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Investigating the impact of lean construction principles on contractors' project performance in Ethiopia using PLS-SEM

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ABSTRACT

The construction industry faces challenges, such as schedule overruns, cost overruns, poor quality, and safety issues. Lean construction is a valuable concept for waste reduction and improving project performance. This study explored the impact of lean construction principles on contractors' project performance in Ethiopia. Using a quantitative method and simple random sampling technique, 159 respondents from construction companies were selected. This study introduced partial least squares structural equation modeling (PLS-SEM) in the study area. The results showed that process/technology lean principles, people/culture lean principles, and integrated project delivery variables had a direct positive impact on contractor performance. There was also a significant indirect relationship between process/technology-lean construction principles and project performance with a complementary partial mediation effect. However, no significant indirect associations were found between people/culture-lean construction principles and project performance through mediation of onsite construction waste management. The study used FIMIX-PLS to test robustness and detect hidden heterogeneity at non-critical levels. The findings provide researchers and practitioners to identify the influences that are critical for contractors' projects performance improvement, and that results in the best possible outcome.

1. Introduction

Ethiopia's construction sector is projected to grow at an average annual rate of over 8% between 2023 and 2026 (Fei, 2021). However, 182%, 37.6%, and 44% of projects are overrun by planned schedules, budgeted costs, and quality requirements (Wubishet, 2003; Wu et al., 2017). Over 80% of projects run budgets and experience delays (Sinesilassie et al., 2016). Nearly 40% of project time is wasted on non-value-adding activities (Ayalew et al., 2016). Construction waste management remains a major challenge in Ethiopia, with most generated waste not being managed at the point of generation. Therefore, new methods and approaches are needed to overcome these challenges. Lean construction is a project management approach that focuses on maximizing value and minimizing waste throughout the construction process (Khopade et al., 2022). It uses principles from lean manufacturing, such as standardized workflows, pull systems, and just-in-time theory, to optimize construction resources (Trivedi & Kuma, 2014; Khopade et al., 2022). Lean construction can streamline processes, reduce costs, and increase customer value. Effective waste management practices, including human resources, material and equipment, construction methods, administrative, and regulation, can improve efficiency(Jingkuang, 2011; Ajayi et al., 2017; Fikri, 2020; Gangolells et al., 2014). Lean construction can also address productivity issues in the construction sector through integrated project delivery (IPD) with multiparty contracts, offering better schedules, budgets, quality, and less litigation (Bennet, 2012). Lean Construction is a method of improving performance in various countries, including Chile, India, KSA, and China. It enhances workflow reliability, planning, control, and waste reduction. Chile experienced a 41% increase in process productivity, 14% efficiency, and 17% cycle time reduction (Alarcón *et al.,*2008). India saw positive benefits in schedule, cost, safety, and quality (Abhiram, 2016). In China, it improved customer satisfaction, quality, productivity, and reduced construction time (Song and Liang, 2011). The Ethiopian government aims for construction sector

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growth through project management tools, innovative technologies, and techniques. BIM adoption roadmap prepared in 2019 addresses industry challenges in low acceptance and implementation.

This study integrates lean construction concepts into a unified nomological network, focusing on process/technology-lean construction principles, people/culture-lean construction principles, integrated project delivery, and contractors' project performance. It uses the mediation effect on on-site construction waste management. PLS-SEM techniques, widely applied in business and social science research, have gained prominence in fields like medicine, agriculture, geography, environmental science, and engineering(Hair et al., 2019; Poul Chao, 1996; Franke & Richey, 2010). However, there is a critical gap in research on the use of PLS-SEM in construction management, particularly no study in the Ethiopian context. Batra, (2023) identified seven domains where construction management scholars commonly use PLS-SEM: sustainability, building information modeling, project success and performance, human resource management, risk management, project claims, and procurement.

This study investigates the impact of lean construction principles on contractors’ project performance in the Ethiopian construction industry. It examines the direct effect of process and technological lean principles, people and cultural principles, and integrated project delivery on contractors' performance and their indirect effect through the mediation of on-site construction management. Partial least squares structural equation modeling (PLS-SEM) SmartPLS4 software was used to analyze the survey data. The findings offer insights into lean construction implementation in Ethiopia and serve as guidelines for contractors to improve project performance.

