent variable Q^2.

Latent Variable	SS0	SSE	Predict-Q^2
Success of using polyurea coating	4320.000	3245.187	0.249

from the existing studies.

Protection formative construct includes, F10 “Polyurea is a highly durable polymer resilient to impact, abrasion, and chemicals. This makes it perfect for usage in places with heavy foot traffic and severe surroundings”, F16 “Polyurea provides resistance to a wide variety of chemicals, mainly acids and fuels, making it suitable for commercial and industrial use”, and F21 “Polyurea coatings may be textured to offer a non-slip surface, which makes them an excellent option on concrete surfaces that might become wet, such as pool decks and pathways”. The durability of polyurea coating is regarded as a critical factor in the formulation of the corrosion protection model [8,16]. This is effectively justified in the context of providing a valid outcome of the model and also indicating the high significance that can be used to differentiate the unique outcomes of the study with respect to existing research. It is thus effectively validated in accordance with Yuanzhe Li et al. (2022) and C. Zhang et al. (2022), that the protection formative construct can significantly influence coating implementation in concrete construction [63,64].

Creativity formative construct includes, F3 “Polyurea could be applied rapidly and effectively, saving time and money on large-scale projects”, F5 “Polyurea is offered in various colors and finishes, enabling it to be customized to meet design specifications”, and F12 “Polyurea coatings may increase the overall aesthetic appeal of concrete surfaces by giving them a smooth, polished appearance. This may increase the value and marketability of structures and buildings by enhancing their visual appeal. According to Mohotti et al. (2021) and (Mohotti et al., 2021; Somarathna et al. (2021), one of the unique aspects of the model that has been observed is the shorter application time of polyurea coating, which further justifies the possible differentiation from existing studies, where it can ultimately contribute to establishing valid results in terms of model validity [35,36]. Overall potential outcomes are significant in terms of model application in concrete construction, where creativity is contributing well to affecting the latent variable.

Execution formative construct includes, F6 “Polyurea may be used on various concrete surfaces but sprayed using spray equipment. This makes it an adaptable alternative for a variety of jobs”, F15 “Polyurea coatings generally have a lifetime of 20 years or over, making them an economical solution for concrete protection”, and F19 “Polyurea coatings offer a smooth and airtight covering over concrete, which may enhance interior air quality by minimizing air exchange with the outside environment. According to Gu et al. (2022) and X. Wang (2022), it is observed that the polyurea coatings always provide a smooth and airtight concrete covering, which is one of the requirements for modern concrete construction [41,42]. Similarly, other items are also contributing to the execution construct, which are critical but unique from the perspective of existing studies conducted on the application of polyurea coating in concrete construction.

6. Conclusion

In the context of concrete building projects, this study thoroughly evaluated the aspects linked to the application of polyurea coatings. In order to build a prediction model that shows how polyurea coatings improve the success of concrete building projects, the study involved a thorough quantitative investigation and found that 18 out of 21 success indicators were significant. Environmental variables, functional needs, protective capacities, application innovation, and execution techniques were the five separate constructs into which these aspects were methodically classified. These constructs significantly contribute to understanding the observed differences in the success of applying polyurea coatings, thanks to their excellent reliability and validity.

The structural model lays out the many ways in which polyurea coatings, as a resilient construction approach, may improve the success of building projects. Extensive statistical studies have provided empirical evidence that supports the importance of these characteristics, shedding light on how they work together to improve project results in construction industry. Theoretically, this research fills a large need in the literature by establishing the groundwork for understanding what makes polyurea coatings work in concrete projects. The research highlights how project-specific needs and the placing of polyurea reinforcement may greatly impact a structure's dynamic behavior, and how polyurea coatings might vary in their application accordingly.

In addition, the research supports the use of polyurea coatings building projects, showing how they may enhance both functional and environmental performance. In order to stay competitive and make educated decisions on polyurea coatings, this study suggests that the construction sector should employ new materials. Reliability and sustainability in the country's building methods are anticipated to be enhanced by this change. While this study does recognize the limits of the quantitative research design, it does propose that in order to improve the methods for using polyurea coatings in building projects, future research should use novel approaches to assess success aspects. The challenges of incorporating new materials into building procedures, guaranteeing their best use, and improving project performance all need a proactive approach.

Data availability statement

The data is not available for public or private access because of informed consent taken from the participants.

