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Functional analysis of LIDAR technology in optimizing efficiency and sustainability in construction sector

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ABSTRACT

The construction is fraught with growing environmental and efficiency issues contributing a significant percentage toward the use of energy worldwide and carbon emission. Among several technologies that are now coming to light in the sustainable area of management of construction, one with good promise is LIDAR (Light Detection and Ranging). The purpose of this research is to fill a big knowledge gap regarding the direct impacts on construction project management from LIDAR, like cost, safety, environmental influence, precision, and efficiency. The results, therefore, demonstrate that there were significant improvements in different aspects of the system, which included time efficiency (0.27), cost-saving (0.126 average effect), safety (0.148), and reduction of environmental impact (0.372). Equally, the value of the predictive relevance $Q^2 = 0.529$ further highlights the capability of the model for accurate predictions. This study supports the view that integration of LIDAR may be a strategic enabler of sustainable practice.

1. Introduction

The construction industry is now at a very crucial moment, with increasing environmental problems [1]. On the world stage, the consumption of its energy approaches 36 %, while for its carbon emissions contribution, it stands at about 39 % [2]. This grim reality above does underline an urgent need for out-of-the-box strategies furthering sustainable development in this sector. Among the emerging assistance of technology with the potential to cause paradigm shifts, LIDAR (Light Detection and Ranging) technology comes up as a potentially useful replacement [3]. The data collection in precision and efficiency of LIDAR is at a very outstanding level, and it has great potential for affecting transformation to management approaches [4]. The prime importance in the present industry is to balance these three factors of economic viability, environmental responsibility, and social equity mutually [5]. The current paper aims to explore the fundamental contribution of LIDAR technology in improving the efficiency and effectiveness of project management in the realm of sustainable construction. This underlines that the implementation of this technology may bring in a decrease in environmental footprint and raise effectiveness for the sector. According to studies, initiatives such as this have the potential to reach up to 20 % in savings of expense and labor [6,7].

Relatively, this LIDAR technology thus grows to be a vital aspect in environmental management because of being able to provide the much-needed support for biodiversity assessment, conservation effort, and management of natural resources. Just the example is in the fact that LIDAR technology can penetrate through forest canopies, hence true estimation of tree height, biomass, and canopy structures within forestry [8]. This data is hence of great significance in estimating the carbon stock, sustainable management of the forest, and monitoring changes that can take place over the long duration [9]. Besides, LIDAR mapping represents one of the new applications that contribute to better habitat restoration, erosion monitoring, and flood risk management in littoral zones [10].

In addition to this, LIDAR technology contributes to the change in methods of managing agricultural sustainability [11]. Precision

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farming, to a much greater extent, benefits from LIDAR data since it can avail comprehensive crop and terrain data when farming with minimal input and boosted output levels [12,13]. Agricultural practitioners can make use of this information to optimally develop their irrigation systems, create proper tactics for rotation of crops, and measures for soil conservation all will contribute to the rise in productivity of agriculture and, hence, to the reduction in ecological impact that generates improved economic opportunities [14,15].

Sustainability management comprises social equity and well-being, together with environmental and economic considerations. LIDAR technology secures and improves communities through infrastructure development and disaster management [16,17]. The application of LIDAR data in urban areas, based on this, would mean the designing of green spaces, transport networks, housing developments, and any kind of future infrastructure that befits environmental sustenance and at the same time is accommodative to all its dwellers, hence enhancing social integration and overall well-being [18]. Moreover, improved topographic details provided by LIDAR exhaustive terrain models may facilitate the improvement in preparedness and response strategies of the disaster-prone region, resulting in life savings and minimization of the socioeconomic consequences of such catastrophes [19,20].

While the benefits from such technologies could be enormous, the fact that there must be a large investment at the outset and technical complexities are such that everyday sustainable management would require specialized knowledge presents clear difficulties [21,22]. However, with the large development of technology and the available sources, such issues get less pressuring. With the advancement in technology that facilitates greater precision of their methods, allowing them to be cheaper, the use of such equipment would expand. Prospective LIDAR applications in sustainable management begin to look quite promising [23,24].

The construction industry is currently grappling with significant environmental challenges, including excessive resource consumption, carbon emissions, and inefficiencies in project execution. Traditional methods often fall short in addressing these issues, leading to the necessity of adopting more advanced technologies. LIDAR has emerged as a potential game-changer by offering precise data collection and analysis capabilities that can enhance construction practices. Despite its promise, the integration of LIDAR in construction is hindered by limited understanding and application. This research aims to bridge this gap by systematically exploring the potential of LIDAR technology to improve environmental sustainability in construction projects. The objectives include identifying the specific challenges LIDAR can address, evaluating its effectiveness in real-world scenarios, and providing a framework for its broader adoption within the industry. The objective is to evaluate the vital importance of the technology of LIDAR clearly and critically for advancement in the ecological aspects of construction projects. This research will attempt to demonstrate the huge benefits that LIDAR technology leverages to improve project results, reduce expenses, and maximize resource allocation by offering an image and conceptual structure of how these technological advancements connect to improved methods in sustainable building.

However, with the apparent importance of integrating advanced technologies in the sustainable management strategies, there is a clear lack of understanding and applying LIDAR persistently within the construction domain. This clearly draws the line before the eyes of the readers, showing very limited focus of the current study only on the direct implications and benefits of LIDAR technology within the scope of construction management, rather than its widespread use in environmental science and urban planning. The paper represents a new contribution in the field of LIDAR technology and its application to the sustainable management practices of the construction industry. This research aims at establishing the relationship between the technological potential and its practical application through technical assessment of LIDAR capability, in combination with practical insights drawn from case studies and empirical data. In this way, applying this comprehensive approach is a manner not only to answer to the existing research gap but also to offer an answer in the academic voice of sustainable construction by suggesting the implementation of LIDAR technology more widely as one of the means to reach a future that is more environmentally sustainable.

1.1. Key implementation gains

To further analyze its diversifying applications, the case studies that have been provided are an emblematic report of the significant impacts of LIDAR technology to the construction industry, in this case, covering Projects A through to E and reporting on the application of LIDAR in various aspects. However, ranging from all these, a very large variety of projects come, such as structures for commercial and residential use, infrastructure, etc. Herein, the role of LIDAR technology becomes very central for increasing the accuracy, effectiveness, and safety of such projects [25].

- **Project A** is a telling example of how significant time can be saved with the use of LIDAR technology. In regular types of surveys, for instance, the span within which LIDAR was implemented in this vast infrastructure development project to facilitate site evaluation for strategic planning was cut by a very huge margin [26,27].
- **Project B** is one of the examples of commercial construction projects where LIDAR was used for its cost reduction. Integrated with the LIDAR technology, which provides accuracy in estimation and optimization of the stages in the construction process, project B was a large success in relation to cost and waste reduction [28,29].
- **Project C** illustrates the capabilities of LIDAR for accuracy to make sure results fall in line with project specifications. An accurate LIDAR proved to be a key ingredient in this residential development project, allowing for the smooth integration of complex architectural features and the elements of the landscape with a minimum amount of error and no excess labor [30,31].
- **Project D** illustrates the case where environmental benefits can accrue due to the use of LIDAR technology in construction planning. The project showed sustainable construction methodologies with high efficiency in the use of resources, minimizing site disturbance, resulting in the major reduction of the carbon footprint created [32,33].
- **Project E,** which focused on the improvement of infrastructure and utilities. Herein, the LIDAR technology that this project has used affords safety. Thus, technologies for comprehensive risk assessment allow for the taking of measures beforehand for hazard identification and mitigation. For this, there is a sharp reduction in on-site incidents [34,35].

1.2. Cost savings

Fig. 1 economically associated with the integration of LIDAR Technology with Construction Projects gradually reduces the costs and briefly tells the benefits. This graph represents the cost development in the long run of projects based on a comparison of traditional surveying techniques and those based on LIDAR. This can be seen from the following line graph, which indicates a decreasing trend in costs related to technology-project deployment and reflects short-run financial savings with decreasing long-run expenses gradually [36]. In essence, these are savings brought about by more precision and accuracy, made possible by LIDAR in the entire stages of planning and executing the project, with remarkable drastic cuts in expensive revisions and delays. Further, the use of LIDAR technology in the processes of surveying and mapping means that material wastage and general costs of construction pursuits are lowered [37]. The visual representation hence proves evidence to the high financial benefits offered by LIDAR technology and hence confirms it to be a key enabler in cost-effective and effective construction project management [38]. The diagram below explains the

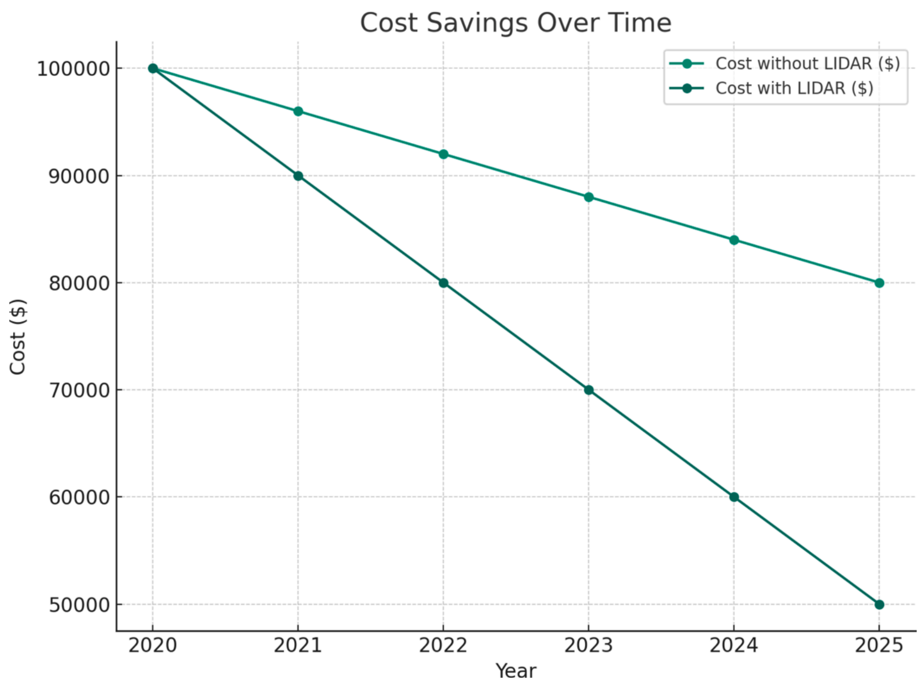

Fig. 1. Cost savings by implementing LIDAR in construction sector.