2. Literature review

2.1. Theoretical Background

2.1.1.Lean principles: Lean is a widely recognized management concept that focuses on “doing more with less” by utilizing the least amount of time, resources, people, and physical space to accomplish tasks that provide value to customers(Koskela,1992). The practice of separating waste from value-added operations in an organization and its supply chain is known as “Lean” (Womack et al., 1997). Lean construction is a practical application of lean manufacturing principles, or lean thinking, to the construction environment (Mollasalehi et al., 2016; Rosi et al., 2020; Dixit & Saurabh, 2019). The approach has four roots: dissatisfaction with project performance, the success of the Toyota production system, efforts to establish project management on a theoretical foundation, and the discovery of anomalous facts from traditional thinking and practice (Howell & Ballared, 1994). The five basic principles of lean construction by Womack et al. (1997) included identifying the value, mapping the value stream, creating flow, establishing pull, and seeking perfection. According to Bajjou et al. (2019), lean construction principles can be divided into customer focus, people involvement, supply, continuous improvement, waste elimination , planning and scheduling, quality, standardization, and transparency principles contributing to the strengthening of their goals. Liker (2004) incorporated and associated high-level guiding principles from his Toyota Way model, which covers a synopsis of the 14 principles with the four categories of philosophy, process, people/partners, and problem-solving that can be used to construct any organization. Numerous academics have proposed that continuous workflow, pull systems, standardized work, visual control, and the use of trustworthy technology are all aspects of the lean concept when viewed in the context of related processes and technological concepts (Koskela,1992; Womack et al., 1997; Liker, 2004; Aziz & Hafaz, 2017). However, the hard part of lean requires the involvement of people and culture, including leadership management, teamwork, and continuous improvement (Korb, 2016; Minas, 2016; Mohammed, 2001; Musa et al., 2016).

2.1.2. On-site construction waste management: Waste management practices significantly enhance project efficiency by reducing the time and effort required for waste handling and disposal. This allows contractors to focus on core construction activities, leading to enhanced productivity, efficient workflows, and reduced project delays (Li et al., 2018). Waste refers to the process and operational concept where resources are used to produce a product but have no value (Viana et al., 2012). It includes unwanted products or materials used in construction processes, such as change orders, design errors, defects, rework, omissions, safety costs, and excess consumption of materials (Ansah et al., 2016; Koskela et al., 2007) . Lean construction terminology includes seven types of waste: waste due to overproduction, waiting periods, transport, the system itself, stock, operations, and waste due to defects (Womack & Jones, 1997). Despite limited understanding of construction waste in the industry, understanding it can help reduce barriers to performance improvement. Five significant waste management practices for successful on-site waste minimization include human resources, materials and equipment, construction methods, administration, and regulation (Jingkuang, 2011; Ajayi et al., 2017; Fikri, 2020; Gargdells et al., 2014).

2.1.3. Integrated project delivery: The methods used for delivering construction projects are crucial for determining stakeholder collaboration during planning, design, and construction phases. The choice of the project delivery mechanism is crucial for improving performance and achieving resource savings. A collaborative project delivery system can enhance quality and satisfaction (Ashcraft, 2022). The American Institute of Architects California Council (2007) defined integrated project delivery (IPD) as a construction approach that emphasizes collaboration, communication, and integration among all stakeholders to increase efficiency and involve all participants in design, fabrication, and construction phases. It breaks down traditional silos and fosters a cooperative environment (Jazayeri & Pajouhi, 2017). IPD is introduced using a multiparty contract, delivering higher-quality projects faster and at no significant cost premium. These results are valuable to decision makers in choosing the appropriate delivery system for their projects (Asmar et al., 2013).

2.2. Conceptual Review and Hypothesis Development

2.2.1. Lean construction principles and contractor project performance: Rosi et al. (2020) found that certain lean principles, such as waste management and employee involvement, positively impact project performance. Demirkesen (2020) highlighted the significant relationship between Lean implementation and safety performance, suggesting that firms excelling in Lean practices also achieve better safety performance. Lean construction concepts have been applied to various construction projects, resulting in advantages such as improved whole-life costs, customer satisfaction, safety, reduced project timelines, enhanced building quality, and improved contractor compensation (Akinradewo et al., 2018). Studies have shown that lean construction projects are easier to manage, safer, completed sooner, cost less, and have better quality (Alarcón et al., 2008). In Malaysia, Roslie (2020) demonstrated the appropriateness and acceptability of lean principles for construction project performance. In Australia, Fauzan and Sunindijo (2021) confirmed a strong correlation between lean construction principles and project performance indicators and recommended areas for improvement.

