Hindawi
Journal of Engineering
Volume 2023, Article ID 8824795, 21 pages
https://doi.org/10.1155/2023/8824795

Research Article

Analyzing the Success of Adopting Metaverse in Construction Industry: Structural Equation Modelling

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Received 13 June 2023; Revised 4 August 2023; Accepted 1 September 2023; Published 29 September 2023

Academic Editor: Yuanxin Zhou

The application of metaverse technology in the field of civil engineering has the potential to improve project efficiency and accuracy. Nevertheless, the pervasive adoption and effective integration of metaverses are contingent on a number of crucial factors. This study investigates the critical factors underlying the successful implementation of metaverse technology within a business context. This research employs a comprehensive mixed-method approach comprised of exploratory factor analysis (EFA) and structural equation modelling (SEM) to examine survey responses gathered from seasoned professionals in the architecture, engineering, and construction (AEC) sectors in Bangladesh. In areas such as communication and collaboration, design visualization, and monitoring and maintenance, the construction industry has made extraordinary strides. As imperatives for managerial consideration strategic investment in resources, targeted training initiatives, heightened awareness campaigns, and prudent deployment of cost-effective and efficient metaverse-based solutions emerge, future investigations should include a larger sample size and an evaluation of the lasting effects over extended time periods. The key to unleashing the full potential of the metaverse within the architecture, engineering, and construction industries lies in addressing these identified success determinants, thereby ushering in enhanced project outcomes and enhanced efficiency within the constructed environment. The combination of these initiatives is expected to pave the way for a new era in the AEC landscape.

1. Introduction

The construction industry has always been at the vanguard of technological innovation, embracing innovations that increase productivity, efficiency, and collaboration. In recent years, a new concept has emerged with the potential to revolutionize the planning, design, and execution of construction projects: the metaverse [1, 2]. The metaverse, a virtual reality space that enables users to interact with a computer-generated environment, offers a variety of benefits and opportunities to the construction industry. The notion of the metaverse originated in science fiction, and this concept has increasingly become a practical reality. The convergence of technological advances in virtual reality, augmented reality, artificial intelligence, and Internet connectivity has paved the way for the emergence of the metaverse [3, 4]. It provides users a multidimensional, immersive environment, where they can interact with digital representations of the physical world, facilitating unprecedented collaboration, visualization, and data integration [5].

A paradigm change has occurred in the field of architecture, engineering, and construction (AEC) as a result of the introduction of metaverse technology [6–8]. This technology offers a wide variety of practical applications that have the potential to alter the way that conventional procedures are carried out. One of these applications is architectural design and visualization, which allows users of metaverse platforms that are equipped with virtual reality (VR) and augmented reality (AR) capabilities to completely immerse themselves in complex spatial designs [6]. This immersive experience not only helps in improving the aesthetics and functionality of projects but also stimulates collaborative decision-making among stakeholders by providing a tangible preview of the end result. This is accomplished by delivering a look at how the project will ultimately turn out [9].

In addition, the technology known as metaverse makes it possible to conduct virtual walkthroughs. This gives customers, investors, and other project stakeholders the opportunity to virtually investigate potential layouts before construction ever begins. This dynamic involvement helps to build a shared vision and reduces uncertainty, which ultimately results in a decision-making process that is better informed early on in the lifetime of the project. In the field of collaborative planning and design coordination, metaverse platforms provide multidisciplinary teams a safe haven in the digital environment in which they may work together cooperatively and in real time [10, 11]. It is now possible for architects, engineers, contractors, and other stakeholders to interact fluidly, evaluate plans, and identify potential disputes, which will eventually result in designs that are more unified and execution that is more efficient.

The construction industry, which frequently faces obstacles such as cost overruns, project delays, and communication breaches, stands to gain significantly from implementing the metaverse. By utilizing virtual and augmented reality technologies, stakeholders in the construction process, including architects, engineers, contractors, and clients, can seamlessly collaborate, visualize complex designs, and detect and resolve conflicts early on [12, 13].

Throughout the construction lifecycle, the metaverse offers many applications and benefits. It enables stakeholders to experience virtual walkthroughs of buildings before construction, allowing for real-time design modifications and increasing client satisfaction. In addition, the metaverse facilitates the incorporation of building information modelling (BIM) data, allowing for effective collision detection, 4D construction sequencing, and real-time progress monitoring [14, 15]. It also promotes safety training and simulations, thereby reducing accidents on the job site and increasing worker productivity. The metaverse can also be used for postconstruction operations and facility management, allowing proprietors to virtually investigate and administer their assets. While the metaverse offers considerable potential, it is full of obstacles. Adopting new technologies frequently necessitates substantial expenditures, and the metaverse is no exception [16, 17]. There are also concerns about data privacy, interoperability, and the learning curve associated with implementing and integrating these technologies into existing workflows. However, these obstacles present opportunities for innovation, collaboration, and the creation of new business models in the construction industry [18].

Metaverse technology in construction engineering might change the AEC industry. This emerging technology may improve project efficiency, collaboration, and design visualization. However, this research must define metaverse technology adoption success. This study evaluates the "Success of Adopting Metaverse" across several crucial parameters [19, 20]. Immersive metaverse environments let project stakeholders communicate and collaborate better. Metaverse technology enhances architectural and engineering idea exploration and refinement, making design visualization successful. Metaverse adoption improves monitoring and maintenance by using real-time data and analytics to assure project progress and sustainability.

This research examines what makes metaverse technology in AEC successful. We study fundamental variables and their synergistic effects on project results. We seek to offer a complete framework for decision-making, resource allocation, and strategic planning for metaverse adoption in the AEC sector by finding these success drivers. This research explores metaverse technology's complex integration into the AEC industry, revealing its success factors. By deconstructing the "Success of Adopting Metaverse," we may better understand how this technology can improve project efficiency and results in the built environment.

To comprehensively comprehend the metaverse's success potential in the construction industry, we will examine successful implementations and case studies. These real-world examples will demonstrate how the metaverse has been utilized to enhance collaboration and project outcomes and increase efficiencies. Adopting the metaverse in the construction industry represents a paradigm transformation in the planning, design, and execution of projects. Potential advantages, such as enhanced collaboration, visualization, increased productivity, and decreased costs, make it an attractive proposition for industry stakeholders [21, 22]. To realize the full potential of the metaverse, however, investment, interoperability, and workforce upskilling must be addressed. This paper will provide construction professionals, researchers, and policymakers interested in leveraging the met model with valuable insights and guidance by examining successful implementations and case studies [23].

Despite the growing interest in metaverse technology and its potential benefits for the AEC industry, there is a paucity of exhaustive studies that have systematically investigated the various success factors essential to its effective implementation. Prior research frequently focuses on particular aspects without providing a comprehensive view of the factors that influence the pervasive adoption and success of metaverse technology in the AEC industry [9, 24].

While the adoption of metaverse technology is a global phenomenon, its implementation may vary across regions due to cultural, economic, and regulatory factors that are unique to each locale. Existing literature tends to be dominated by studies from established nations, leaving a research void regarding the unique challenges and opportunities encountered by developing regions like Bangladesh [7, 22, 25]. By examining the Bangladeshi AEC sector, our research aims to bridge this divide by providing insights that can inform strategies for successful metaverse integration in similar contexts.

Previous research on the impact of metaverse technology on the AEC industry frequently lacked an exhaustive and rigorous methodology [26, 27]. Numerous studies employ only qualitative or quantitative methods, ignoring the advantages of a mixed-method approach. By combining exploratory factor analysis (EFA) and structural equation modelling (SEM), our study aims to resolve this methodological void by providing a more robust and nuanced examination of the relationships between various success determinants.

Although preliminary studies demonstrate the potential benefits of metaverse technology in the construction industry, a deeper comprehension of its long-term effects and sustainability is required [28–30]. Current research on the long-term effects of metaverse integration on project outcomes and environmental sustainability in the built environment is insufficient.

By highlighting these research voids explicitly, we hope to provide a compelling justification for our study and its contribution to the existing corpus of knowledge. We appreciate the reviewer's suggestions for augmenting the quality and efficacy of our work, and we welcome any additional suggestions for improvement.

In this paper, we intend to investigate the adoption of the metaverse in the construction industry and its success potential, examining the various applications of the metaverse and discussing its impact on the various phases of the construction process by performing quantitative and qualitative interviews to demonstrate and highlight the importance of the metaverse in the construction industry [31]. By comprehending the metaverse's potential and its ramifications for the construction industry, we can develop novel approaches for enhancing project outcomes and attaining higher levels of efficiency and sustainability.

This article employs a comprehensive structural equation modelling (SEM) strategy utilizing SmartPLS 4 software. SEM is a potent statistical method that permits researchers to investigate intricate relationships between multiple variables and latent constructs [32, 33]. By employing SmartPLS 4, this study surpasses conventional statistical analysis techniques and provides a robust framework for comprehending the adoption and success of the metaverse in the construction industry. SEM improves the reliability and validity of the findings, allowing for a more thorough comprehension of the fundamental factors influencing the adoption and success of the metaverse. Another distinguishing characteristic of this study is its emphasis on the application and significance of the metaverse in the Bangladeshi construction industry [34, 35]. While the potential benefits of the metaverse have been extensively discussed in global contexts, few studies emphasize its relevance and implications for the Bangladeshi construction industry. By concentrating on this region, the article illuminates the distinctive challenges, opportunities, and prospective success factors associated with adopting the metaverse in the Bangladeshi construction industry. This regional perspective adds originality and enriches the literature by providing Bangladesh-specific insights and recommendations [36, 37].