context of LIDAR technology as an immensely important investment in finances to bring forward eco-friendly and cost-effective ways of construction by accurately visualizing data [39]. The actual economic benefits are briefly represented in the line graph, showing a slow drop in costs when the use of this technology is introduced in construction projects. The graph represents the variation of cost in the long term of the projects through traditional ways of land surveying and with the use of LIDAR technology [40]. From the line graph, it is obvious the trend; costs of the projects that use the LIDAR technology are constantly going down, not just the immediate financial gains, but a progressive reduction in the amount of money spent. Costs incurred through higher precision and better productivity that LIDAR improves through better execution and project planning both in the preparation and on-the-job processes, reducing expensive rebuilds and delays [41]. The involvement of the technology with the mapping processes also brings down the material wastage, adding to the cost of construction [42]. This diagrammatic representation is the proof for substantial monetary benefits that LIDAR technology brings in, hence further describing its status as an indispensable enabler to manage cost and time efficiency in the construction project development. The graphic shows that investment of their money is vital to the progress of environmentally sustainable and economically viable construction methods, using accurate visualization

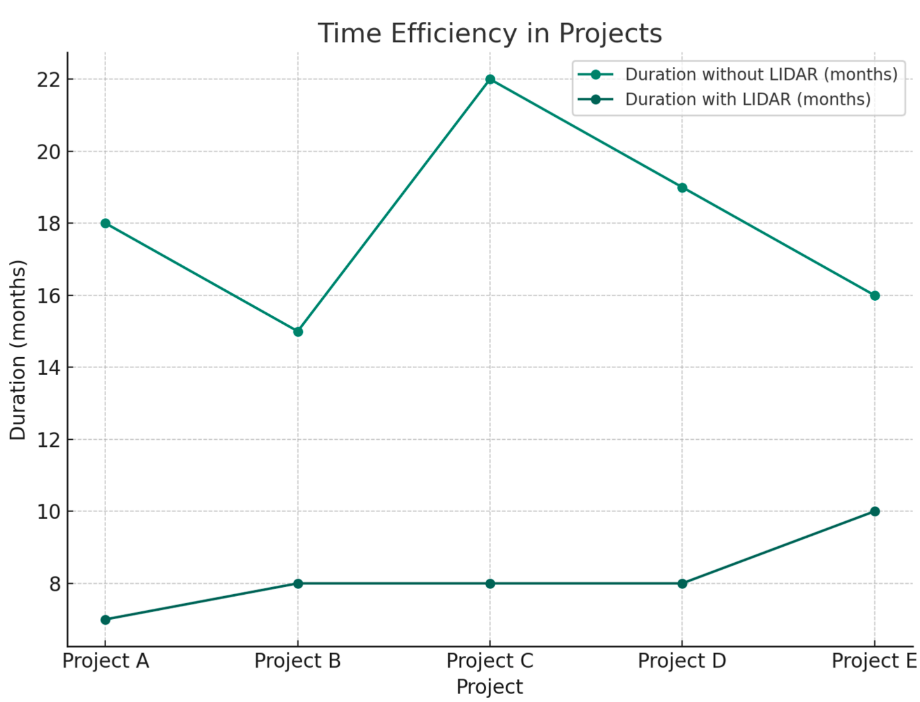

Fig. 2. Time efficiency by implementing LIDAR in construction sector.

of data carried out by LIDAR technology.

1.3. Time efficiency

As indicated through the comparison of the time charts shown in Fig. 2, LIDAR technology used in construction projects indeed brought much improved efficiency in time management. This graphic comparison of the project durations carried out with and without the assistance of LIDAR shows that completion time has always been reduced for a whole range of finished projects [43]. Introducing technology as a solution to building projects will cut down the time the survey and plan preparations of a project normally take [44]. They consequently lead to short project time, as per the bar graph. This efficiency of time would, in turn, allow for a faster transition, thus giving an upper hand in the dynamically unbroken construction field where time is required, not only for reducing administration costs, but as the saying goes, “time is money” [45].

1.4. Accuracy improvement

Various construction sites are shown by Fig. 3 of how the measurements improved with the help of LIDAR technology [45]. These graphics will show the improvement. Each map point will compare parameters before/after LIDAR to show an accumulated project %. The trend lines across these places show that LIDAR improves accuracy. This would conclude that the presence of accurate topographical and measurement data takes place in LIDAR [46]. This information must be accurate so that there is no misinterpretation leading to errors in construction. It also ensures that project requirements are met precisely, reducing costly changes and delays [45].

1.5. Safety enhancements

Fig. 4 has been applied to illustrate how the safety on-site has increased due to the application of LIDAR technology. The diagram shows the distribution of incidents that occurred in Project A before and after the implementation of the technology [47]. These show a great decrease in the number of incidents, and the improvement is attributed to better risk assessment using LIDAR. Throughout the project execution course, the LIDAR technology will allow for the early detection of suspected risks through effective analysis of the site. This will, in return, make it easy to take proactive actions to control the possible risks [48]. This graph enhances the critical significance of LIDAR in boosting safety measures at the construction site, which protects the life, and the welfare of the staff engaged in construction work [49].

All graphical analyses explain the different benefits of LIDAR technology in the construction sector, and, in one word, justify its importance toward improvements in productivity, precision, environmental friendliness, and human security [50]. The use of LIDAR technology, in contrast, is tantamount to a revolution in the field and gives a clear starting indication towards better management of the construction work [51].

1.6. Comparison with other studies

The assessment of predictive relevance and importance-performance in this study provides insights that align with and extend the existing literature on technology adoption in the construction industry. In comparison to previous studies, which often emphasize the critical role of technological readiness and management support in driving successful implementation, our findings corroborate these factors as key drivers but also highlight the nuanced role of external environmental factors. For instance, studies by Felipe, Leidner [52] and Lu and Ramamurthy [53] demonstrated the significance of internal organizational capabilities in predicting successful technology integration, yet our model also underscores the impact of industry regulations and market conditions, factors that were less emphasized in prior research.

Furthermore, while Phadermrod, Crowder [54] employed a similar importance-performance analysis, their results predominantly focused on the internal performance metrics, such as employee readiness and training efficacy. In contrast, our study broadens the scope by incorporating external variables, revealing that while internal factors are critical, external pressures and supports also significantly shape the success of technology adoption. By situating our findings within the broader context, it becomes evident that while there is a consensus on the importance of certain internal factors, our research contributes a more

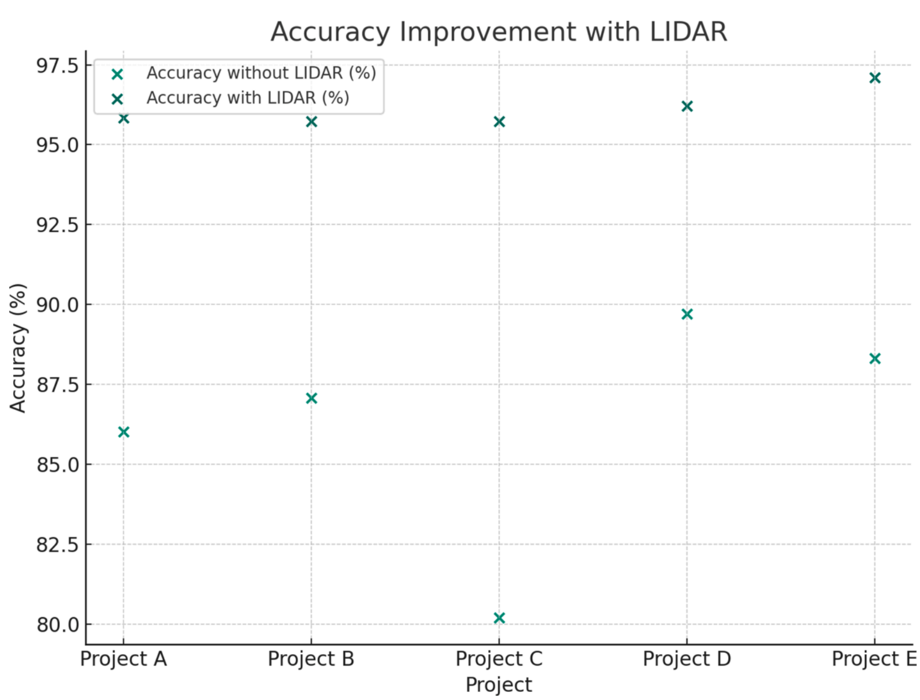

Fig. 3. Accuracy improvement by implementing LIDAR in construction sector.

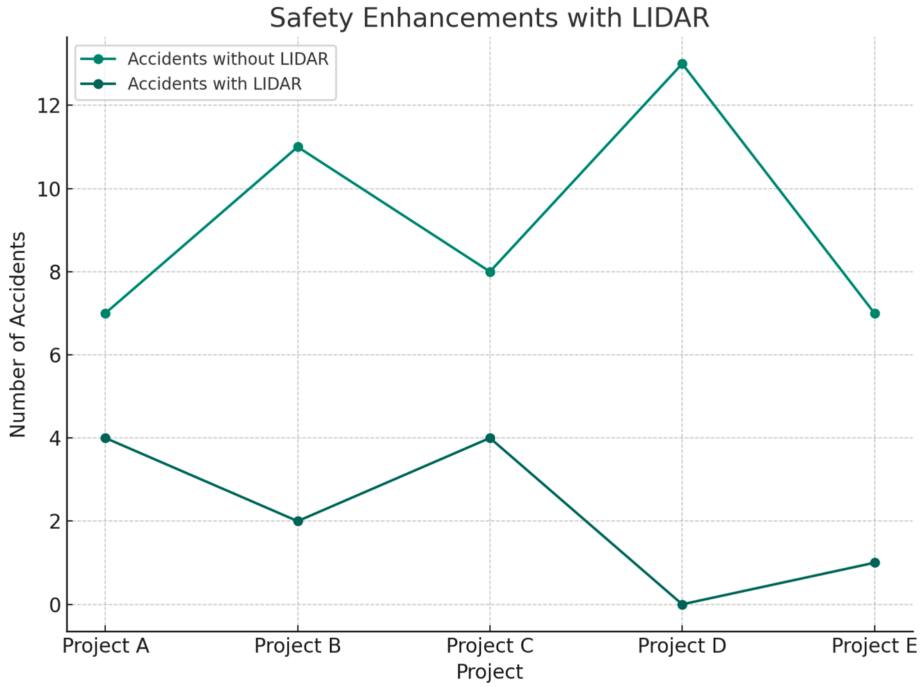

Fig. 4. Safety enhancements by implementing LIDAR in construction sector.

comprehensive understanding by integrating both internal and external influences, thereby offering a more holistic view of what drives technology adoption in the construction industry [55]. This expanded perspective not only aligns with the existing body of work but also provides new avenues for future research to explore how external factors interact with internal capabilities to influence technology outcomes [56].