H_1: *Process/ Technology Lean principles have a direct positive and significant effect on contractors' project performance.*

H_2: *People/Culture lean principles have a direct positive and significant effect on contractors' project performance.*

2.2.2. Integrated project delivery and contractors project performance: The construction sector requires strong coordination, cooperation, and performance from various stakeholders, including contractors. Implementation of integrated project delivery (IPD) improves project outcomes in China (Mei, 2022). IPD eliminates team fragmentation, enhances communication, aligns interests and objectives, and fosters coordination and cooperation among contractors. It also leads to better project outcomes (Mesa et al., 2016).IPD projects, particularly building projects, have lower costs and schedule growth than other delivery methods (Yu et al., 2019).Comparing IPD projects with conventional methods, significant improvements were found. IPD is an efficient technique for increasing stakeholder involvement, improving construction planning, reducing risk, time, cost, and waste, and addressing low productivity issues (Hanna, 2016). Collaborative practices can significantly impact delivery times and costs, and safety and quality metrics (Mei, 2022).

H_3: *Integrated Project delivery has a direct positive significant effect on contractors' project performance.*

2.2.3. Mediating role of on-Site construction waste Management: On-site waste management in construction projects is closely linked to lean principles, which aim to remove waste and create value through continuous improvement. Lean construction involves efficient processing and disposal of construction waste, as well as plans to reduce waste generation (Bosnich, 2019; Santorella, 2017). The input-output model by Bajjou and Chafi (2021) and Hosseini et al. (2012) emphasized the application of lean construction in waste reduction and process improvement.

Construction project on-site waste management is positively correlated with contractor success, as it can save costs, increase productivity, and improve safety (Fikri, 2020). Proper waste management also helps contractors comply with client demands and environmental rules, leading to better project performance. Implementing efficient waste management practices can lead to significant cost savings, as contractors can minimize disposal costs and the need for new material purchases, resulting in lower project costs and improved profitability (Gangolells et al., 2014). Proper waste management also increases project efficiency, reducing the time and effort needed for waste handling and disposal. This allows contractors to focus on essential aspects of construction, improving productivity and workflows, and reducing project delays (Li et al., 2018). Good waste management methods also reduce potential dangers and hazards, resulting in a safer workplace, higher employee morale, and better project management (Ajayi et al., 2017). On-site construction management mediates the relationship between lean principles and construction project management by implementing these principles in the construction project management process.

H_4: *On-Site construction Waste Management mediates the relationship between Process/ Technology Lean principles and contractors' project performance.*

H_5: *On-Site construction Waste Management mediates the relationship between People/Culture Lean principles and contractors' project performance.*

3. Methodology

This study employed quantitative research design and a questionnaire survey to test the proposed hypothesis of research conceptual model as shown in Fig. 1.

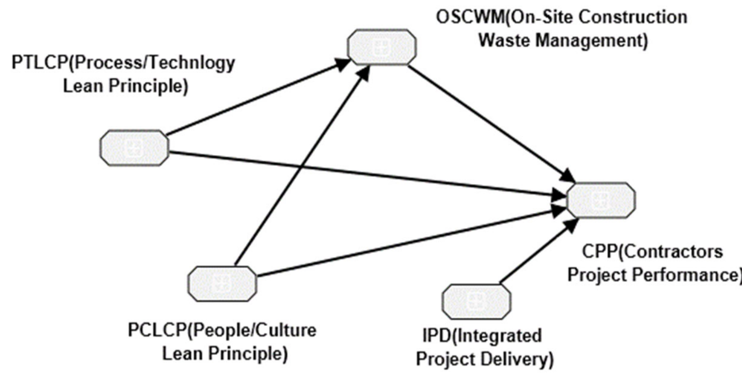

Fig. 1. Research conceptual model

3.1 Sample Characteristics

The study focuses on general contractors with valid registrations from MoUDC,(2022)and sufficient construction and managerial experience. Over 260 contractors are registered under G1 to G3, with over 980 staff working as project managers, construction/site engineers, and office engineers. To determine the required sample size, a power analysis was performed using G*Power 3.1.9.7 for Windows, with a projected minimum sample size of 159 for a small effect size of f2 = 0.05, alpha = 0.05, and power = 0.8.

3.2 Questionnaire Design and Data Collection

The study utilized a modified questionnaire adapted from literature and refined after expert feedback. The questionnaires had two sections for general information and five constructs rated on a seven-point Likert scale. A simple random sampling approach was used, with 185 questionnaires distributed to construction professionals in 2023. The data was analyzed using IBM SPSS version 26 software. According to table 2, results showed that 59% of respondents had over eleven years of professional experience, while 41% had less than ten years. The majority of respondents were in project management, site engineering, and office engineer positions, indicating a good base of personal professional experience and educational level.