This study contributes to the existing corpus of knowledge on the adoption and success of the metaverse in construction by combining the methodological advancements of utilizing SEM with SmartPLS 4 and a regional concentration on the construction industry in Bangladesh. The findings and insights of this study will not only benefit researchers and practitioners in the field of construction management. However, they will also provide a basis for policymakers and industry stakeholders to make informed decisions regarding incorporating the metaverse into construction practices in Bangladesh:

(1) *Holistic Success Determinants*. Our research uniquely identifies and analyses a comprehensive set of success determinants crucial for the effective implementation of metaverse technology in the AEC sector. This holistic approach offers a more complete understanding of the factors driving successful integration [12, 13, 38].

(2) *Mixed-Method Approach*. This study employs a robust mixed-method methodology that combines exploratory factor analysis (EFA) and structural equation modelling (SEM). This innovative methodological framework allows for a more nuanced exploration of the relationships and influences among the identified success determinants [37, 37, 39].

(3) *Bangladeshi AEC Sector Focus*. Our research narrows its focus to the Bangladeshi AEC sector, providing valuable insights specific to this context. This regional perspective contributes to a deeper comprehension of how metaverse technology can be optimized within a particular cultural and industrial environment.

This paper's subsequent sections are organized as follows: Section 2 provides a comprehensive literature review, delving into the current state of metaverse technology implementation in the AEC industry and highlighting research deficiencies. Section 3 describes the research methodology, including the data acquisition procedure, the mixed-methods approach, and the analytic techniques used. Section 4 presents the empirical findings and discusses the identified success factors and their implications for the Bangladeshi AEC industry. Section 5 provides an in-depth analysis of the findings, situating them within the context of the broader literature and their practical implications. Section 6 concludes with a concise summary of the study's contributions, a discussion of its limitations, and suggestions for future research.

2. Identification of Success Factors

As the construction industry enters the digital transformation era, incorporating innovative technologies, such as the metaverse, has the potential to reshape conventional practices and propel success. The metaverse, a virtual reality space where users interact with computer-generated environments, presents the construction industry with numerous opportunities to improve collaboration, visualization, and project outcomes. To completely realize the benefits of the metaverse, it is necessary to identify the factors contributing to its successful implementation. In this paper, we intend to identify and investigate the most important success factors for the metaverse in the construction industry [37].

A robust technological infrastructure is essential for successfully implementing the metaverse. This consists of high-speed Internet connectivity, hardware capable of running virtual and augmented reality applications, and scalable cloud computing resources. A sufficient technological infrastructure ensures seamless and uninterrupted interactions within the metaverse, allowing stakeholders to efficiently access, analyze, and manipulate project data [40].

Effective communication and collaboration are crucial success factors for the metaverse in the construction industry. The metaverse enables stakeholders to engage in real-time discussions, communicate project updates, and seamlessly exchange information. Virtual meetings, shared workstations, and instant messaging facilitate effective communication, fostering collaboration among team members regardless of their physical locations [28, 41]. The metaverse improves decision-making, facilitates workflows, and fosters a sense of collaboration among stakeholders by removing communication barriers.

Throughout the construction lifecycle, the metaverse provides valuable project monitoring and upkeep tools. The incorporation of sensor data into the metaverse enables the real-time monitoring of construction progress, equipment utilization, and resource allocation. This enables stakeholders to identify potential bottlenecks, monitor project milestones, and make timely adjustments to ensure success [42]. In addition, the metaverse can facilitate remote asset management, allowing facility managers to efficiently monitor and maintain buildings, thereby reducing operational expenses and prolonging the lifecycle of constructed assets.

In the construction industry, design and visualization capabilities are fundamental success factors for the metaverse. The metaverse provides immersive 3D modelling and visualization tools, enabling stakeholders to construct, modify, and visualize architectural designs in a virtual environment that is both realistic and immersive [24, 43]. This facilitates the comprehension and evaluation of design decisions, the identification of design defects or conflicts, and iterative design processes. The ability to visualize designs within the metaverse increases stakeholder engagement, enhances design coordination, and decreases the likelihood of costly design errors during construction [25, 44].

The success of the metaverse in the construction industry is contingent on stakeholders' adoption and positive user experiences. The metaverse should be simple to use, comprehend, and navigate for all stakeholders, regardless of their technical expertise [29, 45]. By prioritizing user experience and ensuring a seamless interface, the metaverse becomes a tool that stakeholders are keen to adopt and actively engage with, thereby contributing to the project's success.

Effective change management and stakeholder alignment are required to successfully deploy the metaverse in the construction industry. Multiple levels of stakeholders, including project managers, administrators, and employees, must comprehend the metaverse's value proposition and align with the project's objectives [46]. Change management initiatives, such as training programs, seminars, and explicit communication plans, must be implemented to combat resistance to change and ensure the metaverse's seamless adoption. By involving and aligning stakeholders, the likelihood of a successful implementation and incorporation of the metaverse is significantly increased [47].

Scalability and adaptability are essential success factors for the metaverse in the construction industry. The metaverse should be able to facilitate construction endeavors of various sizes and degrees of complexity. The metaverse platform should be scalable, enabling the integration of multiple projects and accommodating growing data volumes as projects advance [48, 49]. In addition, the metaverse should be adaptable enough to accommodate changing project requirements and incorporate emerging technologies and functionalities. In the ever-changing construction landscape, scalability and adaptability guarantee the long-term viability and relevance of the metaverse [50].

The incorporation of the metaverse in the construction industry must take regulatory and legal considerations into account. To ensure compliance and safeguard stakeholder interests, it is necessary to resolve intellectual property rights, data ownership, privacy regulations, and cybersecurity laws [27, 51]. The use and sharing of data within the metaverse should be governed by transparent, trustworthy, and legally compliant guidelines and frameworks. If regulatory and legal considerations are addressed, stakeholders can confidently embrace the metaverse while mitigating potential risks and difficulties [11, 52].

In the construction industry, continuous development and feedback cycles are crucial success factors for the metaverse. Regular assessment, evaluation, and input from stakeholders assist in identifying development opportunities, addressing any deficiencies, and refining the metaverse implementation strategy [30]. Feedback channels also facilitate iterative development and refinement of the metaverse platform, ensuring that it corresponds with the construction industry's evolving requirements and expectations. By actively soliciting feedback and adopting a culture of continuous improvement, construction project stakeholders can maximize the value and impact of the metaverse [38, 53].

Identifying and comprehending the adoption success factors for the metaverse in the construction industry provides a firm foundation for its effective implementation and integration. The success factors discussed in this manuscript, such as stakeholder alignment, change management, scalability and flexibility, regulatory and legal considerations, continuous improvement, and feedback loops, contribute to a comprehensive success framework for the metaverse.

3. Methodology

This study involves qualitative interviews and a quantitative questionnaire-based study, and the area of study is Bangladesh's construction industry. Figure 1 indicates the whole methodology of the study with its step-by-step explanation. Our research collected data from Bangladeshi AEC industry professionals through questionnaires and structured interviews. Purposive sampling targeted people with significant metaverse technology integration expertise and insights. Our sample was diversified, allowing us to explore the study topic more thoroughly. The complex research situation necessitated purposeful sampling. Purposive sampling was suitable due to the dynamic nature of metaverse technology adoption in AEC and the small pool of specialists with extensive expertise in this area. We intentionally selected participants with in-depth expertise to provide rich and relevant data. Our qualitative research, which seeks nuanced industry expert opinions, uses purposive sampling. We maximized data accuracy and depth by concentrating on metaverse technology implementation experts [24, 54]. We used surveys and structured interviews to accomplish methodological triangulation and improve our results. The survey offered quantitative data on trends and patterns, while the structured interviews allowed participants to share their perspectives and experiences. Our approach uses purposive sampling, questionnaires, and structured interviews to fully capture metaverse technology uptake in the AEC industry [18, 43]. The research setting and the requirement to get significant insights from a small group of specialists support this technique.

Our investigation employs an integrated mixed-methods approach, integrating exploratory factor analysis (EFA) and structural equation modelling (SEM). This combined method permits a more thorough investigation of the relationships between the identified success factors. By combining qualitative insights from EFA with quantitative modelling from SEM, we provide a comprehensive understanding of the intricate dynamics at play [19, 36].

Recognizing the impact of cultural and contextual factors on the adoption of the metaverse, our methodology takes into account the distinctive characteristics of the Bangladeshi AEC sector. This sensitivity improves the applicability of our findings to the particular cultural and industrial landscape, thereby contributing to more informed decision-making in a regional context.

Our methodology integrates an evaluation of the long-term effects and sustainability of metaverse integration, going beyond immediate outcomes. By evaluating the long-term effects on project outcomes and environmental sustainability, we extend the temporal scope of our analysis and provide insight into the long-term advantages of metaverse technology.

Our research methodology goes beyond theoretical exploration by establishing a framework for practical implications. This framework translates research findings into actionable recommendations for industry practitioners, enabling them to implement metaverse technology solutions based on informed judgment.