1.7. Methodology

This methodology informs how the systematic approach is initiated with a very good conceptual framework established through a comprehensive review of the literature as shown in Fig. 5. Subsequently, structured data acquisition is made to obtain relevant information. This questionnaire is framed parallel to the point that formulating a hypothesis guides empirical inquiry. Then, using an exploratory factor analysis, the latent variables are disclosed, and the finding validated through a statistical test. Following this, a SEM analysis is performed to elucidate the intricate interconnections between the variables. From the end of this iterative process, a model SEM is developed and subjected to the final comprehensive assessment of the convergent and discriminant validity of the measures to obtain the accurate and distinct measure. One major contribution this study makes is developing a comprehensive model framework, a final deliverable out of such a rigorous process. While the snowball sampling method was chosen for its effectiveness in reaching specialized populations within the construction industry, measures were taken to mitigate its inherent limitations regarding representativeness. To enhance diversity among the survey respondents, initial participants were selected from a broad range of backgrounds, including varying geographic locations, organizational roles, and levels of experience in the construction industry. These initial participants were carefully chosen to include individuals from different sectors, such as commercial, residential, and industrial construction, as well as from both large firms and smaller, independent contractors. Furthermore, participants were explicitly encouraged to refer individuals who not only matched the criteria for expertise but also represented diverse demographic groups, including different genders, ages, and ethnic backgrounds. This approach aimed to ensure a more comprehensive and inclusive dataset, capturing a wide array of perspectives within the industry. Additionally, the sampling process was monitored, and adjustments were made as necessary to avoid over-representation of any single group, thereby striving to achieve a balanced and diverse sample.

1.8. Identification of factors and expert validation

From literature identifies the potential variables to be used in the study and is presented in the factor identification section of the methodology, whereas the systematic literature review is taken up for an extended literature review subject to peer-reviewed publications, reports from the industry, and theoretical frameworks adopted to consider both established and emerging aspects that could influence the research. The first list of criteria was stringently validated after the literature review. The help taken for this is 10 industry experts of great practical experience and exposure in relevant sectors. The experts in this criterion are selected, based on professional experience and contributions of value to the field, being able to make valuable comments on relevance and the use of derived criteria. The literature review variables are, therefore, handed for validation to professionals in a structured phase of consultation. Experts were asked to critically examine the relevance, influence, and the setting feasibility of each factor by interviews and group discussions. This procedure has been followed to ensure the final components to be built based on academic research and industry standards. Then, experts were invited for advice on the merging of relevant criteria, removal of duplicate or unnecessary information, and addition of any component which would have improved comprehensiveness of the study but was neglected. These use the collaborative filtering method on the most important elements, making the study easier and more relevant to academic and industrial partners. Revision of the factor yielded intellectual and practical knowledge factors. The unified set of criteria influences the questionnaire design and analysis of the data. Academic rigor and validation through the industry of the research is ensured, which remains to be one that supports strong, relevant results and useful insights for the field.

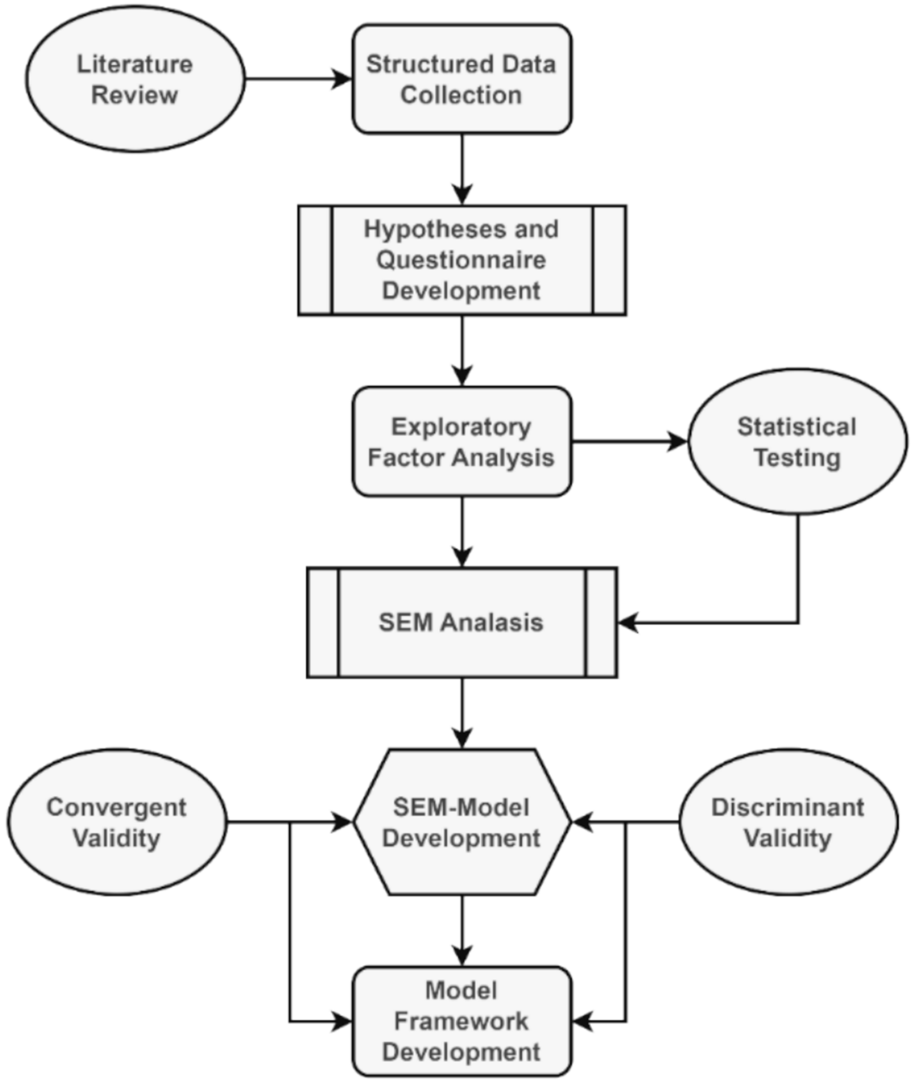

Fig. 5. Flow chart of the study.

1.9. Expert selection and validation process

For the validation of factors identified through the literature review, a panel of 10 experts was meticulously selected based on their extensive experience and expertise in the construction and sustainable technology sectors. The selection criteria included professionals who have at least 15 years of industry experience, hold senior positions such as project managers, civil engineers, and sustainability consultants, and have a proven track record of working with advanced construction technologies, including LIDAR. Additionally, some experts were chosen from academic backgrounds, possessing doctoral degrees and significant research contributions in construction management and sustainable practices. The validation process was conducted through a two-round Delphi method, ensuring a systematic and consensus-driven approach. In the first round, the experts were provided with a comprehensive list of factors derived from the literature review and were asked to evaluate each factor's relevance and clarity using a structured questionnaire. They were also encouraged to suggest additional factors or modifications based on their professional insights. Feedback from the first round was analyzed and used to refine the list of factors. In the second round, the revised list was redistributed to the same panel for further evaluation and confirmation. Consensus was achieved on the critical factors to be included in the study, ensuring that the framework is both comprehensive and grounded in practical applicability. This rigorous validation process enhanced the reliability and validity of the research instruments, providing a robust foundation for subsequent data collection and analysis.

1.10. Data collection

Carrying out the development and distribution of a questionnaire that measures opinions and views on Rawalpindi, Pakistan, was a key focus in the methodology section. The development of the questionnaire was preceded by a thorough review of existing literature. A 5-point Likert scale was constructively used to capture the subjects' nuanced responses, including relevant factors and variables. The survey was designed to be administered to a pool of 219 likely volunteers, targeting both novices and experts with comprehensive knowledge in the research area. The chosen distribution strategies aimed to ensure maximum outreach and a representative cross-section of the population.

As a result of this distribution effort, 101 completed replies were received, yielding an estimated response rate of 46.12 %. This rate is significant, especially the survey's demographic focus and specialized content. A high response rate is often indicative of high interest and involvement from respondents, important in both academic and market research contexts [24]. This response rate, considered acceptable by previous academic standards, suggests that the data collected may provide vital insights for further investigation. The effectiveness of the questionnaire's creation and distribution process, as evidenced by the high response rate, further legitimizes the research technique. This level of participation from the study's subjects sets a solid foundation for the next stages of inquiry.

1.11. EFA and statistics analysis

Further assuring that the dataset is suitable for factor analysis and for wide consideration of the item features, the procedure of carrying out the exploratory factor analysis (EFA) includes more statistical tests and evaluations. These procedures used Kaiser-Meyer-Olkin (KMO) measures of sample adequacy, Bartlett's Test of Sphericity, and analyses of item means, variances, inter-item covariances, and correlations. All these are considered in the following sub-sections:

The KMO gives the measure of sampling adequacy of the data in question on its factor analysis. In particular, the KMO portrays the proportion of variance between the variables that may be common variance to all the variables. The value will be nearing 1; a greater percentage of variance is shared between variables, so it will give us clear indications that the data is fit for factor analysis. The maximum value of the index is 1, and the index will have different values ranging from 0 to 1. It is generally accepted that an EFA may be regarded appropriate if the KMO value is more than 0.6. Basically, the test helps in testing the null hypothesis in which the matrix of the correlations is basically an identity matrix. If that would be correct, then these variables are unrelated and should not be used to conduct factor analysis. If the result of the test is statistically significant ($p < 0.05$, for example), then the null hypothesis shall be rejected. This implies that the variables are highly correlated with each other for factor analysis and hereby give reason for the use of exploratory factor analysis (EFA). This study analyzes item means and variances to see the primary trends and variability in the data. Though the item variances show the level of variability in replies, the response that is how the respondents differ in their response, item means will tell what the average reply to each of the questions is by the researcher. Item means can also be referred to as item averages.

These relations are determined with items through either covariances or inter-item correlations. Since covariances measure the amount of change that takes place together between two random variables, one can consider that covariances are dependent on the scale of the variables measured. The computed covariance between the variables also gives correlations that provide a standardized measure of the strength and direction of relationships sustained between the items. The high intercorrelations point to the possibility that maybe these items are measuring the same underlying concept and, therefore, maybe they are candidates for grouping under the same factor. Maybe this is so. These statistical measurements and evaluations that EFA approach includes, therefore, dig deeper into the study in that it ensures the data are fit for factor analysis and gives a complete understanding of the characteristics of items and easily factors that underlie the data. This is taking place simultaneously, devising an approach to EFA using PCA for the extraction of the initial components, fixed loading criteria, and Varimax rotation for better interpretability. It also worked on the significance of the item along with further testing of the KMO measure, the Bartlett test of Sphericity, in addition to detailed item analysis.