Table 1
Respondents' background information

Category		Frequency	Percent
Years of experience	1-5	42	25.4
	6-10	25	15.3
	11-15	59	35.6
	>16	39	23.7
Educational Background	Doctor Degree	3	1.81
	Master Degree	61	37.0
	Bachelor Degree	101	61.2
Job position	Construction/site Engineer	39	23.6
	Office Engineer	22	13.3
	Project managers	87	52.7
	Others	17	10.3

3.3 Variable and measurement: To evaluate the model constructs, we used the following metrics. First, Lean principles were divided into two categories to gauge the opinions of respondents: process and technological concepts (each with five items), and people and cultural concepts (each with four items). The nine elements that the latent variable lean principle considers formative indicators. These measures provide context for the concept of lean production, which supports the latent variable of the lean principle. Additionally, we used the five items for on-site construction management variable measurement from (Jingkuang,2011; Ajayi et al., 2017). Key performance indicators and assessment standards for contractors' project performance have varied. The scale was adapted from a survey tool created by (Wubshet,2003; Ingle & Mahesh,2020). To verify the comprehensiveness and face of validity of the measures, experts interview were performed with 12 local senior project managers in June 2023, which revealed no issue, finally two university professors proofread the survey. An overview of our measurement items is included in Appendix A.

3.4. Factor and Common Method Bias Assessment

The study used PLS-SEM to assess data normality, revealing a regular distribution. The data normality was assessed using skewness and kurtosis analysis, ranging from -0.649 to 1.358. Common method of bias (CMB) was reduced using a Harman single-factor test and principal component analysis (PCA). The Harman test revealed five factors, with one factor explaining

38.64% of the covariance. The PCA test showed no effect of common method bias on the questionnaire. Overall, the study demonstrated data normality and no CMB.

3.5. Data Analysis and Findings

PLS-SEM: It is a widely used method for analyzing complex models, overcoming the dichotomy between explanation and prediction. It is suitable for exploratory research and confirmatory ,research (Hair et al., 2017; Sarstedt et al., 2020; Sarstedt et al., 2016; Müller et al., 2018). PLS-SEM is suitable for analysis with small sample sizes, offers greater statistical power (Ringle et al., 2020). When a research model incorporates formative measurement models, this method is favored because it facilitates a deeper comprehension of indirect effects or mediation (Asyraf, 2013; Moqbel et al., 2020; Latan, 2017). PLS path model creation and estimation were executed using the latest version of SmartPLS4 software, released in 2023. PLS-SEM evaluation criterion and stages are shown in Fig. 2 below.

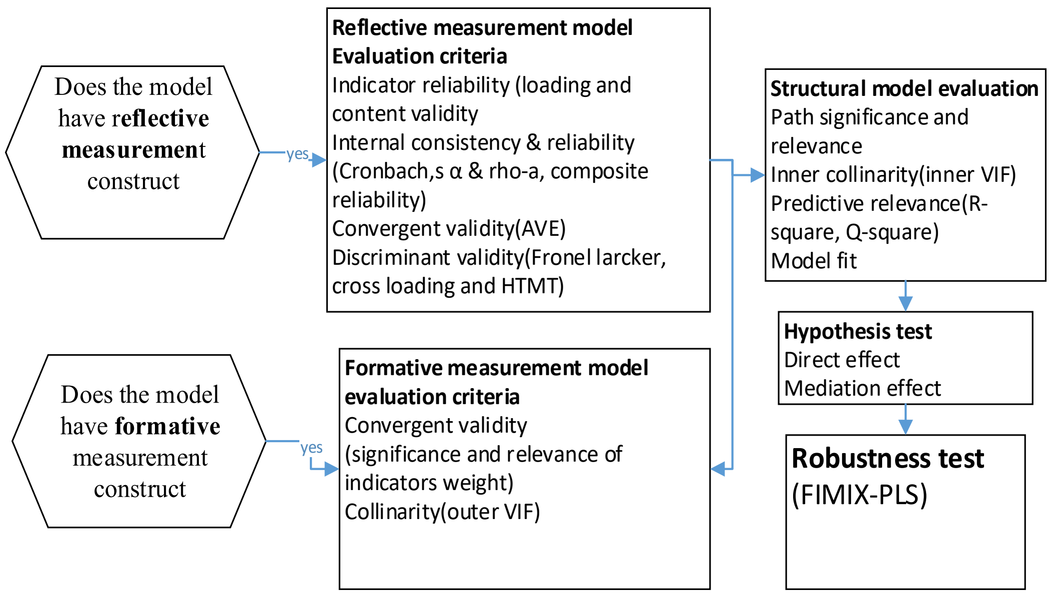

Fig. 2. PLS-SEM evaluation Stages

3.5.1 Evaluating the reflective measurement model: The reflective measurement model was evaluated using assessment criteria, with indicator loadings above 0.708 being advised (Hair et al., 2017) as shown in the above Fig. 2. To improve convergent validity, indicators were deleted with loadings less than 0.7. All indicator loadings for reflectively assessed constructs are above the cutoff value of 0.7 (Moqbel et al., 2020) ,as shown in Fig. 3, indicating adequate reliability. From Table 1, the internal consistency reliability values of all constructs are good, with Cronbach's alpha, Composite reliability rho_a, and Composite reliability rho_c over the 0.70 cutoff. AVE values of 0.612 and 0.736 are above the minimum requirement of 0.50 (Hair et al., 2021).