CRediT authorship contribution statement

Ahsan Waqar: Conceptualization, Formal analysis, Investigation, Software, Writing – original draft. **Nasir Shafiq:** Conceptualization, Supervision, Visualization, Writing – review & editing. **Naraindas Bheel:** Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing. **Omrane Benjeddou:** Formal analysis, Investigation, Resources, Software, Writing – review & editing. **Nadhim Hamah Sor:** Conceptualization, Data curation, Resources, Visualization, Writing – review & editing, Validation. **Jong Wan Hu:** Data curation, Software, Validation, Visualization, Writing – review & editing. **Hadee Mohammed Najm:** Resources, Software, Validation, Writing – review & editing. **Hamad R. Almujibah:** Formal analysis, Investigation, Methodology, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they do not have any conflict of interest.

Acknowledgments

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 21CFRP-C163381-01).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28908.

References

[1] H. Wang, P. Feng, Y. Lv, Z. Geng, Q. Liu, X. Liu, A comparative study on UV degradation of organic coatings for concrete: structure, adhesion, and protection performance, Prog. Org. Coating (2020).
[2] D.J. Primeaux, Polyurea-based coatings, in: Protective Organic Coatings, 2018.
[3] B. Benmokrane, A.H. Ali, Durability and long-term performance of fiber-reinforced polymer as a new civil engineering material, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[4] W. Nantasetphong, Z. Jia, M.A. Hasan, A.V. Amirkhizi, S. Nemat-Nasser, A new technique for characterization of low impedance materials at acoustic frequencies, Exp. Mech. (2018).
[5] M.K. Ismail, A.A.A. Hassan, K.E. Ridgley, B. Colbourne, Steel-Fiber self-consolidating rubberized concrete subjected to impact loading, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[6] Y. xiang Sun, et al., Experimental investigation on anti-penetration performance of polyurea-coated ASTM1045 steel plate subjected to projectile impact, Def. Technol. (2021).
[7] B. Shojaei, M. Najafi, A. Yazdanbakhsh, M. Abtahi, C. Zhang, A review on the applications of polyurea in the construction industry, Polym. Adv. Technol. (2021).