1.12. SEM analysis

Structural Equation Modeling (SEM) is a powerful statistical technique that allows researchers to examine complex relationships between multiple variables simultaneously. In this study, SEM was used to understand how different factors, identified through our research, interact with each other and contribute to the overall outcomes in the construction industry.

1.13. Measurement model

This phase evaluates the reliability and validity of the measurement model in Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 4. Indicator reliability was assessed with CR scores greater than 0.7, and AVE values at 0.5 indicated more than 50 % of the indicator variance was accounted for, representing construct validity [57]. The Heterotrait-Monotrait (HTMT) ratio of correlations indicated discriminant validity with values less than 0.9, confirming that different phenomena were measured by the constructs [58]. Ensuring that the indicator accurately assessed its corresponding component was crucial for the integrity of the measurement model.

1.14. Structural model

The model evaluation tested construct linkages and studied hypotheses using path coefficient and bootstrap analysis. Bootstrap analysis with 5000 resamples estimated Standard Errors (SE) and was instrumental in determining the strength and direction of the correlations for each path coefficient. T-values exceeding 1.96 at 5 % significance for a two-tailed test and p-values below 0.05 were deemed statistically significant. This methodology facilitated advanced SEM analysis to examine the theoretical relationships in the model under the study's conditions using SmartPLS 4.

1.15. Predictive relevance

Blindfolding is essential in measuring predictive relevance in SmartPLS 4 PLS-SEM. This method systematically omits data points, estimates the model with the remaining data, and predicts the omitted data. This process is repeated until all data points have been predicted, generating the predictive relevance metric, Q2. Positive Q2 values indicate successful prediction of endogenous constructs, with values greater than zero suggesting model forecasts surpass baseline mean predictions. This assessment evaluates the model's ability to predict unseen or omitted data, potentially enhancing the model's forecast accuracy and rendering the theoretical framework under evaluation more viable.

1.16. Importance-Performance index

SmartPLS 4 calculates an Importance-Performance Analysis (IPA) matrix for PLS-SEM by assessing model construct importance and performance. This involves examining path coefficients for importance, indicating the strength and relevance of construct links, and construct scores for performance, showing how effectively each construct is realized in observed data. The IPA matrix segregates components into quadrants based on importance and performance to identify areas for improvement and strategic focus. Constructs that are crucial yet underperforming require immediate attention, while those that are vital and performing well are considered strengths. This strategic tool aids decision-makers in concentrating resources and efforts to enhance model efficacy and achieve objectives.

2. Results and analysis

2.1. Demographic details of respondents

Fig. 6 shows the number of years of experience the experts involved in the purpose of the study had regarding their work. This was to help refine the variables identified during the literature review. The pie chart sections indicate the number of specialists having years of experience that specify from 10 to 15. This will result in a more even and coherent mix of the people coming into this study, in the mid-career to late career stages and with in-depth expertise and knowledge. Besides, the fact that the way of refining the factor is based on a very exhaustive and broad

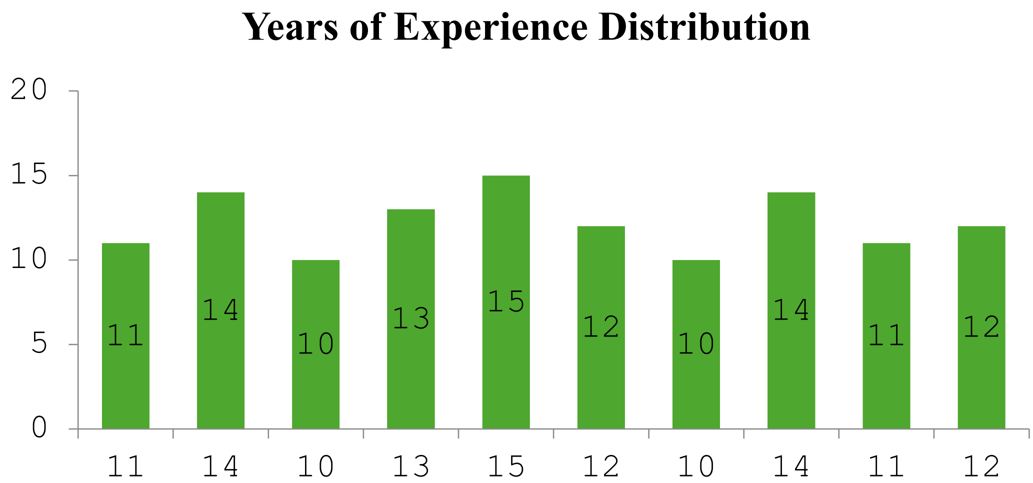

Fig. 6. Experience of 10 respondent of qualitative interviews.

array of professional experiences in the sector, it is very important to present the fact that a variety of perspectives are of the essence.

Demographics information includes clear cohorts classified with gender, level of expertise, and profession shown Table 1. The analysis gives that there are men who contributed to 93.1 % while there are females who contributed to 6.9 %; in this case, they total 94 and 7, respectively. This shows that the group is going to highly predominate with men. The group is going to be subdivided into five subgroups based on people's experience. Out of the total, 23 individuals, or 22.8 %, have from 0 to 5 years of experience. Twenty of the group are professionals, 6 to 10 years 19.8 % of the total. Sixteen members have experience ranging from 11 to 15 years in the total group 15.8 % of the total. There are 12 individuals who represent about 11.9 % of the entire workforce and have an experience range of 16–20 years. The largest segment is 30 respondents with a percentage of 29.7 %, having more than 20 years of experience. This only goes to show that the distribution represents high variation in the level of competence but signals important emphasis on those who have vast experience. From a professional perspective, they are divided into three roles: project managers 35 persons, which is 34.7 % of the whole group. 41.6 % of persons represented were of a subset of forty-two persons sub-professionally. Under the post of safety engineers, twenty-four make up 23.8 % of the whole group. Level of distribution: this level of distribution focuses majorly on a very high proportion of jobs related to engineering and project management within the business.

2.2. Identified factors

The subjects of great importance in relation to the context of project management include time efficiency, cost savings, safety improvement, environmental impact, and accuracy improvement, as these are classified among the significant aspects shown in Table 2. These are further divided into eight variables that provide precise details of the techniques or elements that might be used in the achievement of progress or improvements. For instance, cost saving encompasses strategies like building optimization and reduced reliance on physical models, all aimed at reducing expenses. The main aim of Safety Enhancement is to increase overall safety through the implementation of safety measures aided by technology advancement, such as improved training and planning. Environmental Impact aims at reducing adverse environmental impacts through the optimum use of resources and effective waste management. Enhanced Accuracy seeks to increase the precision and reliability of project outputs using improved measurement, documentation, and visualization techniques. The core concept behind Time Efficiency is accelerating project timelines and enhancing collaboration to reduce wasteful practices. This structured method allows individuals to gain a comprehensive understanding of the various aspects of project management and highlights the interconnectedness of these factors in pursuing successful projects.

Table 1
Demographic details of respondent of main questionnaire.

Category	Subcategory	Count	Percentage
Gender	Male	94	93.1
	Female	7	6.9
Experience	0 to 5 Years	23	22.8
	6 to 10 Years	20	19.8
	11 to 15 Years	16	15.8
	16 to 20 Years	12	11.9
	Over 20 Years	30	29.7
Profession	Project Manager	35	34.7
	Civil Engineer	42	41.6
	Safety Engineer	24	23.8

2.3. Exploratory factor and statistical analysis

In the Exploratory Factor Analysis (EFA) results presented in Table 3, several items exhibited cross-loadings, where they loaded significantly on more than one component. To address this, a systematic approach was adopted for item assignment to specific components. The primary criterion used for assigning items was the magnitude of the factor loading. Items were assigned to the component where they demonstrated the highest loading, provided that the difference between the highest and the next highest loading was at least 0.1. This threshold was chosen to ensure a clear distinction between the components and to reduce ambiguity in the factor structure. For items with smaller differences between loadings, additional considerations were applied, such as the conceptual alignment of the item with the component's underlying construct and its consistency with the overall theoretical framework of the study. Items with ambiguous loadings that could not be clearly assigned were further analysed to determine whether they should be excluded from the final factor structure or retained based on their relevance and contribution to the component's interpretability. This approach allowed for a more precise categorization of items into distinct components while maintaining the integrity and interpretability of the factor structure. The clarified criteria helped ensure that each component represented a coherent set of items, thereby strengthening the validity of the subsequent analyses.Table 4 shows the KMO and Bartlett's test results indicating the data set acheived the minimum criteria of 0.7.

Based on the results of the EFA using Principal Component Analysis

Table 2
Identified constructs and 8 variables are finalized after literature review and expert opinion.

Constructs	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6	Variable 7	Variable 8
Cost Saving	Reduced need for physical prototypes	Efficient resource allocation	Decreased labor costs	Lower rework expenses	Enhanced project planning	Savings from reduced project delays	Minimized legal liabilities from errors	Optimization of construction schedules
Safety Enhancement	Reduced site accidents	Improved worker training	Enhanced emergency planning	Remote monitoring capabilities	Better risk management	Safer equipment operation	Improved site access planning	Enhanced site security and surveillance
Environmental Impact	Less site disturbance	Improved sustainability planning	Enhanced habitat assessment	Optimized material usage	Reduced carbon footprint	More efficient water use	Decreased impact on local wildlife	Better management of waste materials
Accuracy Improvement	Enhanced measurement precision	Improved quality control	Better site visualization	Increased data reliability	Detailed as-built documentation	Precision in material fitting	Error reduction in design and execution	Facilitates digital twin creation
Time Efficiency	Faster data collection	Accelerated project timelines	Streamlined design phase	Reduced manual tasks	Enhanced project coordination	Quick stakeholder updates	Efficient use of project management tools	Reduction in time spent on inspections
Innovation	Innovative design processes	Use of cutting-edge technologies	Integration of smart systems	Adoption of sustainable materials	Collaborative project platforms	Enhanced data analytics for decision making	Streamlining regulatory compliance	Leveraging AI for project management

Table 3
EFA analysis conducted on main questionnaire results.