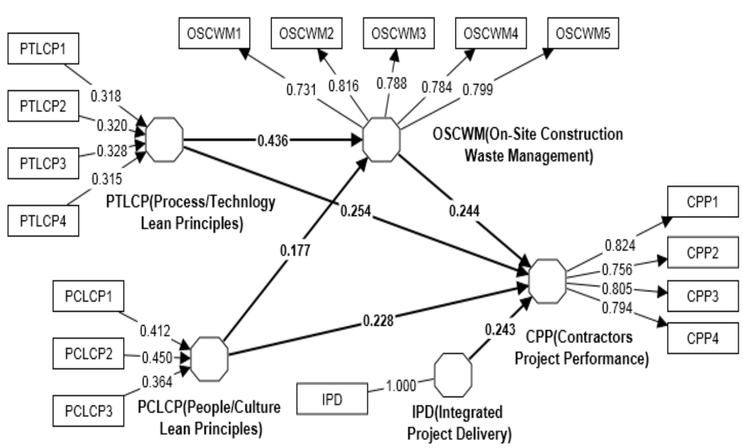

Fig. 3. Structural model evaluation. The final model with factor loadings, path coefficients

Table 2
Loading, convergent validity, and reliable estimates

Measures	Outer Loading	Cronbach's Alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	AVE
On-Site Construction Waste Management		0.840	0.843	0.887	0.612
OSCWM1	0.795				
OSCWM2	0.813				
OSCWM3	0.790				
OSCWM4	0.806				
OSCWM5	0.702				
Contractors Project performance		0.880	0.882	0.917	0.736
CPP1	0.814				
CPP2	0.764				
CPP3	0.826				
CPP4	0.802				

Table 3 revealed that all HTMT values are much below the more cautious 0.85 threshold value, and for conceptually related items, HTMT is below 0.90 (Hair et al.,2018). To confirm that the HTMT ratios are statistically substantially different from 1.0, it is also advised to perform an inferential test using bootstrapping.

Table 3
Discriminant validity, Heterotrait-Monotrait (HTMT) results

	CPP	IPD	OSCWM
CPP			
IPD	0.741		
OSCWM	0.758	0.542	

3.5.2 Evaluating the formative measurement model: The study focuses on the validity, reliability, and convergence of formative constructs using indicator weights. The indicator weight value is above the threshold of 0.70, and the Variance Inflation Factor (VIF) is used to assess collinearity. The highest VIF value for the formative indicator PCLCP2 is 1.792, below the conservative threshold of 3 (Amora, 2023 and Ringle et al., 2020). Collinearity does not reach critical levels in any formative measurement construct. From Table 4, the significance of the indicator weights is tested using bootstrapping, percentile bootstrap confidence intervals, and two-tailed testing at the 0.05 significance level (Sarstedt et al., 2020; Miles, 2014). The results show that all construct measures have acceptable levels of validity and reliability, allowing for the structural model's value to be considered.

Table 4
The significance and relevance of the formative items

Formative Constructs	Formative indicators	Outer weight (outer loading	95% confidence interval	T test	Significance (p<0.05)?
People/Culture	PCLCP1	0.816	[0.729 0.873]	22.780	Yes
	PCLCP2	0.873	[0.822 0.908]	39.922	Yes
	PCLCP3	0.732	[0.622 0.800]	16.542	Yes
Process/ Technology	PTLCP1	0.722	[0.546 0.829]	10.039	Yes
	PTLCP2	0.775	[0.675 0.839]	18.971	Yes
	PTLCP3	0.778	[0.605 0.861]	12.569	Yes
	PTLCP4	0.796	[0.695 0.862]	19.336	Yes

3.5.3 Structural model assessment: The study assessed the collinearity, predictive power, and model fitness of constructs, with the exception of one relationship between PTLP and PCLP. The majority of VIF values were below the conservative threshold of 3, indicating that the model's internal collinearity is not significantly affected by the predictor constructions' collinearity. The study also examined the explanatory power of the model, focusing on Contractors Project Performance (CPP) and On-Site Construction Waste Management (OSCWM) variables. The R2 value of 0.656 and 0.337 indicated substantial and moderate explanatory power, respectively(Hair et al.,2018, Ingle, 2020). The f2 effect size was relatively medium for relationships PTLCP → OSCWM, but PCLCP → OSCWM had a weak f2 effect size of 0.021(Miles, 2014). The PLS path model had lower out-of-sample predictive error compared to the naïve LM model benchmark, with one indicator showing high predictive power (Hair et al., 2018). The SRMR of the research model is 0.073, indicating it is well-fitting (Henseler & Sarstedt, 2013).