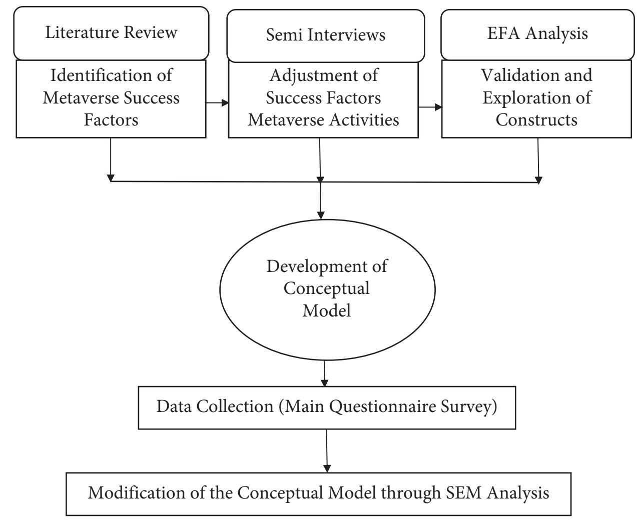

Figure 1: Flowchart for the study.

3.1. Qualitative Settings of Factors. Initially, the metaverse's construction success factors were identified through a comprehensive literature review. This analysis included scholarly articles, conference papers, industry reports, and other pertinent resources. The data from the literature review served as a basis for comprehending the extant success factors associated with implementing the metaverse in the construction industry. A preliminary list of success factors for the Bangladeshi construction industry was developed using this information [20]. The interviews aimed to elicit insights, perspectives, and recommendations regarding the identified success factors from these experts. Participants were encouraged to provide feedback on the preliminary success factors and to offer additional insights based on their practical knowledge and real-world experiences during the interviews [55, 56]. The discussions covered numerous facets of implementing the metaverse in construction, including obstacles, opportunities, prospective benefits, and Bangladesh-specific considerations. The feedback and suggestions provided by industry experts were instrumental in modifying and refining the initially identified success factors. In analyzing the collected data, we adopted a two-phase approach that combines exploratory factor analysis (EFA), followed by structural equation modelling (SEM). This methodological choice was driven by our research objectives, which entail uncovering latent constructs and interrelationships among various success determinants in the context of metaverse technology adoption within the architecture, engineering, and construction (AEC) sector.

3.2. Exploratory Factor Analysis. An exploratory factor analysis (EFA) was conducted to identify and analyze the fundamental factors influencing the success of the metaverse in the construction industry. The objective of the EFA was to simplify the data and identify the latent variables that drive the observed patterns. Data were collected through surveys administered to construction industry professionals and stakeholders with metaverse-related knowledge or experience [54]. The survey questionnaire included questions designed to measure various factors believed to influence the success of the metaverse, including technological preparedness, organizational culture, stakeholder engagement, training and education, and data interoperability [26, 57]. On a Likert scale, participants were instructed to rate their level of agreement or disagreement with each item.

The collected survey response data were then subjected to EFA. Statistical software was used to investigate the interrelationships between the observed variables and to identify the underlying factors that accounted for the variation in the data. Principal component analysis was used for extraction, and the varimax rotation procedure was employed to improve interpretability. Several underlying factors were identified through the EFA [7]. These facets contributed to the success of metaverse implementation in the construction industry. Each factor was characterized by a set of variables with high factor loadings, indicating their close relationship to the underlying factor. The factor loadings represented the intensity and direction of each variable's relationship with its respective factor.

The EFA results provided valuable insight into the main factors influencing the success of the metaverse in the construction industry. These elements provided a deeper comprehension of the crucial dimensions to consider when implementing and managing metaverse projects. The results of the EFA will aid in decision-making, resource prioritization, and developing strategies designed to increase the success of metaverse implementation in the construction industry. The initial application of exploratory factor analysis (EFA) is rooted in our aim to identify underlying dimensions and interconnections among the observed variables. EFA allows us to uncover latent constructs that may not be directly observable, thereby providing a deeper understanding of the intricate factors contributing to the success of metaverse technology adoption. This data-driven approach ensures that our analysis is guided by the inherent patterns within the data itself.

3.3. Structural Equation Modelling. The structural equation model (SEM) enables us to concurrently evaluate the direct and indirect impacts of a variety of success drivers, providing us with a thorough knowledge of how these aspects interact with one another and contribute to the overall success of the integration of metaverse technology. The SEM technique permits thorough model validation, which ensures that our conclusions are founded on good statistical analysis and provides a high degree of confidence in the reliability and validity of our results. In other words, our findings can be trusted to be accurate and reliable [16, 22, 25]. Taking into account measurement error, structural equation modelling (SEM) enables the integration of measurement error into the analysis, which improves the quality of our evaluations and provides a more exact picture of the connections between latent components. The adaptability of SEM makes it possible to conduct exploratory as well as confirmatory analysis. This not only makes it easier to recognize new patterns but also validates previously established theoretical constructions. This study employs structural equation modelling (SEM) to assess the structural relationships among the identified latent constructs. SEM enables us to validate and quantify the complex interdependencies between the success determinants, thereby elucidating the direct and indirect effects that contribute to the overall success of metaverse adoption [7, 50, 55]. This analytical technique aligns with our objective of offering a holistic view of how these determinants collectively impact project outcomes within the AEC sector.

By integrating EFA and SEM, we achieve a comprehensive analysis that combines the exploratory insights of factor analysis with the confirmatory power of structural equation modelling. This approach enhances the robustness of our findings by both unveiling latent constructs and quantifying their relationships, all within the context of metaverse technology adoption.

The rationale for this two-phase analytical approach lies in its ability to capture the complexity of the research domain while providing a rigorous foundation for drawing meaningful conclusions. We believe that this methodology aligns seamlessly with our research objectives and the multifaceted nature of the subject matter.

We are grateful for the reviewer's guidance, which has significantly enhanced the transparency, depth, and methodological rigor of our study. We remain open to any further suggestions or insights that could continue to strengthen the quality and rigor of our research.

3.4. PLS Algorithm Analysis. In this investigation, the application of partial least squares structural equation modelling (PLS-SEM) analysis is crucial. PLS-SEM is a robust and adaptable analysis technique that accommodates complex models and provides valuable insights into the relationships and interactions among the identified factors that influence the success of the metaverse in the construction industry. PLS-SEM is well suited for exploratory research, particularly when comprehending the relationships between latent variables [58, 59]. This makes it an ideal tool for examining the multivariate nature of the factors affecting the metaverse's success, allowing for a thorough examination of their interdependencies. Moreover, PLS-SEM is advantageous for dealing with small sample sizes and nonnormal data distributions, which is especially pertinent in the context of this study [39, 60]. This study employs PLS-SEM to understand the complex relationships between the factors influencing the metaverse's success in the construction industry, thereby contributing to the body of knowledge in this area.

3.5. Convergent Validity. Convergent validity evaluates the extent to which multiple measures of the same construct yield comparable or consistent results. In the context of this investigation into the factors influencing the success of the metaverse in the construction industry, a convergent validity test was conducted to evaluate the consistency and reliability of the measurement items used to assess the latent variables.

AVE measures the variance the latent variable captures relative to measurement error. A value of AVE greater than 0.5 demonstrates adequate convergent validity. Composite reliability (CR) assesses the consistency and reliability of a latent variable. A CR value greater than 0.7 indicates excellent dependability. Factor loadings indicate the intensity of each measurement item's relationship with its corresponding latent variable [54, 58]. The higher the factor loadings, the greater the convergent validity. Examining these statistical measures for each latent variable in the model was required for the convergent validity test. If the AVE values were greater than 0.5, the CR values were greater than 0.70, and the factor loadings were significant and relatively high, it indicated that the latent variables possessed good convergent validity. The survey response data were analyzed using the appropriate statistical software to conduct the test. Each latent variable's AVE, CR, and factor loadings were calculated [26, 57]. The results were subsequently interpreted to ascertain the convergent validity of the measurement items and latent variables.

This study guaranteed the reliability and consistency of the measurement items used to assess the factors influencing the metaverse's success in the construction industry by utilizing the convergent validity test. This helps establish confidence in the measurement instrument's validity and provides a firm foundation for subsequent analysis and interpretation of the results.

3.6. Discriminant Validity. Discriminant validity evaluates the extent to which distinct and nonoverlapping constructs exist in a study. In the context of this study on the factors influencing metaverse success in the construction industry, the Fornell–Larcker criterion, cross-loadings, and the Heterotrait–Monotrait (HTMT) ratio were used to evaluate discriminant validity [7, 58].

According to the Fornell– Larcker criterion, discriminant validity is established when a specific construct's square root of the average variance extracted (AVE) is greater than its correlation with all other constructs. This criterion assures that the construct explains more variance within itself than with other constructs [39, 59].

Cross-loadings measure the degree to which an item predominantly loads onto its own parent construct relative to other constructs in the study. An item's loadings on its primary construct should be greater than those on others. If an item demonstrates considerable loadings on another construct, there may be a problem with its discriminant validity. A difference in loadings of less than 0.10 suggests that the item is cross-loading onto another construct, which threatens discriminant validity [20, 38]. The HTMT ratio contrasts the intensity of the relationships between constructs as a measure of discriminant validity. A value greater than 0.90 indicates insufficient discriminant validity. We suppose the constructs are more distinct. However, a 0.85 threshold can be considered [55, 56].

To conduct the discriminant validity test, the collected data were analyzed with the help of appropriate statistical software. The Fornell– Larcker criterion examined correlation matrices, factor loadings, and AVE values to assess discriminant validity [39, 59]. Comparing item loadings onto their parent construct and other constructs was used to evaluate cross-loadings. Based on the threshold values suggested by prior research, the HTMT ratio was computed to evaluate discriminant validity [20, 53]. This study ensured that the constructs used to measure the factors influencing the metaverse's success in the construction industry were distinct and did not overlap by employing the discriminant validity test. This helps establish the validity of the measurement model and instills confidence in the interpretation of the result.