	Component 1	2	3	4	5	6
IMP12	0.662					
IMP33	0.660					
IMP26	0.583					
IMP18	0.571					
IMP8	0.537					
IMP6	0.516					
IMP21	0.503					
IMP4						
IMP15						
IMP28						
IMP16						
IMP20		0.654				
IMP34		0.642				
IMP11		0.593				
IMP24		0.581				
IMP29		0.550				
IMP9		0.512				
IMP27						
IMP2			0.671			
IMP7			0.613			
IMP22			0.570			
IMP14						
IMP25						
IMP32						
IMP19						
IMP5				0.690		
IMP31				0.611		
IMP17				0.525		
IMP3				0.504		
IMP13						
IMP23					0.736	
IMP10					0.507	
IMP30						
IMP1						0.853

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 20 iterations.

Table 4
KMO and Bartlett's test.

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.902
Bartlett's Test of Sphericity	Approx. Chi-Square	6502.687
	df	561
	Sig.	0.000

(PCA) with Varimax rotation, six components have been identified by analyzing their scree plot and eigenvalues. The appearance of a clear elbow in the scree plot after the first component suggests that this variable explains a much larger share of the observed variability in the data compared to the succeeding variables. The identified factors from literature and Various items (IMP12, IMP33, IMP26, and others) demonstrate significant loadings on separate components. This observed trend offers empirical proof that the items in question are likely to be dependable indicators of the basic factors they seek to evaluate. The reliance of each item on a single component reinforces the trustworthiness of the extracted components and indicates the existence of separate factor structures. Fig. 7 shows the scree plot which is generated after conducting exploratory factor analysis.

Table 5 shows summary of the item statistics table provides a detailed overview of the means, variances, the correlations of the items. The average score of 4.245 for each item indicates that most respondents gave these things higher marks. The covariance and variance of the items are used to quantify the relationship between the items and the extent of their variability, respectively but the subsequent component explains a far less proportion, namely 3.284 % of the variation in total. As each subsequent component contributes a decreasing proportion of the total explained variance, this pattern persists. After the sixth component extraction, the sum of loadings is the total variation accounted for by the components that were extracted, which amounts to 67.222 %.

Table 6 shows the correlation among the component counts and the Eigenvalues for the components. The graph shows a sudden decline after the first part, followed by a slow rebound starting from the second part. The visual representation confirms the results derived from the eigenvalues, highlighting the significance of the first component in explaining the variations found in the dataset.

The study results demonstrate that the main aspect accounts for the highest proportion of variation, implying that most of the construct being evaluated may be attributable to this one underlying element. The other components provide additional explanatory capacity, albeit it is somewhat less considerable.

2.4. SEM analysis-measurement model

First, the EFA analysis produces six categories. The sixth excluded factor category is due to single variable standing in the group. The main factors may be cost savings, safety enhancements, and the level of environmental impact, improvement of accuracy, and time efficiency. Table 7 above shows the Cronbach Alpha, Composite Reliability (Rho-A and Rho-C), and Average Variance Extracted. Cronbach's Alpha—this is

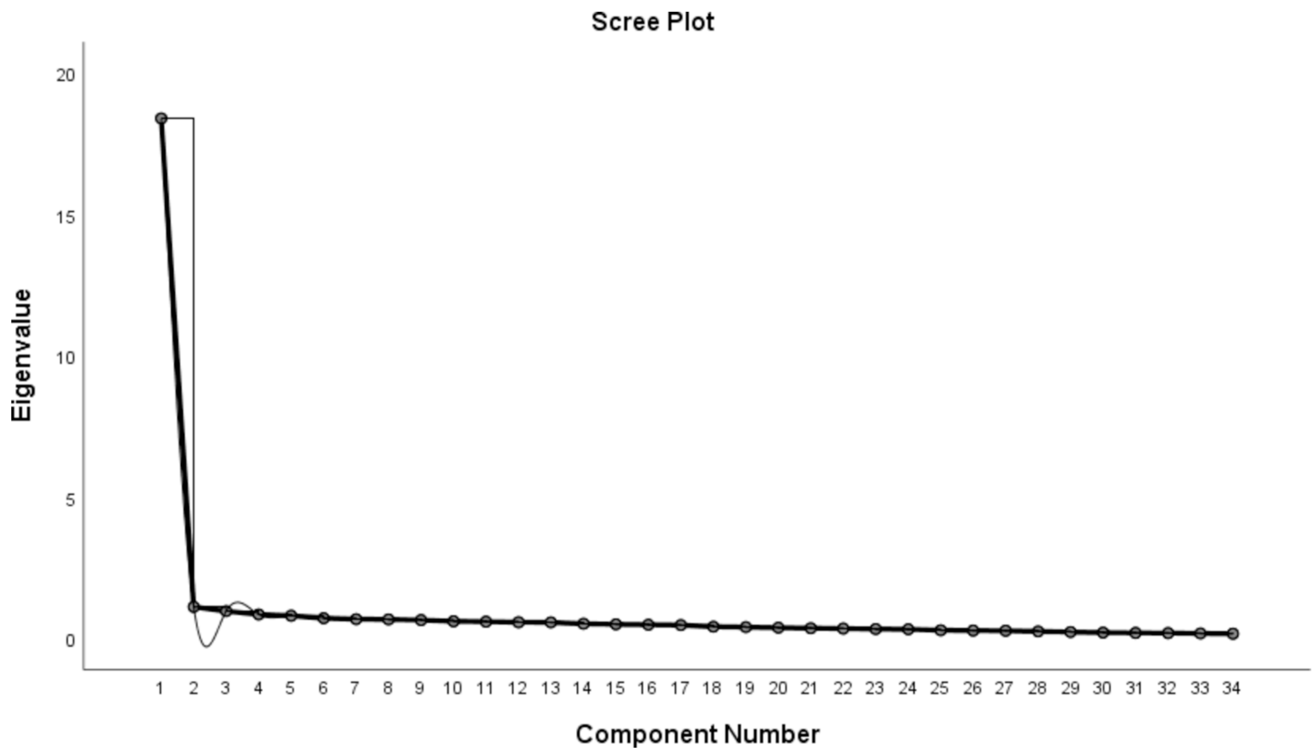

Fig. 7. Scree plot of factors.

Table 5
Summary item statistics.

Summary Item Statistics	Mean	Minimum	Maximum	Range	Max / Min	Variance	N of Items
Item Means	4.245	4.072	4.540	0.468	1.115	0.006	34
Item Variances	0.891	0.455	1.067	0.612	2.343	0.011	34
Inter-Item Covariances	0.468	0.049	0.672	0.623	13.854	0.009	34
Inter-Item Correlations	0.523	0.089	0.697	0.609	7.876	0.006	34

a type of measure of internal consistency showing how similar objects are. Accordingly, the coefficient measures the scale reliability that hence is usually derived. The values above 0.7 can be accepted if consistently the items are reflecting the concept. All construct values stand above 0.7 and cover components in the range of 5 factors. The composite reliability (rho-a and rho-c) would be computed if the reliability comes from different markers which are latent but belong to one construct. These measures of reliability of test items in internal consistency have been found to be more reliable than Cronbach's alpha, especially in structural equation modeling. Rho-a uses factor loadings, while rho-c uses standardized loadings of factor loadings and of the items. The acceptable level of values beyond 0.7 has been accepted to be presented dependability. Average Vari: This is a measure that expresses the indicator variance of a latent variable against the measurement errors. Construct validity: It provides information to what extent variability is created in the construct by its components. Construct is acceptable with the variation of more than 50 % of the component. Generally, from the table above, there is internal consistency and reliability between constructs, which is noted to be good, with both Cronbach's Alpha and the composite reliability score being above 0.7. Time Efficiency contributed the least AVE value among elements, which was 0.649, while Cost Savings had the highest, with 0.785. But all constructs have explained a lot of variation, indicating that even if the elements within the constructs might explain variation better, they still have good construct validity.

2.5. *SEM analysis- structural model*

The findings, as tabulated in the Table 8, give a quantitative analysis of the relationship between the variables' number and implementation with the LIDAR technology. Considering the public audience and the information's credibility presented, the extracted benefits from the implementation of these factors would include time efficiency, cost reduction, improvement of safety, reduction of environmental impact, and enhancement of accuracy. It has details for a factor and assesses the standard deviation (SD), T value, P value, observed (O) mean effect, and model-predicted (M) mean effect. The model, predicted by the mean cost effects, saving and observed, is at 0.126, with a standard deviation of 0.013. This factor has a statistically significant relationship with LIDAR implementation, the T value of 9.679 and a P value of 0 at one point or another, indicating a substantial effect. The mean effects of safety enhancements are 0.148, as predicted by the model, with a standard deviation of 0.015. The obtained T value of 9.609 and the associated P value clearly establish added credence to the fact that there is statistical significance, and hence, the LIDAR technology would be highly beneficial for safety enhancements. It was also established that the observed and model-predicted mean effects of the environmental impact are significantly higher at 0.372 and 0.371, respectively, having a standard deviation of 0.02. Thus, it is statistically significant, with an extremely robust relationship with the implementation of LIDAR, the T value of 18.474, with a P-value at zero. The improvement in accuracy

Table 6
Component analysis of factors with Eigen values.

Component	Initial Eigenvalues			Extraction Sums of Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	18.404	54.128	54.128	18.404	54.128	54.128	5.665	16.661	16.661
2	1.117	3.284	57.413	1.117	3.284	57.413	4.659	13.704	30.365
3	0.966	2.840	60.252	0.966	2.840	60.252	4.159	12.232	42.597
4	0.850	2.499	62.752	0.850	2.499	62.752	3.690	10.852	53.449
5	0.805	2.367	65.119	0.805	2.367	65.119	3.021	8.885	62.334
6	0.715	2.104	67.222	0.715	2.104	67.222	1.662	4.888	67.222
7	0.683	2.008	69.230						
8	0.674	1.982	71.213						
9	0.649	1.910	73.122						
10	0.608	1.787	74.909						
11	0.594	1.748	76.657						
12	0.574	1.687	78.344						
13	0.568	1.671	80.016						
14	0.519	1.527	81.542						
15	0.501	1.474	83.016						
16	0.485	1.426	84.442						
17	0.471	1.385	85.828						
18	0.417	1.226	87.053						
19	0.401	1.180	88.234						
20	0.379	1.114	89.347						
21	0.361	1.062	90.410						
22	0.351	1.031	91.441						
23	0.331	0.974	92.414						
24	0.324	0.952	93.367						
25	0.290	0.853	94.219						
26	0.279	0.820	95.039						
27	0.273	0.804	95.843						
28	0.248	0.730	96.573						
29	0.229	0.673	97.245						
30	0.208	0.611	97.856						
31	0.196	0.575	98.431						
32	0.188	0.553	98.984						
33	0.177	0.520	99.505						
34	0.168	0.495	100.000						

Extraction Method: Principal Component Analysis.