3.6 Hypothesis testing

This study proposed three direct hypotheses (H1–H3) and two mediation hypotheses (H4-H5) to address the research objectives.

Direct effect. Table 5 shows the results of evaluating the direct hypotheses. In the research model figure 1, indicated that the impact of process/technology lean construction principles on contractors' project performance was significantly positive (β=0.254, t =2.505, p < 0.05) thus supporting hypothesis 1. The next finding is that there is a significance influence between people/culture lean construction principles and contractors' project performance with positive direction (β=0.288, t =3.284, p < 0.001), thus supporting hypothesis 2; it can be concluded that the higher the people/culture lean construction principles practice the higher contractors' project performance improvement. In the subsequent direct hypothesis testing, it was found that there a positive significant influence of integrated project delivery on contractors' project performance improvement (β=0.243, t =4.059, p < 0.001), hence supporting Hypothesis 3. In this study, impact of process/technology and people/culture lean construction principles on contractors' project performance was indirectly measured through the mediation of on-site construction waste management.

Table 5
Summary of hypothesis testing

	Path(β)	Confidence 95%	Standard deviation (STDEV)	t- value	P values	Decision
Hypothesis1:PTLCP→ CPP	0.254	[0.049,0.442]	0.101	2.505	0.012	Supported
Hypothesis2:PCLCP→ CPP	0.228	[0.090,0.366]	0.069	3.284	0.001	Supported
Hypothesis3:IPD→ CPP	0.243	[0.135,0.372]	0.060	4.059	0.000	Supported

Mediation Test: After direct hypothesis testing, this study investigated the indirect relationship among People/Culture lean construction principles and Project Performance and Process/Technology lean construction principles and Contractor's project performance. To test these hypothesized effects, we will apply the procedure shown in Fig. 4.

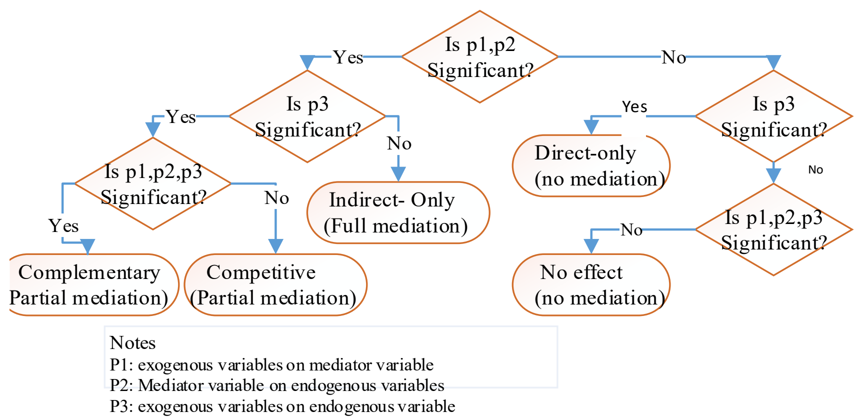

Fig. 4. Mediation role Decision. Adopt (Hair et al., 2017)

The first step was already performed by the direct effect test p1, p2 and the results showed in Table 6 that was significant except associations between People/Culture lean construction principles and on-site construction waste management (β=0.177, t =1.911, p>0.05).

Table 6
Mediation Hypothesis test result

	Path (β)	95% Confidence	Standard deviation (STDEV)	t- value	P values	Decision
Direct Effect						
P1 :PCLCP→ OSCWM	0.177	[0.006,0.372]	0.092	1.911	0.056	Unsupported
P1':PTLCP → OSCWM	0.436	[0.168,0.630]	0.117	3.711	0.000	Supported
P2 :OSCWM→ CPP	0.244	[0.112,0.377]	0.069	3.560	0.000	Supported
P3:PCLCP→ CPP	0.228	[0.090,0.366]	0.069	3.284	0.001	Supported
P3':PTLCP→ CPP	0.254	[0.049,0.442]	0.101	2.505	0.012	Supported
Indirect Effect						
H4:PCLCP → OSCWM→ CPP	0.043	[0.005,0.100]	0.024	1.836	0.066	Unsupported
H5:PTLCP→ OSCWM → CPP	0.106	[0.026,0.221]	0.051	2.081	0.038	Supported