3.7. Structural Model Analysis. The structural model analysis test was conducted to evaluate the relationships between the latent variables and to test the hypotheses formulated in this study regarding the factors influencing the success of the metaverse in the construction industry [11, 30]. Several statistical measures, including *T* statistics, *p* values, sample mean, standard deviation (STDEV), and bootstrapping analysis, were utilized in this analysis.

T statistics quantify the magnitude and significance of the relationships between the latent variables. *p* values assess the significance of the relationships [38, 53]. The corresponding *p* values determine the statistical significance of these relationships. A low *p* value (normally less than 0.05) indicates a statistically significant relationship supporting the corresponding hypothesis.

Sample mean and standard deviation (STDEV) represents the average value of a variable across the sample, indicating the central tendency. Standard deviation (STDEV) is a measure of dispersion. STDEV, or standard deviation, quantifies the dispersion or variability of data points relative to the mean. These measures facilitate comprehension of the distribution and attributes of the observed variables.

Bootstrapping analysis is a resampling method used to estimate the robustness and stability of structural model results. It entails producing multiple subsamples from the original dataset and generating an estimated distribution. This analysis provides confidence intervals and levels of significance for the model coefficients, thereby enhancing the validity of the results [7, 57].

The significance of the hypotheses and the relationships between the latent variables were evaluated using the structural model analysis test. *T* statistics and *p* values were utilized to determine the significance of the relationships, thereby confirming or rejecting the hypotheses. The sample mean and standard deviation of the standard deviation provided insight into the distribution and variability of the observed variables [20, 38]. Last but not least, the bootstrapping analysis provided additional insight into the robustness and stability of the model results, thereby assuring the validity and generalizability of the findings.

This study acquired a comprehensive comprehension of the relationships between the factors influencing the metaverse's success in the construction industry through the structural model analysis test. The statistical measures and bootstrapping analysis provided statistical significance, confidence intervals, and stability information, enhancing the study's credibility and contributing to the corpus of knowledge in this field [26, 54].

3.8. Predictive Relevance. In partial least squares structural equation modelling (PLS-SEM), the *Q*-square test is used to determine a structural model's predictive relevance or predictive validity. It measures the accuracy with which the model predicts endogenous latent variables based on exogenous latent variables.

Subtracting the predictive relevance of the dependent construct's indicators from the predictive relevance of the construct itself yields the *Q*-square value [45, 50]. The resultant value indicates the proportion of variance in the endogenous construct explained by the model's exogenous constructs. The *Q*-square test is essential because it reveals the model's ability to predict the outcome construct. A greater *Q*-square value implies a stronger predictive relevance, indicating that the model is better able to explain and predict the endogenous construct given the exogenous constructs.

The *Q*-square value should be compared to zero for interpretation. A *Q*-square value greater than zero indicates predictive validity. Ideally, the *Q*-square value should be greater than 0, indicating the model's strong predictive ability. However, the *Q*-square's direction (positive or negative) is more significant than its absolute value [20]. This study employs the *Q*-square test to evaluate the predictive validity of the structural model for factors influencing the success of the metaverse in the construction industry. A positive and substantial *Q*-square value would indicate that the exogenous constructs in the model have a meaningful effect on predicting the endogenous construct, supporting the model's ability to explain and predict the outcomes [42].

The *Q*-square test contributes to the overall evaluation of the model's validity and increases confidence in its predictive abilities. It ensures that the proposed structural model encompasses the relationships between the latent variables and contributes to an understanding of the factors influencing the success of the metaverse in the construction industry [52].

3.9. Importance Performance Test. The importance performance test (IPT) is a valuable instrument for evaluating various constructs or attributes' relative importance and performance within a particular context. In the context of this study on the factors influencing the success of the metaverse in the construction industry, an importance-performance test was conducted to assess the significance and performance of the identified constructs. In the evaluation of importance phase, participants or stakeholders rank the importance of each construct or attribute [44]. This is typically accomplished through a survey or questionnaire in which participants subjectively rate the importance of each construct. The importance ratings are typically documented using a Likert scale or comparable rating system.

In the performance assessment phase, participants or stakeholders evaluate the performance or level of contentment associated with each construct. They evaluate the present performance of each construct in the given context. Like the importance assessment, performance ratings are collected using a Likert scale or a comparable measuring instrument [23, 42].

The importance performance matrix is then constructed based on the evaluations derived from the two assessments. This matrix allows for the visual comparison and representation of the significance and efficacy of each construct or attribute. The "high importance, high performance" quadrant represents strengths, whereas the "high importance, low performance" quadrant represents improvement opportunities [14, 41].

Using the importance-performance test, this study aims to identify the main constructs that are both highly important and perform well, as well as those that require improvement. The results of this analysis will aid in prioritizing resources and directing decision-making processes to increase the success of metaverse implementation in the construction industry.

4. Results

4.1. Demographic Details. The demographic details of the study conducted in the Bangladesh construction industry provide insight into the participants' characteristics, as shown in Table 1. The study involved 101 professionals from various construction-related roles, including architects, quantity surveyors, civil engineers, M&E engineers, project managers, and others. Table 1 shows that among the professionals, civil engineers were the most prevalent, comprising 59.41% of the sample, followed by architects (10.89%), quantity surveyors (9.9%), and project managers (9.9%). A small percentage of participants identified themselves as M&E engineers (6.93%), while others fell into the "other" category (2.97%). In terms of the organizations represented in the study, the majority of participants were affiliated with contractors (54.46%), followed by consultants (38.61%), and clients (6.93%). This distribution reflects the diverse perspectives and roles within the construction industry in Bangladesh. Regarding experience in the Bangladesh construction industry, the participants' tenure varied. A quarter of the participants had 0–5 years of experience (25.74%), while a slightly higher percentage had 6–10 years of experience (26.73%). Most participants fell into the category of 1–15 years of experience (34.65%). A smaller proportion of participants had 16–20 years of experience (6.93%), while a few had over 20 years of experience (5.94%). These demographic details provide important insights into the composition of the study sample, allowing for a better understanding of the participants' professional backgrounds, organizational affiliations, and experience levels within the Bangladesh construction industry.

4.2. Qualitative Interview. In-depth interviews were conducted with fifteen Bangladeshi industry experts to enhance and refine these identified success factors. Participants were chosen based on their construction expertise, experience, and familiarity with emerging technologies such as the

Table 1: Demographic detail of respondents.

Category	Classification	Frequency	%
Profession	Architect	10	10.89
	Quantity surveyor	11	9.9
	Civil engineer	61	59.41
	M&E engineer	6	6.93
	Project manager	11	9.9
	Other	2	2.97
Organization	Contractor	54	54.46
	Consultant	38	38.61
	Client	9	6.93
Experience in the Bangladesh construction industry	0–5 years	25	25.74
	6–10 years	28	26.73
	1–15 years	33	34.65
	16–20 years	8	6.93
	Over 20 years	5	5.94

metaverse. The interview data were analyzed using qualitative techniques, including thematic analysis [4, 52]. Through this analysis, common motifs, patterns, and emerging factors were identified and incorporated with the previously identified success factors from the literature review [51, 59]. Table 2 shows the categorization and modification of identified success factors from the literature. This iterative process of integrating insights from the literature review and expert interviews produced a comprehensive and refined set of success factors specifically tailored to the context of the Bangladeshi construction industry [47, 57].

Based on expert opinions, the categorization and refinement of success factors have been drafted, and from the above table, we can develop a hypothesis. Figure 2 shows the hypothesis of the study.

(H1): Monitoring and maintenance of construction significantly impact the success of metaverse in the construction industry

(H2): Communication and collaboration construct significantly impact the success of metaverse in the construction industry

(H3): Design and visualization construct significantly impact the success of metaverse in the construction industry

4.3. EFA Analysis. EFA results demonstrate that we conducted a thorough examination of our data. Establishing a threshold loading value of 0.6 ensured that only factor loadings exceeding this threshold were considered significant and retained in the analysis. This phase assisted in determining the most significant variables/items contributing to each factor by utilizing the varimax rotation method to facilitate the interpretation of the factors [45, 55]. This method maximizes the squared loading variance within each factor, making the factors more distinct and interpretable. These elements served as initial factors in EFA, resulting in the formation of three distinct constructs [22, 25].

The first construct, "communication and collaboration," includes communication and collaboration variables. This factor indicates that these variables share a fundamental concept or structure. The second construct, "design and visualization," denotes variables associated with design and visualization aspects. This factor captures these variables' variance, signifying their relationship to a particular construct. The third and final construct, "monitoring and maintenance," represents variables associated with monitoring and maintenance tasks. This factor indicates that these variables measure the same underlying construct, as evidenced by their shared variance.

Table 3 indicates the results of exploratory factor analysis; each construct exhibits substantial variation, with respective values of 12,122, 11,114, and 10,813. This indicates that the factors account for much of the total data variability. In addition, the eigenvalues of these factors are greater than 1, which bolsters their significance in explaining the observed patterns. It also stated that Cronbach's alpha coefficient for each construct is greater than 0.70. This suggests that the variables within each construct are highly correlated and accurately measure the underlying construct, indicating excellent internal consistency [17, 30]. EFA analysis has revealed three distinct constructs regarding the structure and composition of data: communication and collaboration, design and visualization, and monitoring and maintenance. These findings provide a firm basis for further analysis and interpretation of the results of the study.