Table 7
Validity checks of results in partial least square method by using smart pls.

Constructs	Cronbach's alpha	Composite reliability (rho-a)	Composite reliability (rho-c)	Average variance extracted (AVE)
Cost Savings	0.726	0.727	0.879	0.785
Safety Enhancements	0.751	0.76	0.857	0.667
Environmental Impact	0.914	0.915	0.931	0.659
Accuracy Improvement	0.82	0.823	0.881	0.65
Time Efficiency	0.892	0.894	0.917	0.649

Table 8
Validity checks of results in partial least square method by using smart pls.

Hypothetical Relation	(O)	(M)	SD	T Value	P Value
Cost Savings-> LIDAR	0.126	0.126	0.013	9.679	0
Safety Enhancements −> LIDAR	0.148	0.148	0.015	9.609	0
Environmental Impact −> LIDAR	0.372	0.371	0.02	18.474	0
Accuracy Improvement −> LIDAR	0.184	0.184	0.017	10.75	0
Time Efficiency −> LIDAR	0.27	0.27	0.016	16.477	0

was computed at 0.184 of the observed and model-predicted mean effects, with a standard deviation of 0.017. This relationship gives the obtained T value, which was 10.75, and a P value of 0, clearly suggesting that the improvement of accuracy in LIDAR technology was statistically significant. Finally, according to the model, the mean effects of time efficiency observed, and the standard deviation were 0.016, while the mean effects of change time efficiency observed and the standard deviation were 0.27. The derived T value at 16.477 and corresponding P value at 0 indicate that there is a significantly positive correlation of time efficiency with the use of LIDAR. Generally, the results from the study have recommended strong statistical relationships that exist between the adoption of LIDAR technology and a series of benefits, including cost, safety, environmental benefits, and accuracy, among many others.

LIDAR technology reduces costs asymmetrically, as seen in the histogram in Fig. 8. A long tail extends to higher values, while the data points are clustered around a center range. The prevalence of this skewness shows that although most cost reductions come within an anticipated range, some are much bigger. Since the histogram shows a positive skew in cost reductions, LIDAR may result in a range of savings results, including rare big savings that vary from the average.

Both the amplitude and the dispersion of the LIDAR-related safety gains are shown in the histogram shown in Fig. 9. However, the distribution shows a considerable rightward skew, which indicates that LIDAR has led to significant safety advantages in some instances. A central tendency clusters most of the benefits seen in the data. Histogram asymmetry demonstrates that LIDAR has the potential to enhance safety in application circumstances ranging from moderate to outstanding.

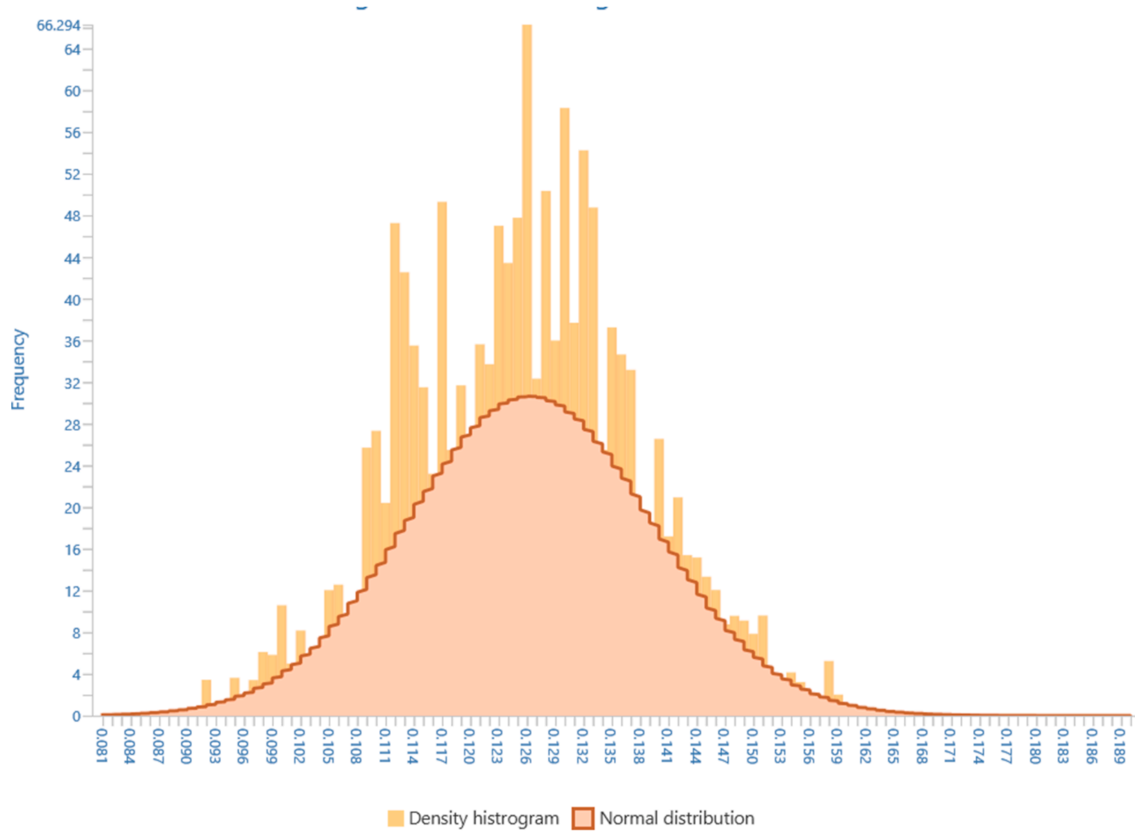

Fig. 8. Cost savings in relation to LIDAR implementation histogram.

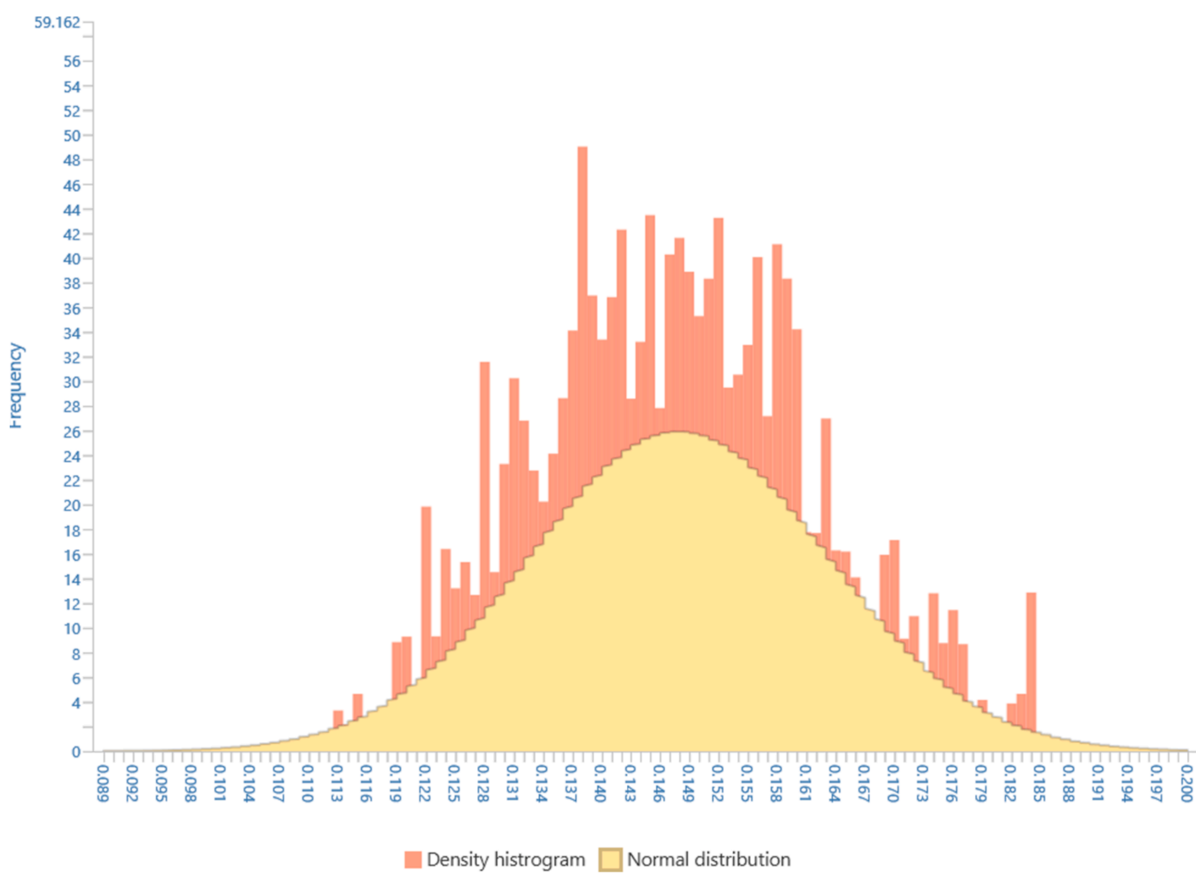

Fig. 9. Safety enhancement in relation to LIDAR implementation histogram.

The frequency of environmental consequences that have been detected and ascribed to the adoption of LIDAR technology is represented in the histogram that is exhibited and displayed in Fig. 10. The data, which are shown by pink bars, display a distribution that reaches its highest point and then gradually decreases to the right. This indicates that the distribution is right-skewed, meaning that most of the environmental effects are clustered around a lower range, but there are certain cases that exhibit substantially heavier impacts.

LIDAR technology has increased accuracy frequency, as seen in our histogram Fig. 11. The yellow data distribution shows peaks and declines, indicating efficiency gain discrepancies. The line is tilted to the right, indicating that although most accuracy increases occur in a normal range, there are also instances with much larger advancements. The red curve beneath the surface represents the normal distribution, a data comparison model. Certain unusually large gains show the technology's popularity and effectiveness in enhancing accuracy across a range of applications. Real-world statistics suggest that LIDAR technology improves accuracy overall.

The histogram shown in Fig. 12 LIDAR-related time efficiency benefits. The lavender bars show the frequency of events throughout a variety of time efficiency improvements during the research. Most time efficiency increases cluster around a mean value, as seen by the graph's symmetrical distribution around a central peak. The data distribution's close alignment with the maroon normal distribution curve reveals that LIDAR's time efficiency enhancements follow a normal distribution with less significant deviations from the mean. The maroon normal distribution curve matches the data distribution closely. Symmetry and normal distribution alignment show LIDAR's constant effect on time efficiency. It proves that LIDAR improves operation speed in several scenarios.