Subsequently, the indirect impact was used as a mediating variable to see if there was a significant association between the independent and dependent variables. Zhao et al. (2010) cited in Cohen,(2013) identified four types of mediation effects: indirect-only; direct-only mediation; complementary mediation; competitive mediation, Table 5 shows the results of the mediation effect. The results indicated significant associations between Process/Technology lean construction principles and project performance by on-site construction waste management PTLCP→ OSCWM → CPP (β=0.106, t =2.081, p<0.05). The model's considerable direct and indirect effects indicated that complementing partial mediation was the kind of mediation effect. On the contrary, no significant associations between People/Culture lean construction principles and on-site construction waste management PCLCP → OSCWM→ CPP (β=0.043, t =1.836, p>0.05) but direct significance relation between People/Culture lean construction principles and project performance PCLCP→ CPP (β=0.288, t =3.284, p < 0.001) ,the model suggested that direct only (no mediation) between the two constructs effect between people/Culture lean construction principles and project performance.

3.7. Robustness Checks

The study aims to assess the robustness of structural models in terms of unobserved heterogeneity, nonlinear effects, and endogeneity. It employs FIMIX-PLS, a method that combines the benefits of mixed models and PLS models, to identify data structure and minimize the impact of outliers. Using FIMIX-PLS successfully, emphasizing the need to make correct choices to avoid incorrect results and false conclusion(Sarstedt, et al., 2020).FIMIX-PLS can also be used to assess the sensitivity of the model to changes in the underlying data. This can be useful for validating the model and ensuring that it is reliable and robust to data changes. Matthews et al., (2016) introduced the FIMIX-PLS method by assuming a one-segment solution, using the default settings for the stop standard (10^{-10}=1.0E-10), the maximum number of iterations (5000), and the number of repetitions (10). We initially computed the minimum sample size needed to estimate each segment in order to establish the maximum number of segments to extract. The results of a post hoc power analysis using G*Power 3.1.9.7 for Windows (a statistical power analysis program) assuming an effect size of 0.15 and a power level of 80% suggest that the minimum sample size requirement is 55, which allows for extracting a maximum of 3 segments as shown in table 7. We therefore ran for two to three segments, using similar settings as in the initial analysis.

The results of the fit indicted for the one- to three-segment solutions paint an ambiguous picture (Table 8). Sarstedt et al., (2020) have shown that whenever modified AIC with factor 3(AIC3) and consistent Akaike's information criterion (CAIC) show the same number of segments, the results likely appropriate to number of segments. However, in our analysis AIC3 indicates a three segments, whereas CAIC indicates one segment solution. Sarstedt et al., (2016) also note that if AIC4 and BIC are well, this is a sufficient condition for determining the number of segments within FIMIX-PLS. Both criteria point to a one segment solution which also appears to be densely crusted according to EN criterion. The analysis result did not unambiguously point to a specific segment solution. Because MDL5, CAIC, AIC4 and BIC points the same number of segment, even if AIC3 points to different segment number. We therefore decided that unobserved heterogeneity is not a critical level, which supported the results of the entire data set's analysis.

Table 7
Relative segment size (N=159)

No of segments	Segment1	Segment2	Segment3
1	1.000		
2	0.926	0.074	
3	0.854	0.075	0.071

Table 8
Fit indices for one-to-three segment solution

criteria	Number of segments		
	1	2	3
AIC(Akaike's information criterion)	710.563	693.705	**678.26**6
AIC3 (modified AIC with factor 3)	718.563	710.705	**704.266**
AIC4 (modified AIC with factor 4)	**726.563**	727.705	730.266
BIC (Bayesian information criteria)	**735.410**	746.506	759.021
CAIC (consistent AIC)	**743.410**	763.506	785.021
HQ (Hannan Quinn criterion)	720.649	715.139	**711.047**
MDL5 (minimum description length with factor)	**898.801**	1093.711	1290.039
LnL (Log Likelihood)	347.281	-329.853	**-313.133**
EN(entropy statistic)	**0.000**	0.810	0.860
NFI (non-fuzzy index)	**0.000**	0.845	0.855
NEC (normalized entropy criterion)	**0.000**	31.353	23.087

4. Discussion

The study evaluated reflective and formative assessment models, revealing high levels of indicator reliability and internal consistency reliability. The reflective constructs had indicator loadings above the cutoff value of 0.7, indicating high levels of convergent validity. The formative constructs also showed convergent validity, collinearity, and significant reliability. The study assessed the structural model's collinearity, predictive power, and model fitness, finding that collinearity among predictor constructs is not a significant problem. The explanatory power of the model, focusing on Contractors Project Performance and On-Site Construction Waste Management variables, was found to be substantial and moderate. The PLS prediction model had high predictive power, with reflective endogenous constructs having greater relevance.