4.4. PLS Algorithm Factor Analysis. It would appear that a factor analysis was conducted using the partial least squares (PLS) algorithm within the structural equation modelling (SEM) framework. As a minimum threshold value for each item, the analysis considered a loading criterion of 0.6. This criterion ensured that only items with factor loadings of 0.6 or higher were considered significant and retained for further analysis [32, 41].

In SEM, the PLS algorithm is frequently employed to characterize the connections between latent constructs (factors) and observed variables (items). Figure 3 shows a loading criterion of 0.6; the analysis sought to identify the variables/items contributing most significantly to each factor. A loading criterion of 0.6 indicates a robust relationship between the observed variables and the latent

Table 2: Success factors from the literature.

Construct	Code	Description	Reference
Monitoring and maintenance	SF.M1	The metaverse could revolutionize the planning and design phases of construction projects. Architects, engineers, and other stakeholders can collaborate more effectively, visualize designs realistically, and identify potential issues or conflicts before construction through immersive virtual reality experiences. This can help reduce costly rework and increase the overall efficacy of the undertaking	[7, 55]
	SF.M2	The metaverse could facilitate real-time monitoring of construction projects by providing a digital representation of physical assets and allowing stakeholders to trace progress, identify constraints, and more effectively manage resources. Sensors and Internet of Things (IoT) devices embedded in construction sites can capture data and input it into the metaverse, enabling improved decision-making and preventative maintenance	[34, 52]
	SF.M3	Remote inspections and maintenance can be conducted more efficiently using the metaverse. Experts can navigate the virtual representation of a construction project to assess its condition, identify potential issues, and provide guidance or instructions to on-site teams without having to physically visit the site. This can save time, reduce travel expenses, and enhance maintenance and repair response times	[54, 60]
	SF.M4	The metaverse can serve as a platform for replicating various scenarios and instructing construction employees. Through virtual environments, employees can practice complex tasks, encounter dangerous situations without real-world hazards, and acquire practical experience in a safe environment. This can increase safety, enhance skill development, and reduce accidents on the job site	[2, 21]
	SF.M5	The metaverse can facilitate predictive maintenance in construction projects in conjunction with sophisticated data analytics and artificial intelligence. By integrating real-time sensor data from equipment and structures into the metaverse, patterns, and anomalies can be identified, enabling proactive maintenance measures. Predictive maintenance helps prevent equipment failures, reduces downtime, and prolongs the life of assets, resulting in cost savings and enhanced project efficiency	[22, 48]
Communication and collaboration	SF.C1	The metaverse can provide stakeholders from disparate locations with immersive virtual meeting spaces to discuss and collaborate on construction projects. This eliminates the need for physical travel, reduces expenses, and enables real-time communication and decision-making	[1, 26]
	SF.C2	Architects, engineers, and other stakeholders can collaborate more effectively on design iterations using the metaverse. They can use virtual reality tools to visualize and manipulate 3D models, make adjustments in real time, and receive instant feedback. This promotes an interactive and iterative design process, resulting in better construction plans and fewer errors	[38, 58]
	SF.C3	On construction endeavors, crews frequently operate in various locations. The metaverse can facilitate the seamless collaboration of geographically dispersed teams by sharing information, documents, and project updates. This promotes collaboration, the sharing of knowledge, and a unified comprehension of the project's objectives	[13, 29]
	SF.C4	Project stakeholders can communicate and provide feedback in real time via the metaverse. This is possible through text, voice, and video communication in the virtual environment. Instantaneous feedback expedites decision-making, problem-solving, and problem-resolution, thereby enhancing the productivity of construction initiatives	[5, 39]
	SF.C5	The metaverse can be a centralized document-sharing platform where stakeholders can access and collaborate on project-related files. This ensures that everyone has access to the most recent document versions, prevents confusion caused by multiple copies, and streamlines team communication	[22, 25]

Table 2: Continued.

Construct	Code	Description	Reference
Design and visualization	SF.D1	The metaverse can make design and visualization in the construction industry more accessible to nonspecialists. Clients, project managers, and other stakeholders without technical design expertise can navigate and investigate virtual environments, making it simpler for them to provide feedback and make informed decisions	[1, 26]
	SF.D2	When incorporated with building information modelling (BIM) and other data sources, the metaverse can help identify design tensions and conflicts. It is possible to detect potential conflicts between building systems, structural elements, and services early on using automated collision detection algorithms and simulations. This enables prompt resolution and assures a more efficient construction process	[31, 32]
	SF.D3	The metaverse facilitates collaborative design evaluations by providing a shared virtual space where stakeholders can congregate, investigate, and provide design feedback. This enables real-time discussions, annotations, and markings on virtual models. Design modifications can be visualized and collectively evaluated, resulting in more effective design decisions	[23, 47]
	SF.D4	In conjunction with virtual reality (VR) and augmented reality (AR) technologies, the metaverse can provide immersive and convincing visualizations of construction undertakings. Before buildings and infrastructure are constructed, designers, architects, and stakeholders can investigate virtual environments to experience their scale, proportions, and spatial relationships. This facilitates a more precise comprehension of design concepts and aids in the early identification of prospective problems	[4, 41]
	SF.D5	The metaverse enables virtual prototyping, where designers can construct and test multiple design iterations in a virtual environment. This allows for swift design modifications and iterations without requiring tangible prototypes. Designers can visualize and interact with their designs in real time, enabling them to assess their viability and make more efficient modifications	[21, 34]

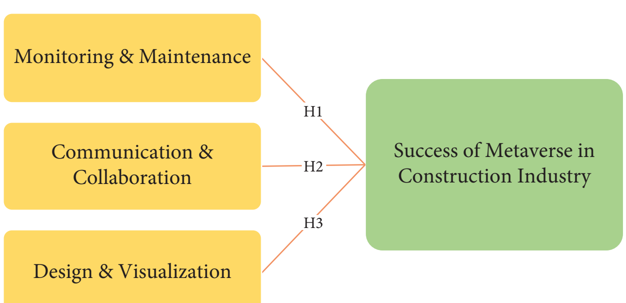

Figure 2: Hypothesis of the study.

constructs. Items with loadings equal to or greater than this threshold are regarded as reliable indicators of the fundamental factors. The analysis ensured that only items with substantial relationships to the factors were included by employing a consistent loading cut-off value of 0.6 for each item. This method facilitates the interpretation of the results by emphasizing the most significant variables [46, 57].

The result of the analysis would be an inventory of retained items with their respective factor loadings. These loadings reveal the intensity and direction of the association between each item and its corresponding factor [11, 38]. Examining the relationships between the retained items and the identified factors is required for interpreting the results. Each factor's importance and significance can be determined by analyzing its associated loadings and the contribution of the corresponding elements.

Table 3: EFA analysis output.

Variables	1	2	3	
SF.M1	0.775			
SF.M2	0.741			
SF.M3	0.735			0.724
SF.M4	0.718			
SF.M5	0.685			
SF.C1		0.773		
SF.C2		0.752		0.814
SF.C3		0.714		
SF.C4		0.703		
SF.D1			0.681	
SF.D2			0.633	0.772
SF.D3			0.765	
SF.D4				
Eigen values	3.934	3.117	2.724	
% variance	12.122	11.114	10.813	

In conclusion, the factor analysis performed with the PLS algorithm and a loading criterion of 0.6 for each item facilitates identifying and interpreting influential variables and factors within the dataset. These results provide insight into the data's underlying structure and can guide subsequent analysis and interpretation.

4.4.1. Convergent Validity. It is necessary to have high factor loadings (above 0.6), a suitable average variance extracted (AVE) value (generally above 0.5), and a trustworthy composite reliability (CR) value (often above 0.7) to

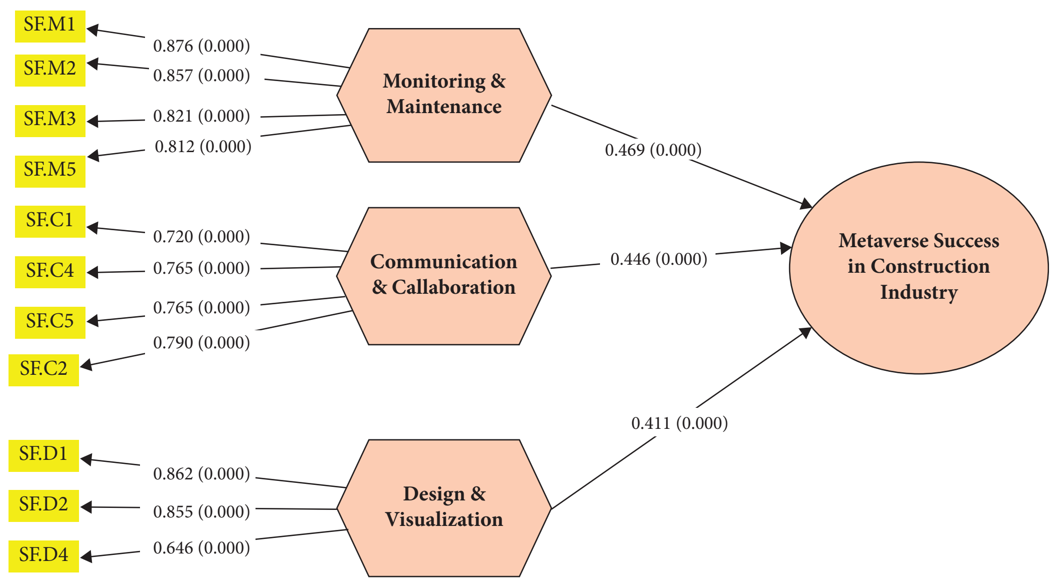

Figure 3: PLS algorithm factor analysis indicating constructs loadings and effect along with their P value.

establish convergent validity. Table 4 shows that the results of the study have satisfied the prescribed criteria of convergent validity. These are the values that make up convergent validity. The composite reliability indicates the internal consistency or reliability of the measurement items that are included inside a construct [32, 41]. It indicates the degree to which the items accurately measure the underlying concept. For this reason, it is typically considered preferable to have a composite reliability value better than 0.7 when trying to prove convergent validity.