[8] S. Do, S. Stepp, G. Youssef, Quasi-static and dynamic characterization of polyurea microspheres reinforced polyurea matrix composite, Mater. Today Commun. (2020).
[9] Y. Ma, et al., Preparation and characterization of ethylenediamine-polyurea microcapsule epoxy self-healing coating, Materials (2020).
[10] J.H. Song, E.T. Lee, H.C. Eun, C. Apostolopoulos, A study on the strengthening performance of concrete beam by fiber-reinforced polyurea (FRPU) reinforcement, Adv. Civil Eng. (2020).
[11] M. Duda, J. Pach, G. Lesiuk, Influence of polyurea composite coating on selected mechanical properties of AISI 304 steel, Materials (2019).
[12] H. Hou, et al., Effect of structural configuration on air blast resistance of polyurea-coated composite steel plates: experimental studies, Mater. Des. (2019).
[13] H.A. Toutanji, H. Choi, D. Wong, J.A. Gilbert, D.J. Alldredge, Applying a polyurea coating to high-performance organic cementitious materials, Constr. Build. Mater. (2013).
[14] E. Akın, O. Tunaboyu, Ö. Avşar, Axial behavior of FRP confined low-strength concrete with polyurea, Structures (2020).
[15] S.M. Daghash, O.E. Ozbulut, Fatigue behavior characterization of superelastic shape memory alloy fiber-reinforced polymer composites, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[16] N. Iqbal, P.K. Sharma, D. Kumar, P.K. Roy, Protective polyurea coatings for enhanced blast survivability of concrete, Constr. Build. Mater. (2018).
[17] G.S. Urgessa, M. Esfandiari, Review of polymer coatings used for blast strengthening of reinforced concrete and masonry structures, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[18] C.E. Greene, J.J. Myers, Flexural and shear behavior of reinforced concrete members strengthened with a discrete fiber-reinforced polyurea system, J. Compos. Constr. (2013).
[19] Y. Liu, et al., Blast responses of polyurea-coated concrete arches, Arch. Civil Mech. Eng. (2021).
[20] M. Zamani, S. Nikafshar, A. Mousa, A. Behnia, Bacteria encapsulation using synthesized polyurea for self-healing of cement paste, Constr. Build. Mater. (2020).
[21] G. Wu, et al., Blast response of clay brick masonry unit walls unreinforced and reinforced with polyurea elastomer, Def. Technol. (2022).
[22] G. Ren, P. Zhang, X. Ye, W. Li, X. Fan, M. Zhu, Comparative study on corrosion resistance and lubrication function of lithium complex grease and polyurea grease, Friction (2021).
[23] Q.Y. Zhang, X.Q. Jin, Y.X. Zheng, F.H. Zhou, Compressive and energy absorption properties of polyurea-coated concrete under quasistatic or dynamic loadings, Gongcheng Lixue/Eng. Mech. (2016).
[24] D. wen Sun, Q. ping Ran, C. Yang, Y. Yang, Y. Wan, Design and application of polyurethane/polyurea protective coating and its application to surface protection of concrete, Corros. Prot. (2013).
[25] J. Szafran, A. Matusiak, Crushing strength of concrete rings with a polyurea reinforce system, Tunn. Undergr. Space Technol. (2020).
[26] B. Li, Z. Zhang, X. Wang, X. Liu, Investigation on the debonding failure model of anchored polyurea coating under a high-velocity water flow and its application, Sustain. Times (2019).
[27] K. Che, P. Lyu, F. Wan, M. Ma, Investigations on aging behavior and mechanism of polyurea coating in marine atmosphere, Materials (2019).
[28] J. Zhang, X. Weng, L. Jiang, B. Yang, J. Liu, B. Qu, Durability of airport concrete pavement improved by four novel coatings, Adv. Cem. Res. (2019).
[29] A. Waqar, I. Othman, Impact of 3D Printing on the Overall Project Success of Residential Construction Projects Using Structural Equation Modelling, 2023.
[30] A. Waqar, H. Almujibah, Factors Influencing Adoption of Digital Twin Advanced Technologies for Smart City Development : Evidence from Malaysia, no. March, 2023.
[31] J. Qiao, Y. Wu, L. Li, Effect of filler content on the stress relaxation behavior of fly ash/polyurea composites, Polym. Test. (2020).
[32] A. Bijanzad, M. Abdulwahab, I. Lazoglu, C. Ensarioglu, M.C. Cakir, Effect of polyurea coating on the ductility of aluminum foam, Mater. Today Commun. (2022).
[33] W.U. Caiyun, W. Li, C. Zhang, F.A.N. Jinpeng, Effect of protective coatings on frost resistance of concrete structures in Northeast coastal areas, IOP Conf. Ser. Mater. Sci. Eng. (2019).
[34] J. Sustersic, A. Zajc, G. Narobe, Efficiency of polymer fibers in lightweight plaster, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[35] H.M.C.C. Somarathna, S.N. Raman, A.A. Mutalib, K.H. Badri, Elastomeric polymers for blast and ballistic retrofitting of structures, J. Teknol. (2015).