The study found a significant positive impact of process/technology-lean construction principles on Ethiopian contractors' project performance. People/culture-lean construction principles also had a positive influence on contractor performance. Integrated project delivery positively influenced contractor performance. The indirect relationship between people/culture-lean construction principles and project performance was found to be complementary partial mediation. However, no significant associations were found between people/culture-lean construction principles and on-site construction waste management. The study used the FMIX-PLS to run a robustness test to identify hidden heterogeneity, considering that unobserved heterogeneity is not a critical level.

5. Conclusion

This study explores the impact of lean construction principles on construction project management in Ethiopia, a developing country. The PLS-SEM approach has gained significant attention in construction management, but no studies have been conducted in Ethiopia. The study aims to fill this gap by understanding how lean construction principles influence contractors' project performance. The study highlights the importance of the pull system, visual cues, continuous flow, reliable technology, standardized work processes, strong leadership, customer satisfaction, continuous learning, and integration with integrated project delivery (IPD) in improving project performance. The study also investigates the connections between process/technology-lean construction principles, people/culture-lean construction principles, integrated project delivery, and contractors' project performance using the mediation effect on on-site construction waste management. The study suggests that the Ethiopian government can incorporate lean practices into its construction industry guidelines to promote efficiency, quality, and sustainability of infrastructure development. Lean principles can be used to optimize infrastructure planning and development processes, prioritize investments in projects aligned with lean principles, and design capacity-building programs. Project managers can use lean techniques to optimize project schedules, minimize waste, and improve outcomes.

The study's practical contribution is that the results can be used to improve contractors' project performance by implementing lean construction principles and techniques. It predicts high potential for improvement in Ethiopian contractors' project performance through the application of lean principles. The findings provide a new perspective and method for future research, allowing further researchers to understand the impact of lean construction principles on project performance, expand the scope of research, and conduct related research in combination with the actual situation in developing countries.

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Appendix A
Operational measured variables

S/N	Dimension	Question	Reference
Process / Technology Lean Principles			
1	Pull system	Make certain that tasks only commence when preceding tasks are competed and all necessary resources are available	(Liker,2004)
2	Use Visual control	Use visual tools to highlight schedule status, quality and safety of work.	(Aziz & Hafaz,2013).
3	Continuous flow	Synchronize the sequence and rate of work	(Liker,2004; Yohayu & Mohammed,2009; Madanayake,2015)
4	Reliable technology	Use of tested and proven technology to provide long term benefits	
5	Standardized work	Use clear, easily accessed and up-to-date written standard of process and certain of processes	(Liker,2004)
People / Culture Lean Principles			
6	Leadership	Degree of commitment and problem-solving skills from bottom-top approach	(Korb,2016;Minas,2016)
7	Continuous improvement	Use of improved system for documenting and sharing lessons	(Korb,2016; Kallasy & Hamazeh, 2021)
8	Customer-focus	Executing tasks that satisfy the users requirement, preference and expectation	(Bertelsen & Koskela, 2002; Bajjou et l., 2019).
9	Team work	Working with others to complete the whole work	(Kallasy & Hamazeh, 2021).
Integrated project Delivery			
10	IPD is an effective way to increase the participation of major stakeholders to improve construction planning, reduce risk, time, cost, and waste, and productivity		(Ashcraft,2022; Hana,2016)
On-Site construction waste management			(Jingkuang & Yousong, 2011; Ajayi, 2016; Fikri et al., 2020; Gargdells et al., 2014)
11	Human resources	Training and educating workers on waste management practices and the importance of waste reduction	
12	Material and equipment	Selection of materials and equipment that generate less waste.	
13	Construction method	Adoption of waste minimization practices during construction activities.	
14	Administrative management	Development of waste management plans that outline waste reduction goals, strategies, and responsibilities	
15	Regulation management	Obeying waste management regulations and standards	
Contractors project performance			(Wubshet,2003; Ingle & Mahesh,2020)
16	Time	Completion of tasks and project within the scheduled time frame	
17	Cost	Make sure the project stays within the budget and is finished on time	
18	Safety	Prevent accidents, injuries and ensures compliance with safety standards and regulations	
19	Quality	Confirm that the final deliverables meet or exceed the required standard	