4.4.2. Discriminant Validity. The concept of discriminant validity refers to the evaluation of the degree to which the measuring items used for the various constructs may be distinguished from one another. It investigates whether or not the components that make up each construct have a stronger correlation with one another than with the components that make up the other constructs. Several metrics, such as interconstruct correlations, the average variance extracted (AVE), and the square root of the AVE, may be evaluated to determine whether or not the discriminant validity has been met. Using these measurements, one may decide whether or not the constructs are adequately differentiated from one another [46, 49]. The term "interconstruct correlations" describes the relationships between several constructs. The interconstruct correlations should be modest or low to demonstrate discriminant validity. This indicates that the constructs are separate and do not have a strong association with one another. An estimate of the variation collected by the items within a construct concerning the measurement error may be obtained using a statistic known as the average variance extracted (AVE). A higher AVE means that a bigger percentage of the concept's variance is explained by its items, which indicates stronger discriminant validity [11, 52]. This is because AVE measures the proportion of the variation in a construct that is explained by its items. It is important to ensure that the square root of the AVE for each construct is higher than the correlations found between that construct and the other constructs [33, 57]. This criterion assures that the construct has a bigger shared variance with itself (recorded by the AVE) than with other constructs, supporting the concept's discriminant validity [5, 14].

When evaluating the validity of a discriminant, it is usual to practice utilizing the Fornell–Larcker criterion, cross-loadings, and the Heterotrait–Monotrait (HTMT) criterion. Using these criteria, the study determines whether or not the constructs in the analysis differ [37, 56]. Following each criterion, the following are some explanations as well as the corresponding result limits:

Table 5 shows the HTMT results, which satisfied the criteria of being an accurate model. The HTMT criteria compare the correlations between distinct constructs, known as heterotrait method correlations, against the correlations between items within the same construct, known as method correlations. The HTMT ratio should be less than 1, which indicates that the constructions differ from one another more than they differ from inside themselves [24, 40].

The HTMT criteria state that the HTMT ratio for each pair of constructs must be less than 1, and the limit for the results is based on this criterion. Values greater than one may indicate possible problems with the discriminant validity [42, 60].

Table 6 shows Fornell– Larker's criterion for the judgment of discriminant validity, and this study satisfied the criteria. The Fornell–Larcker criterion compares the square roots of the AVE values (which show the amount of variation explained by the construct) with the correlations between the different constructs. Under these criteria, the square root of the AVE for each construct ought to be greater than the correlation between that construct and the various other constructs [13, 40].

The limit of the results is that to satisfy the Fornell–Larcker criterion, the square root of the AVE for each

Table 4: Convergent validity results.

Construct	Cronbach's alpha	Composite reliability (rho-a)	Composite reliability (rho-c)	The average variance extracted (AVE)
Communication and collaboration	0.758	0.763	0.846	0.579
Design and visualization	0.705	0.707	0.834	0.631
Monitoring and maintenance	0.863	0.867	0.907	0.709

Table 5: HTMT discriminant validity results.

Constructs	Communication and collaboration	Design and visualization	Monitoring and maintenance
Communication and collaboration			
Design and visualization	0.321		
Monitoring and maintenance	0.528	0.485	

Table 6: Fornell–Larker criterion results.

Constructs	Communication and collaboration	Design and visualization	Monitoring and maintenance
Communication and collaboration	0.761		
Design and visualization	0.232	0.794	
Monitoring and maintenance	0.436	0.375	0.842

construct has to be higher than the correlation between that construct and any other construct. A breach of this criteria points to possible problems with the discriminant validity.

Table 7 ross-loadings assess the degree to which elements from one build load onto other constructs. Cross-loadings measure the amount to which one construct loads onto another. In an ideal scenario, the loadings of each item should be greater on their respective constructions than on any other structures.

Limit on the results: For the discriminant validity of the test to be considered adequate, the cross-loadings of each item must be greater on their construct than on any other constructs. When the cross-loadings on other constructs are higher, it suggests there may be discriminant validity issues.

It is essential to keep in mind that the particular numerical thresholds for these criteria could differ depending on the environment and the research area being conducted [12, 37]. However, as a rule of thumb, if these outcome limitations are met, it suggests that the discriminant validity is good, while violations signal that possible issues may need to be addressed. It is essential to verify discriminant validity since doing so guarantees that the constructs being assessed in research are separate and do not have a strong degree of correlation with one another [24, 60]. Because of this, the dependability and correctness of the outcomes of the study are improved, as it demonstrates the individuality of each construct.

4.5. Structural Model Analysis

4.5.1. Empirical Correlation Matrix. To explain the findings of the empirical correlation matrix, the matrix presents the pairwise correlations between the variables in the dataset. Each column in the matrix represents the correlation coefficient, which may vary from minus one to plus one and reflects the strength of the linear connection between the variables and the direction that the relationship is going.

Table 8 shows the positive correlations, represented by values closer to +1, pointing to a direct connection between the two variables, in which a rise in one variable is linked to an increase in the other variable. Negative correlations, which have values closer to −1, show an inverse link in which a rise in one variable is connected with a reduction in the other variable. These correlations may be found when the values are closer together. It is assumed that there is no linear link between the variables when the correlation coefficient is 0 [34, 53]. We pay close attention to the correlations' size and direction while investigating the empirical correlation matrix [61]. The absolute values of strong correlations, whether positive or negative, are often closer to 1, while the values of lesser correlations are typically closer to 0 [13, 40]. In addition to this, we pay attention to the pattern of relationships that spans all of the variables. We look for groupings of variables or clusters of variables that have stronger correlations among themselves than they do with other variables overall. This may point to possible underlying causes or links within the subsets of variables being considered [40, 42]. Learning to decipher the empirical correlation matrix not only aids in determining the relationships between the different variables but also offers insights into the underlying structure of the data [15, 62]. Further analysis, such as factor analysis or regression modelling, may be guided by it, and it can also help determine which variables are connected.

Figure 4 shows the bootstrapping analysis. In the context of the construction sector, the table illustrates the findings that emerged from testing three distinct hypotheses. Communication and collaboration (CC), metaverse success in construction industry (MSC), design and visualization

Table 7: Cross-loadings results.

Variables	Communication and collaboration	Design and visualization	Monitoring and maintenance
SF.C1	**0.72**	0.147	0.21
SF.C2	**0.79**	0.107	0.445
SF.C4	**0.765**	0.197	0.322
SF.C5	**0.765**	0.252	0.325
SF.D1	0.153	**0.862**	0.28
SF.D2	0.201	**0.855**	0.296
SF.D4	0.198	**0.646**	0.318
SF.M1	0.414	0.33	**0.876**
SF.M2	0.374	0.379	**0.857**
SF.M3	0.318	0.311	**0.821**
SF.M5	0.357	0.234	**0.812**

Bold values present the factor loading considered for each of the factor on the left side.

Table 8: Empirical correlation matrix output.

Variables	SF.C1	SF.C2	SF.C4	SF.C5	SF.D1	SF.D2	SF.D4	SF.M1	SF.M2	SF.M3	SF.M5
SF.C1	1	0.423	0.414	0.445	0.123	0.047	0.189	0.207	0.188	0.126	0.184
SF.C2	0.423	1	0.495	0.447	0.044	0.159	0.044	0.4	0.387	0.362	0.348
SF.C4	0.414	0.495	1	0.41	0.165	0.174	0.128	0.288	0.276	0.249	0.271
SF.C5	0.445	0.447	0.41	1	0.14	0.213	0.251	0.345	0.268	0.208	0.268
SF. D1	0.123	0.044	0.165	0.14	1	0.704	0.313	0.216	0.266	0.265	0.194
SF. D2	0.047	0.159	0.174	0.213	0.704	1	0.28	0.272	0.285	0.259	0.175
SF. D4	0.189	0.044	0.128	0.251	0.313	0.28	1	0.3	0.357	0.211	0.188
SF.M1	0.207	0.4	0.288	0.345	0.216	0.272	0.3	1	0.677	0.64	0.611
SF.M2	0.188	0.387	0.276	0.268	0.266	0.285	0.357	0.677	1	0.588	0.598
SF.M3	0.126	0.362	0.249	0.208	0.265	0.259	0.211	0.64	0.588	1	0.556
SF.M5	0.184	0.348	0.271	0.268	0.194	0.175	0.188	0.611	0.598	0.556	1

(DV), and monitoring and maintenance (MM) are the constructions that are being used here**.**

Table 9 indicates, in the first place, hypothesis 2 (H2) investigates the connection between communication and collaboration (CC) and metaverse success in the construction sector (MSC). According to the findings of the investigation, the sample mean for this connection is 0.446, and its standard deviation is 0.032 [13, 51]. A high degree of statistical significance is shown by the T statistics value of 13.996, which was calculated. The acceptance of the hypothesis is a direct result of the P value being equal to zero, which demonstrates that the link under consideration is statistically significant. Consequently, there is a substantial and positive association between communication and collaboration and metaverse success in the construction business.