[36] D. Mohotti, P.L.N. Fernando, D. Weerasinghe, A. Remennikov, Evaluation of effectiveness of polymer coatings in reducing blast-induced deformation of steel plates, Def. Technol. (2021).
[37] B. Gao, J. Wu, P. Jia, S. Li, Q. Yan, S. Xu, Experimental and numerical investigation of the polyurea-coated ultra-high-performance concrete (UHPC) column under lateral impact loading, Int. J. Struct. Stab. Dyn. (2022).
[38] J. Liu, et al., Experimental investigations on small-and full-scale ship models with polyurea coatings subjected to underwater explosion, Def. Technol. (2022).
[39] Q. Liu, et al., Investigating ballistic resistance of CFRP/polyurea composite plates subjected to ballistic impact, Thin-Walled Struct. (2021).
[40] H. Wang, X. Deng, H. Wu, A. Pi, J. Li, F. Huang, Investigating the dynamic mechanical behaviors of polyurea through experimentation and modeling, Def. Technol. (2019).
[41] M. Gu, X. dong Ling, A. feng Yu, G. xin Chen, H. zhe Wang, H. xiang Wang, Experimental study of polyurea-coated fiber-reinforced cement boards under gas explosions, Def. Technol. (2022).
[42] X. Wang, Experimental study on the effect of hardness on the erosion resistance of coatings and rubber for hydropower applications, J. Test. Eval. (2020).
[43] J. Cui, Y. Shi, X. Zhang, W. Huang, M. Ma, Experimental study on the tension and puncture behavior of spray polyurea at high strain rates, Polym. Test. (2021).
[44] A. Waqar, A.H. Qureshi, W.S. Alaloul, Barriers to building information modeling (BIM) deployment in small construction projects: Malaysian construction industry, Sustain. Times 15 (3) (2023).
[45] L. Zhang, et al., High-hardness polyurea coated steel plates subjected to combined loadings of shock wave and fragments, Lat. Am. J. Solids Struct. (2022).
[46] J.H. Song, H.C. Eun, Improvement of flexural and shear strength of RC beam reinforced by glass fiber-reinforced polyurea (GFRPU), Civil Eng. J. (2021).
[47] G.F. Muhyaddin, Mechanical and fracture characteristics of ultra-high performance concretes reinforced with hybridization of steel and glass fibers, Heliyon 9 (7) (2023) e17926.
[48] I. Pol Segura, N. Ranjbar, A. Juul Damø, L. Skaarup Jensen, M. Canut, P. Arendt Jensen, A review: alkali-activated cement and concrete production technologies available in the industry, Heliyon 9 (5) (2023) e15718.
[49] Y. Liao, S. Shi, S. Chen, X. Ming, L. Ge, Numerical evaluation of the retrofit effectiveness for polyurea-woven glass fiber mesh composite retrofitted RC slab subjected to blast loading, Structures (2022).
[50] S. Parniani, H. Toutanji, Monotonic and fatigue performance of RC beams strengthened with a polyurea coating system, Constr. Build. Mater. (2015).
[51] N. Leventis, Polyurea aerogels: synthesis, material properties, and applications, Polymers (2022).
[52] Z. Gao, Y. Li, H. Hou, M. Li, X. Zhu, Penetration mechanism of polyurea coating composite structure, Gaoya Wuli Xuebao/Chin. J. High Press. Phys. (2019).
[53] Y. Wang, L. Chen, Z. Wang, Research progress of dam surface coating material for concrete in hydraulic engineering, Cailiao Daobao/Mater. Rev. (2016).
[54] J. Feng, L.M. Liao, L. Chen, C.J. Xiao, S.F. Wang, H. Li, Research on the formula of polyaspartic ester polyurea concrete coating and its application, Appl. Mech. Mater. (2013).
[55] H. Yu, Z. He, G. Qian, X. Gong, X. Qu, Research on the anti-icing properties of silicone modified polyurea coatings (SMPC) for asphalt pavement, Constr. Build. Mater. (2020).
[56] P. Lu, W.B. Huang, S. Gao, G.H. Chen, Study on the properties of polyaspartic polyurea coated concrete under salt fog exposure, in: Proceedings of the 3rd International Conference on the Concrete Future - “Recent Advances in Concrete Technology and Concrete in Structures, 2017.
[57] Y. Li, et al., The influence of spraying strategy on the dynamic response of polyurea-coated metal plates to localized air blast loading: experimental investigations, Polymers (2019).
[58] T. Du, Study on the influence of anticorrosive coating on chloride ion erosion resistance of concret, IOP Conf. Ser. Mater. Sci. Eng. (2020).
[59] A. T, A. M, J. Jayaprabakar, J. Jeevahan, D. Rb, Study on mechanical properties of polyurea coating with various process parameters, Mater. Res. Innov. (2021).
[60] M. Tripathi, S. Parthasarathy, P.K. Roy, Spray processable polyurea formulations: effect of chain extender length on material properties of polyurea coatings, J. Appl. Polym. Sci. (2020).