2.6. Predictive relevance

Stone-Geisser's Q2 value, calculated from the sum of squares of the observed values (SSO) and errors, quantifies the predictive importance of the construct "Role of LIDAR in Construction". This number measures statistical significance. Q2 = 0.529 after computing SSO = 8942.000 and SSE = 4212.515 as shown in Table 9. This positive Q2 result, which is greater than zero, suggests that the model predicts observed values accurately. This implies the model predicts. This suggests the prediction model accurately represents LIDAR's role in building. LIDAR's practicality is shown by the model's ability to predict over 50 % of construction variation.

2.7. Importance performance index

Fig. 13 constructions on the graph, the x-axis denotes relevance, and the y-axis reflects performance. A positive interpretation of this map shows that each construct's position reflects its performance relative to its importance. Construction in the top-right quadrant is frequently deemed vital and successful. Because they show where resources are spent efficiently. While less important, developments in the upper left may be doing very well. This might mean reallocating resources or overdelivering on their original purpose. Most of the structures on this map perform well, which matches their significance. The broad distribution of constructs on this map suggests a good outcome. This shows that the constructs are being adequately managed, with attention and resources distributed according to their significance.

3. Discussion

Building with LIDAR technology reveals a complex instrument with many benefits for ecologically responsible management. The critical analysis of this research follows the recent literature, which underlines the possible transformation of an advanced technology application for project improvement across its economic, environmental, and safety parameters. Previous research has shown that LIDAR significantly reduces the amount of material waste and improves project timelines [30]. These conclusions can be seen to reflect the huge cost saving. This research will, therefore, add to this knowledge by quantifying the savings that can be achieved using LIDAR technology in the quantification of construction procedures. The security feature of LIDAR facilitates much safety to the construction. This is evident in fewer accidents on-site due to better risks being managed. Safety is the key issue on the site these days, and really, the findings do go a long way toward supporting the fact. This discussion adds that LIDAR can also be an aid in adopting some sustainable practices. One can prove that with a low carbon footprint, LIDAR effectively supports the adoption of some

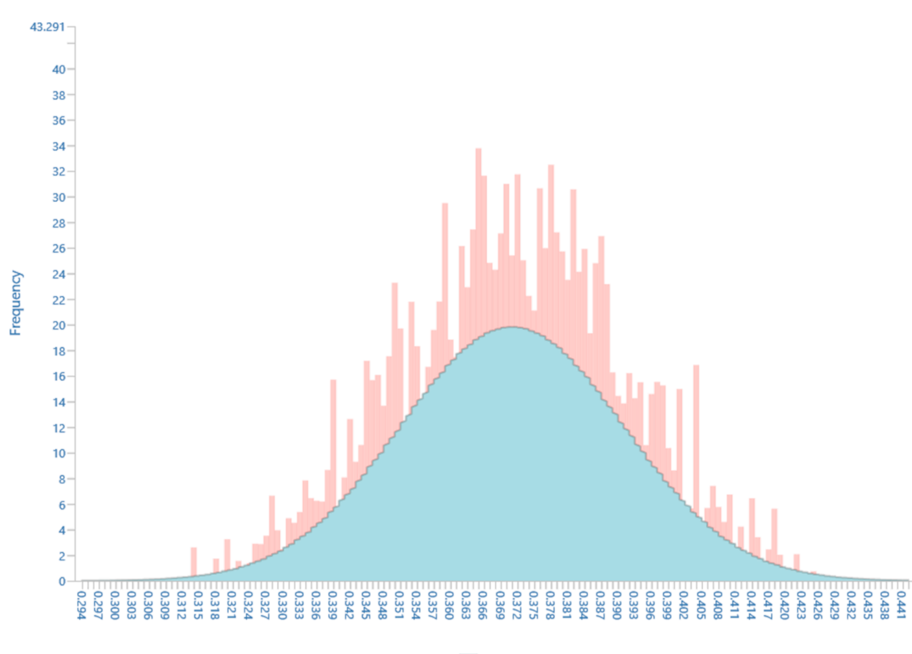

Fig. 10. Environmental impact in relation to LIDAR implementation histogram.

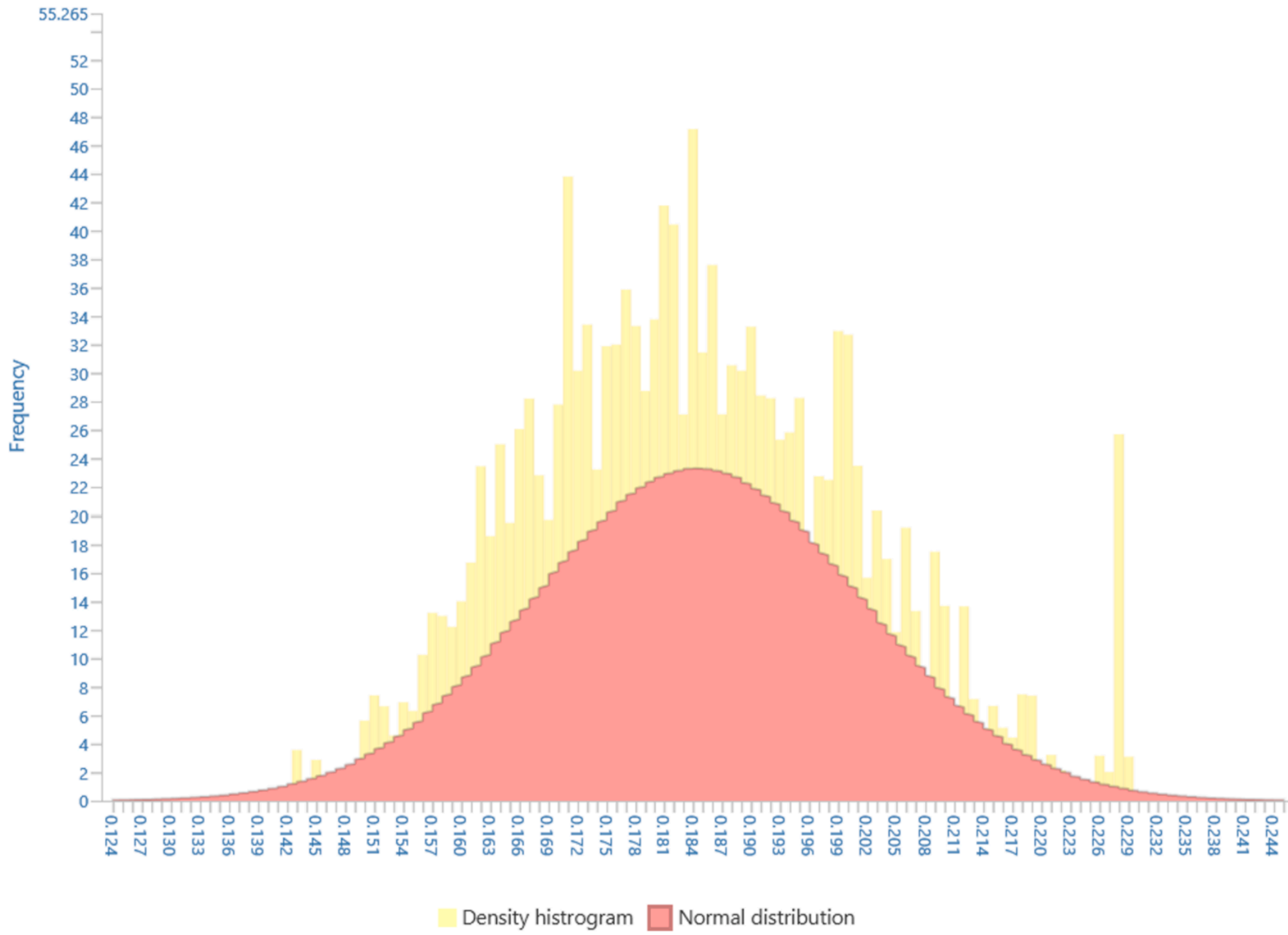

Fig. 11. Accuracy improvement in relation to LIDAR implementation histogram.

ecologically sustainable techniques in construction. These results would seem to support the idea that operational necessity warrants both operational necessity and environmental stewardship with LIDAR in building design in this climate-conscious age. Accuracy is the only advancement from LIDAR, which gives precise data for any construction project. The uses are being expanded in the topographic mapping with the accuracy of the LIDAR data, reducing the chance for costly errors in making sophisticated design easy. All this use means that the application of LIDAR has changed the building industry through improving time management. Statistically, it means the technology may have the effect of shortening project timelines, which gives an edge and meets the very urgent need for quick delivery of projects in industrial growth. The value of Q2 is greater than 0.5, thus meaning that LIDAR has positive prediction power in improving the performance of building projects. These technologies predict that managers should learn LIDAR technology and use it to predict and manage projects. The significance-Performance Analysis matrix further highlights the importance of operational significance of LIDAR and Performance in boosting the value of the strategy. This ensures strategic value. LIDAR effectiveness within the industry is marked with key, successful constructs. The Components show strengths and effective integration. This article brings out clearly the case of the building industry needing to conform to LIDAR technology. It demonstrates the use of LIDAR throughout the sector as, at best, being patchy and requiring more awareness raising, as well as training. While offering the greatest promise in the marketplace today. This place is where the benefits of the LIDAR need to be long-term investigated with time and different building environments. Further research on the limitations of integrating LIDAR could provide some solutions that address problems associated with the cost, complexity, and skill. Furthermore, a cross-sectional study can be conducted to compare construction management best practices regarding sustainability and efficiency with LIDAR technology. In a nutshell, research indicated by this study was that the adoption of LIDAR technology in construction has greatly improved sustainability, safety, and accuracy in information collected and processing, among them cost-effective measures. This study is a contribution to academic discussion and convincing people to use LIDAR for a more sustainable future.