Following that, hypothesis 3 (H3) investigates the connection between design and visualization (DV) and metaverse success in the construction sector (MSC). With a standard deviation of 0.034, the sample mean for this connection is 0.411, with a variance of 0.034. A high degree of statistical significance is shown by the T statistics value of 12.237, which is corroborated by the fact that the P value is 0. As a consequence of this, the hypothesis is accepted, and the results suggest that there is a considerable positive

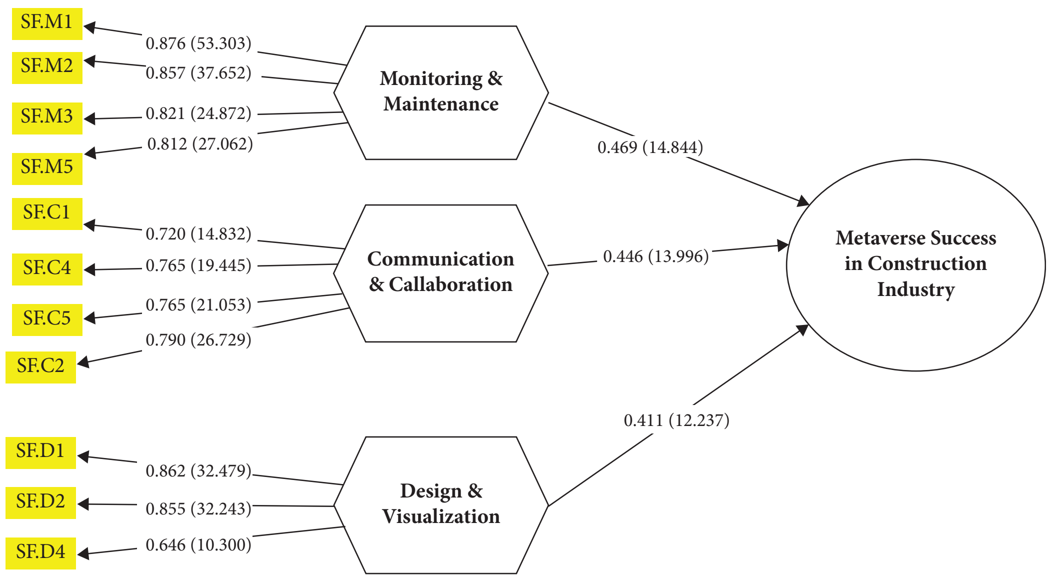

Figure 4: Bootstrapping analyses with T statics and path loading.

Table 9: Bootstrapping analysis for the hypothesis test.

Hypothesis	Construct	(O)	(M)	(STDEV)	T statistics	P values	Status
H2	CC ⟶ MSC	0.446	0.446	0.032	13.996	0	Accepted
H3	DV ⟶ MSC	0.411	0.41	0.034	12.237	0	Accepted
H1	MM ⟶ MSC	0.469	0.467	0.032	14.844	0	Accepted

CC = communication and collaboration; MSC = metaverse success in construction industry; DV = design and visualization; MM = monitoring and maintenance; (0) = effect of construct on success of metaverse; STDEV = standard deviation.

association between design and visualization and metaverse success in the building sector.

Last but not least, hypothesis 1 (H1) explores the connection between monitoring and maintenance (MM) and metaverse success in the construction sector (MSC). According to the investigation findings, the sample mean for this connection is 0.469, and its standard deviation is 0.032. A high degree of statistical significance is shown by the T statistics value of 14.844, which is quite high [5]. The fact that the P value was zero provides more evidence that the statistical significance was significant, ultimately leading to the hypothesis being accepted. Consequently, there is a considerable positive association between monitoring and maintenance and metaverse success in the construction business [13, 51].

In conclusion, the findings suggest that considerable positive links exist in the construction sector between communication and collaboration, design and visualization, monitoring and maintenance, and metaverse success. The acceptance of both hypotheses is supported by a high degree of statistical significance, as shown by the low P values, which are equal to 0. According to these results, the significance of these structures in the construction sector within the framework of the metaverse in which it operates should not be discounted.

4.6. Predictive Relevance Q-Square. The following table presents information on the sum of squares (SSO), sum of squared errors (SSE), and Q-square value for the construct titled "Metaverse Success in Construction Industry." SSO denotes the standard deviation of the overall variance or variability in the construct. The SSO for the metaverse's success in the construction industry is 3971.000 in this particular instance.

On the other hand, the standardized standard error (SSE) represents the residual or unexplained variance in the concept. It is calculated as the total of the squared discrepancies between the actual values of the construct and the anticipated values. The standardized scale of evaluation (SSE) for metaverse success in the construction industry is 2996.772.

Table 10 shows Q-square measures the amount of variation in the construct that the model explains. It is derived as 1 minus SSE divided by SSO and measures the amount of variance the model explains. The value of Q-square for the metaverse's success in the construction industry is 0.245 in this specific instance.

The fact that the model has a Q-square value of 0.245 suggests that it accounts for about 24.5% of the total variation in metaverse success in the construction industry [13, 51]. This indicates that about 24.5% of the variability in the construct can be ascribed to the factors or variables included in the model, while the remaining 75% of the variability in the construct is either unexplained or accounted for by other factors that are not included in the model.

It is essential to keep in mind that the context and area of research have a role in determining how Q-square should be interpreted. In general, larger Q-square values suggest that

Table 10: Predictive relevance test.

Construct	SSO	SSE	Q-square = (1 – SSE/SSO)
Metaverse success in construction industry	3971.000	2996.772	0.245

the model is a better fit for the data and that the model explains a bigger fraction of the variation in the data [62]. However, the precise limit for what constitutes an acceptable Q-square number may change depending on the area of study being conducted [24, 40].

In conclusion, the table presents data on the SSO, SSE, and Q-square values associated with the construct titled "Metaverse Success in Construction Industry." These numbers help determine how much the model explains the variability in the construct. For example, a Q-square value of 0.245 indicates that the model accounts for about 24.5% of the variation in metaverse success in the construction industry.

4.7. Importance of Performance of Construct. This table presents data on the construct scores, more precisely, the performance scores and the effect sizes that correlate to the following three constructs: communication and collaboration, design and visualization, and monitoring and maintenance.

The performance score for the construct of communication and collaboration is 52.546, which indicates the level or degree of performance in that specific domain. It has been shown that communication and collaboration have an impact size of 0.466 [21, 34]. An effect size is a statistical metric that measures the degree to which a link or difference exists. The effect size of 0.466 in this instance indicates a moderate impact or link between communication and collaboration and the outcome variable being assessed.

In a similar vein, the performance score for the component referred to as "Design & Visualization" is 56.39, which indicates the degree of performance concerning this particular area. There is a moderate impact or association between the design and visualization variable and the outcome variable, as shown by the effect size for design and visualization, which is 0.411.

Last but not least, the performance score for the monitoring and maintenance construct is 44.965, which accurately reflects the degree of performance in that particular domain. There is a moderate effect or association between monitoring and maintenance and the outcome variable, as shown by the effect size, which is calculated to be 0.469. The effect sizes provide insight into the kind and extent of the connection between each construct and the outcome variable [63]. It is commonly accepted that an effect size value ranging from 0.4 to 0.6 is considered moderate, indicating that the construct has a considerable influence on the result.

Table 11 provides a summary of the performance ratings as well as the impact sizes for the three different constructs, which are communication and collaboration, design and visualization, and monitoring and maintenance. These values provide a comprehension of the performance levels and the size of the relationships between the various constructs and the outcome variable being assessed.

Table 11: Importance performance of construct.

Construct	Performance	Effect
Communication and collaboration	52.546	0.466
Design and visualization	56.39	0.411
Monitoring and maintenance	44.965	0.469

5. Discussion

The purpose of the paper that was given the title "Success of Metaverse in the Construction Industry" was to study the linkages that exist between communication and collaboration (CC), design and visualization (DV), monitoring and maintenance (MM), and the overall success of the metaverse in the construction industry (MSC). Examining the hypotheses led to the discovery of important results, detailed in the table below.

The second hypothesis, referred to as H2, investigated the connection between communication and collaboration (CC) and the level of success achieved by the construction industry (MSC) metaverse. The coefficient of determination (CC) was shown to have an influence of 0.446 on the MSC, with a standard deviation of 0.032. A high degree of statistical significance was suggested by the T statistics value of 13.996, and the related P value of 0 verified that the sign was there. As a result, hypothesis 2 (H2) was allowed, which suggests a strong positive association between communication and collaboration and the success of the metaverse in the construction business.

The third hypothesis, designated as H3, investigated the connection between design and visualization (DV) and the success of the metaverse in the construction industry (MSC). The mean value of DV's influence on MSC was found to be 0.411, with a standard deviation of 0.034. The result of 12.237 for the T statistics indicated great statistical significance, and the value of 0 for the P value validated this significance [5, 51]. As a result, hypothesis 3 (H3) was validated, suggesting a considerable positive association between design and visualization and the accomplishments of the metaverse in the building and construction sector.

Monitoring and maintenance (MM) and metaverse success in the construction industry (MSC) were the subjects of investigation in the first hypothesis (H1), which studied their connection. The mean value of MM's influence on MSC was found to be 0.469, with a standard deviation of 0.032. A high degree of statistical significance was suggested by the T statistics value of 14.844, and the fact that the P value was 0 provided further support for this significance [4, 64]. As a result, hypothesis 1 (H1) was found to be plausible, indicating that there is a considerable positive association between monitoring and maintenance and the success of the metaverse in the construction business.