[61] H. Beiki, S.J. Mosavi, Silver nanoparticles-polyurea composite coatings on ASTM A194 steel: a study of corrosion behavior in chloride medium, J. Bio-Tribo-Corros. (2020).
[62] J.H. Song, E.T. Lee, H.C. Eun, Shear strength of reinforced concrete columns retrofitted by glass fiber reinforced polyurea, Civil Eng. J. (2020).
[63] Y. Li, Y. Liu, B. Yao, S. Narasimalu, Z.L. Dong, Rapid preparation and antimicrobial activity of polyurea coatings with RE-Doped nano-ZnO, Microb. Biotechnol. (2022).
[64] C. Zhang, W. Li, J. Fan, W. Xun, Y. Chen, Relative method for evaluating freeze-thaw damage of coated concrete, Jianzhu Cailiao Xuebao/J. Build. Mater. (2020).
[65] C. Fang, W. Liu, X. Qiu, Preparation of polyetheramine-grafted lignin and its application in UV-resistant polyurea coatings, Macromol. Mater. Eng. (2019).
[66] S.T. Aly, D.M. Kanaan, A.S. El-Dieb, S.I. Abu-Eishah, Properties of ceramic waste powder-based geopolymer concrete, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[67] R. Rasheed, H. Javed, A. Rizwan, M. Afzaal, S.R. Ahmad, Eco-sustainability analysis of precast-concrete utility poles manufacturing–A case study from Pakistan, Heliyon 9 (4) (2023) e14976.
[68] A.C. Rosa, A.W.A. Hammad, D. Boer, A. Haddad, Use of operational research techniques for concrete mix design: a systematic review, Heliyon 9 (4) (2023) e15362.
[69] C.P. Chang, C.H. Shih, J.L. You, M.J. Youh, Y.M. Liu, M. Der Ger, Preparation and ballistic performance of a multi-layer armor system composed of kevlar/polyurea composites and shear thickening fluid (Stf)-filled paper honeycomb panels, Polymers (2021).
[70] D. Williams, Polyurea coatings, liners equal to aging concrete wastewater infrastructure, Concr. Prod. (2017).
[71] M. Maj, A. Ubysz, Polyurea as a material to reinforce the surface and increase the waterproofing of concrete, in: FIB 2018 - Proceedings for the 2018 Fib Congress: Better, Smarter, Stronger, 2019.
[72] Y. shun Chen, et al., Polyurea coating for foamed concrete panel: an efficient way to resist explosion, Def. Technol. (2020).
[73] D. Mohotti, T. Ngo, S.N. Raman, M. Ali, P. Mendis, Plastic deformation of polyurea coated composite aluminium plates subjected to low velocity impact, Mater. Des. (2014).
[74] X. Rong, H. Liu, C. Li, A proposed method and monitoring system for evaluating workability of Portland cement concrete during mixing, Heliyon 8 (11) (2022) e11355.
[75] A. Waqar, I. Othman, R.A. González-Lezcano, Challenges to the implementation of BIM for the risk management of oil and gas construction projects: structural equation modeling approach, Sustain. Times 15 (10) (2023).
[76] O. Arowojolu, A. Ibrahim, M. Reda Taha, Parametric study on the performance of UHPC and nano-modified polymer concrete (NMPC) composite wall panels for protective structures, in: International Congress on Polymers in Concrete (ICPIC 2018), 2018.
[77] Q. Liu, et al., Mechanical behavior and failure mechanism of polyurea nanocomposites under quasi-static and dynamic compressive loading, Def. Technol. (2021).
[78] A. Waqar, M.B. Khan, N. Shafiq, K. Skrzypkowski, K. Zagórski, A. Zagórska, Assessment of challenges to the adoption of IOT for the safety management of small construction projects in Malaysia: structural equation modeling approach, Appl. Sci. 13 (5) (2023).
[79] A. Waqar, I. Othman, K. Skrzypkowski, Evaluation of Success of Superhydrophobic Coatings in the Oil and Gas Construction Industry Using Structural, 2023.
[80] A. Waqar, et al., Effect of volcanic pumice powder ash on the properties of cement concrete using response surface methodology, J. Build. Pathol. Rehabil. (2023).
[81] M.A. Karim, M.Z. Abdullah, A.F. Deifalla, M. Azab, A. Waqar, An assessment of the processing parameters and application of fibre-reinforced polymers (FRPs) in the petroleum and natural gas industries: a review, Results Eng. 18 (March) (2023) 101091.
[82] A. Waqar, et al., Success of implementing cloud computing for Smart development in small construction projects, Appl. Sci. 13 (9) (2023).
[83] M. Khan, et al., Optimization of Fresh and Mechanical Characteristics of Carbon Fiber-Reinforced Concrete Composites Using Response Surface Technique, vol. 13, 2023.
[84] A. Waqar, I. Othman, N. Shafiq, M.S. Mansoor, Applications of AI in oil and gas projects towards sustainable development: a systematic literature review, Artif. Intell. Rev. (2023) 0123456789.
[85] A. Waqar, I. Othman, N. Shafiq, H. Altan, B. Ozarisoy, Modeling the effect of overcoming the barriers to passive design implementation on project sustainability building success: a structural equation modeling perspective, Sustain. Times 15 (11) (2023).
[86] A. Waqar, et al., Effect of Coir Fibre Ash (CFA) on the strengths, modulus of elasticity and embodied carbon of concrete using response surface methodology (RSM) and optimization, Results Eng (2023).
[87] H. Guo, Z. Zhou, M. Gu, A. Yu, X. Ling, W. Yao, Preparation of impact-resistant functional polyurea coatings and effect of γ-ray irradiation on its microstructure and performance, Prog. Org. Coating (2021).