3.1. Practical implications for construction professionals

The findings of this study offer several key takeaways for construction professionals aiming to implement LIDAR technology successfully. First and foremost, the research underscores the importance of organizational readiness, particularly in terms of management support and technological infrastructure. Construction companies need to ensure that they have the necessary technical capabilities, and that management is fully committed to the adoption and integration of LIDAR into their workflows. This includes investing in the necessary hardware and software, as well as providing training for employees to effectively utilize the technology. The study highlights the critical role of external factors such as regulatory frameworks and market conditions. Professionals should be aware of the legal and industry standards related to LIDAR usage and ensure compliance to avoid potential legal issues. Moreover, staying informed about market trends and emerging best practices can provide a competitive edge in utilizing LIDAR more effectively. Finally, the importance-performance analysis suggests that

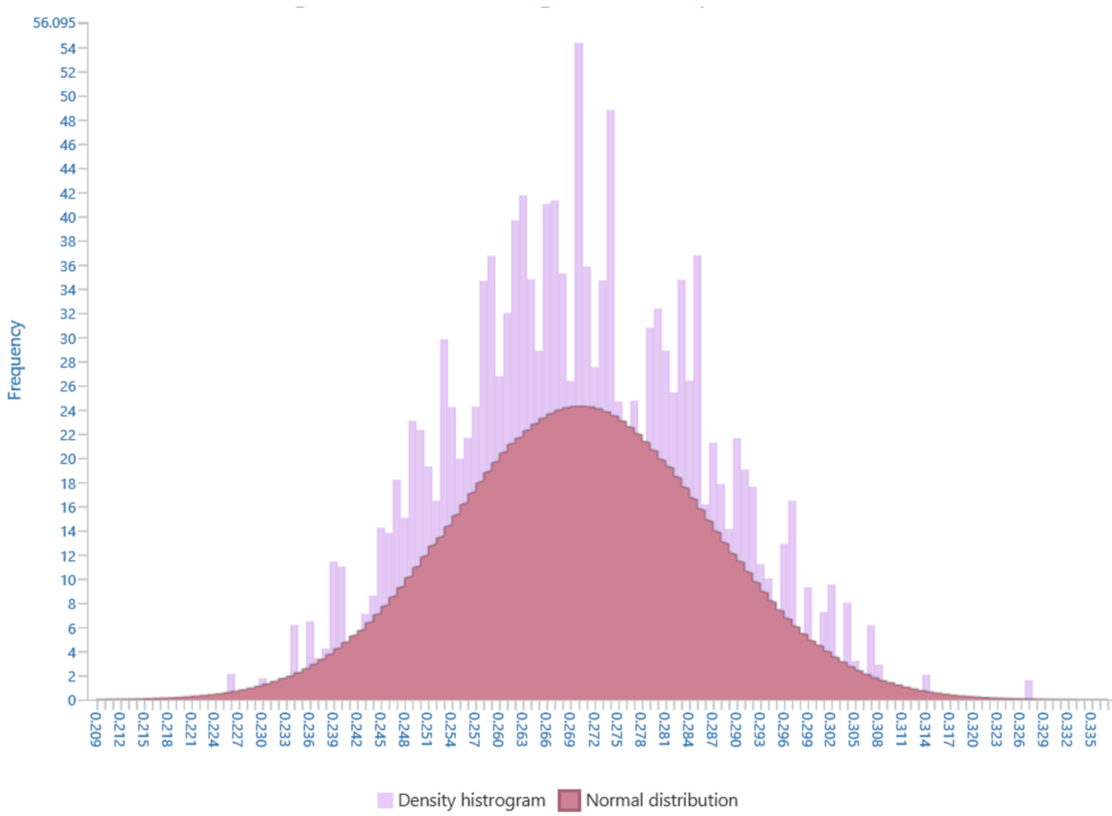

Fig. 12. Time efficiency in relation to LIDAR implementation histogram.

Table 9
Predictive relevance of the factors analysis.

Construct Relevance	SSO	SSE	Q^2 (=1-SSE/SSO)
Role of LIDAR in Construction	8942.000	4212.515	0.529

while LIDAR technology has strong potential, its success hinges on its alignment with specific project needs and contexts. Professionals should approach LIDAR not as a one-size-fits-all solution but as a tool that requires careful consideration of the specific requirements and constraints of each project. By adopting a strategic and well-informed approach, construction professionals can maximize the benefits of LIDAR, leading to improved efficiency, accuracy, and sustainability in their projects.

4. Conclusion

This study has validated the significant role of LIDAR technology in advancing sustainable practices within the construction industry. By demonstrating its effectiveness in enhancing cost efficiency, safety, environmental sustainability, and precision, the research highlights LIDAR as a transformative tool for modern construction. The ability of LIDAR to fast-track project execution and reduce costs, coupled with its precision in risk assessment and measurement, positions it as a critical asset in achieving the industry's safety and environmental goals. Furthermore, the reduction in carbon emissions facilitated by LIDAR technology underscores its contribution to environmental responsibility. A key contribution of this research is the application of predictive relevance and importance-performance analysis, which not only confirms LIDAR's efficacy but also supports its integration into modern building methodologies. These findings offer a pathway for the construction industry to evolve towards a more environmentally conscious and productive future, reinforcing LIDAR's status as a leading method for conducting precise thermal retrofitting analysis. However, this study also has its limitations. The reliance on specific case studies and expert opinions may limit the generalizability of the findings across different contexts and regions. Additionally, the focus on certain aspects of LIDAR technology may have overlooked other emerging technologies that could complement or compete with LIDAR in construction. Future research should explore the integration of LIDAR with other emerging technologies, such as Building Information Modelling (BIM) and drones, to further enhance its applicability and effectiveness. Additionally, studies that involve a broader range of construction projects across diverse geographical and regulatory environments would provide a more comprehensive understanding of LIDAR's potential impact on the industry. Addressing these areas will help solidify LIDAR's role in driving sustainable innovation in construction.

Justification for Addition of Authors.

The addition of new authors is necessary to acknowledge their significant contributions to the research and manuscript development:

1. **Dorin Radu:** Provided critical technical expertise in LIDAR technology for sustainability analysis.
2. **Badr T. Alsulami:** Contributed significantly to data analysis and interpretation.
3. **Branislav Đorđević:** Assisted with the methodological framework and validation of results.
4. **Ahmed Fathi Salih:** Played a key role in literature review and contextualizing findings.
5. **Hamad Almujibah:** Supported manuscript development through drafting and revisions.

CRediT authorship contribution statement

Ahsan Waqar: Writing – review & editing, Writing – original draft, Visualization, Validation, Software. **Dorin Radu:** Funding acquisition, Project administration, Supervision, Writing – review & editing. **Badr T. Alsulami:** Formal analysis, Investigation, Project administration,

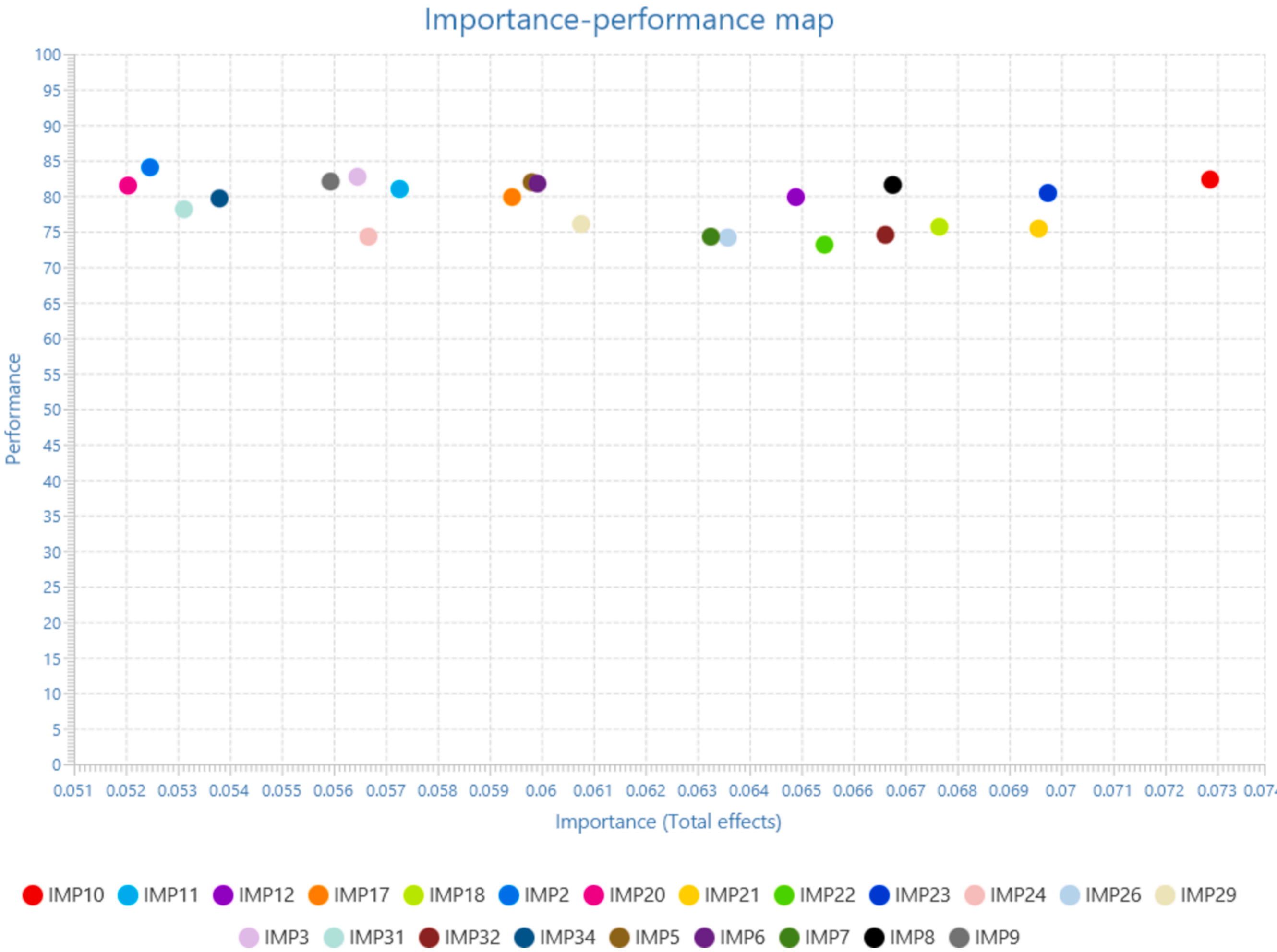

Fig. 13. Importance performance index.

Software, Writing – review & editing. **Branislav Đorđević:** Conceptualization, Data curation, Writing – review & editing. **Ahmed Fathi Mohamed Salih Ebrahim:** Methodology, Resources, Validation, Writing – review & editing. **Hamad R. Almujibah:** Software, Supervision, Visualization, Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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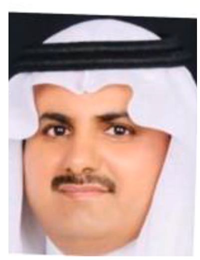

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