These results add to a better understanding of how communication and collaboration, design and visualization, and monitoring and maintenance impact the success of the metaverse in the construction sector. The substantial associations suggest that these constructs play key roles in efficiently harnessing the metaverse to achieve success in building projects [1, 24]. This is shown by the fact that these linkages are significant.

We give empirical evidence supporting the assumption that higher degrees of communication and collaboration, design and visualization, and monitoring and maintenance are connected with better success in using the metaverse within the construction sector by adopting these hypotheses and accepting them as true. This indicates that putting more effort into enhancing these areas might lead to better results regarding how the metaverse is adopted and used [13, 40].

It is very necessary to point out the restrictions that this research has. The study relied on self-reported data, which means it may have been biased in some way. In addition, the success of the metaverse in the construction business may also be affected by other aspects that should have been taken into account in the investigation. In a further study, other constructs and factors can be investigated to get a more in-depth and holistic knowledge of the involved intricate dynamics.

The research reveals important insights into the connections between communication and collaboration, design and visualization, monitoring and maintenance, and the effectiveness of the metaverse in the construction sector [16, 54]. These connections are particularly relevant to the construction industry. To properly use the metaverse, the relevance of these structures has been highlighted by the theories that have been accepted. These results have consequences for industry experts and decision-makers, who may prioritize and improve these areas to maximize the advantages of the metaverse in the construction sector. These findings have practical implications for the construction industry. This research's sample size and representativeness are too small to be considered ideal, which might restrict the results' applicability to a wider population. In addition to this, the dependence on data that was self-reported opens the door to the potential of response biases as well as measurement inaccuracies.

6. Conclusion

In conclusion, the purpose of our manuscript, which was given the title "Success of Metaverse in the Construction Industry," was to investigate the relationships that exist between communication and collaboration (CC), design and visualization (DV), monitoring and maintenance (MM), and the overall success of the metaverse in the construction industry (MSC). We have gotten important results that shed light on the function of these structures in attaining success with the metaverse in the building as a result of our study and evaluation of the hypotheses. These findings may be seen below. Our findings indicate that communication and collaboration, design and visualization, and monitoring and maintenance all contribute substantially to the favorable outcome of using the metaverse in the construction sector. This suggests that increased levels of effective communication and cooperation, sophisticated design and visualization skills, and efficient monitoring and maintenance practice practices are all factors that contribute to more effectively using the metaverse. This contributes to the knowledge of how these components impact the acceptance and utilization of the metaverse in building projects when we accept the hypothesis. Because they emphasize the areas that need attention and development to maximize the advantages of the metaverse, these results have practical significance for industry experts and decision-makers. It is essential to recognize the shortcomings of our research, which include the likelihood of biases caused by the use of self-reported data and the possibility of confounding factors that were not taken into consideration. When planning for future study, it is important to consider the need to overcome these restrictions and investigate other constructions and elements that may affect how well the metaverse performs in the construction business. In general, our research findings provide empirical evidence in favor of a positive correlation between communication and collaboration, design and visualization, monitoring and maintenance, and the effectiveness of the metaverse in the construction sector. These results contribute to the expanding body of information on the utilization of new technologies in construction and may aid industry experts in making informed choices to use the metaverse effectively. With regard to blockchain, the focus of our analysis is on the metaverse ecosystem and how it may benefit from the use of this decentralized ledger technology. We investigate how the characteristics of blockchain technology, such as increased data security, transparency, and traceability, may be incorporated into metaverse applications in a seamless manner. This integration offers the potential to revolutionize transactional processes, promote confidence among stakeholders, and protect the integrity of virtual assets and interactions, all of which are all important goals. In addition, our analysis dives into the field of artificial intelligence and investigates the revolutionary impact it plays in enhancing user experiences, content development, and decision-making within metaverse settings. The combination of artificial intelligence with the technology of metaverses has the potential to provide virtual interactions with a higher level of intelligence and flexibility. Because of this, the architectural design processes, construction simulations, and real-time monitoring that are used in the AEC business may be reshaped.

The most exciting aspect of our research is that it dives into the potential for cooperative endeavors that arise at the convergence of metaverse technology, blockchain, and artificial intelligence. The AEC industry has the potential to benefit from new approaches to problem-solving in the areas of project management, design visualization, and data-driven insights if links between these breakthroughs are established. The use of communication, cooperation, and data analysis might potentially be reimagined as a result of this confluence, which spans the whole of the construction lifecycle. In conclusion, this study contributes to metaverse technology adoption research and the architecture, engineering, and construction (AEC) industry. This study examines the success factors of metaverse technology integration in the AEC sector, revealing the complex linkages that affect project efficiency, collaboration, and design visualization. This research uncovers the many elements of metaverse technology adoption, providing practical insights that may improve the AEC industry. Practitioners and stakeholders may strategically invest in metaverse technology's success determinants. This paradigm helps decision-makers negotiate technological integration, improving project results, stakeholder participation, and cooperation. This research also has practical advantages for the AEC industry. The results suggest ways to increase project efficiency, design procedures, and real-time monitoring, creating a nimbler and more inventive sector. This study guides the AEC industry in maximizing metaverse technology's potential. In conclusion, this study's major contribution resonates in academic and AEC circles. As metaverse technology continues to alter the industry, these insights guide stakeholders toward a future where innovation and efficiency merge, improving project results and transforming the built environment. In addition, these findings contribute to the developing body of knowledge on utilizing emerging technologies in other industries. It is becoming more crucial for the construction industry to embrace the promise offered by the metaverse as the construction sector continues to change. The findings of this research may provide useful information for strategic planning, resource allocation, and implementation methods, all of which are necessary to guarantee the effective incorporation of the metaverse into building projects. Construction stakeholders can navigate the challenges posed by the metaverse and embrace the opportunities it presents if they harness the power of communication and collaboration tools, design and visualization tools, and monitoring and maintenance tools. This, in turn, results in improved project outcomes, increased productivity, and increased competitiveness within the industry.

6.1. Managerial and Empirical Implications. The results of our research illustrate the necessity of effective communication and collaborative effort in harnessing the metaverse for success in the construction sector. Specifically, the findings highlight the need to enhance communication and collaborative efforts. Fostering a climate that is conducive to collaboration, putting in place communication tools and platforms, and promoting open and transparent communication among project teams should be the primary focus of managers and those in charge of leading projects. This may help enhance collaboration, the exchange of information, and decision-making, which can eventually lead to improved project results. The findings of our study highlight the need for sophisticated design and visualization skills to fully exploit the promise of the metaverse. The enhancement of design and visualization skills must be given high priority by managers when it comes to hardware, software, and education expenditures. Construction professionals may build immersive experiences, visualize designs in real time, and spot possible difficulties before they exist by employing virtual and augmented reality technologies. This results in greater design accuracy and enhanced stakeholder involvement.

Research emphasizes how critical it is to have reliable monitoring and maintenance procedures in place to guarantee the success of the metaverse when it comes to building projects. The constant monitoring of the installation of the metaverse, tracking of performance, and proactive maintenance should be given high priority by managers to resolve any technical problems or system difficulties as soon as possible. This will assist in maintaining the functioning and dependability of the metaverse platform, providing a smooth experience for users, and maximizing the advantages received from their use of the platform. The empirical data shown in our research demonstrates positive correlations between communication and collaboration, design and visualization, monitoring and maintenance, and the success of the metaverse in the construction industry. These positive interactions are essential to the success of the metaverse in the construction industry. As mentioned earlier, these results add to more empirical knowledge of how the constructs impact the adoption and utilization of the metaverse. Researchers in the future might expand upon these results by doing an identical study in various settings and fields to evaluate the degree to which the associations discovered are generalizable.

The empirical results highlight the need for assessment and improvement on an ongoing basis of the use of metaverse technology in the construction sector. In various construction contexts, researchers can do more research on the elements that impact the success of communication and collaboration, design and visualization, and monitoring and maintenance. This may give insights into certain tactics and practices that boost these structures' influence on the metaverse's success, hence allowing continual development and optimization. Although the emphasis of our research was on three essential constructions, additional aspects of the metaverse may contribute to its success in the building and construction business. Future research might investigate other structures, such as project management approaches, user acceptability, data security, or stakeholder involvement, to acquire a deeper and more complete knowledge of the intricate dynamics at play. By examining these variables, insights into the complex and multidimensional character of the use of the metaverse in the building may be gained.

The management implications of our research underline the significance of cultivating communication and cooperation, investing in design and visualization skills, and enhancing monitoring and maintenance practices to maximize the metaverse's effectiveness in building projects. Because of the practical implications, further study has to be done to test and build upon our results, evaluate their application in diverse circumstances, and investigate additional elements that impact the development of the metaverse. If players in the construction industry are willing to accept these consequences, they will be better able to traverse the metaverse environment and harness its potential for enhanced project results and development in the sector.

6.2. Limitations and Recommendations. This research's sample size and representativeness are too small to be considered ideal, which might restrict the results' applicability to a wider population. In addition to this, the dependence on data that were self-reported opens the door to the potential of response biases as well as measurement inaccuracies.

Future studies should try to incorporate bigger and more varied samples to increase their generalizability and solve the constraints that have been identified. The validity of the results might be improved by combining data from self-reports with data from objective measurements or by using various data sources. In addition, performing longitudinal research and investigating other factors would give a better knowledge of the dynamics and the impacts that last longer. Comparative research spanning many sectors or locations might provide useful insights into the elements that are distinctive to the industry and assist in the development of specialized strategies.

Data Availability

The data are not available for public or private access.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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