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Deepak Sharma
Department of Mechanical Engineering, Engineering College Bikaner

Dharmendra Singh
Department of Mechanical Engineering, Engineering College Bikaner

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Green Lean Six Sigma Barriers and Efficacy in Ceramic Manufacturing Industries: A PLS-SEM Study

Deepak Sharma[1], Dharmendra Singh[1,*]
[1]Department of Mechanical Engineering, Engineering College Bikaner, 334004, India

*Author to whom correspondence should be addressed:
E-mail: dharmendra3103@gmail.com

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Abstract: The study investigates the impact and effectiveness of the barriers for successful implementation of Green Lean Six Sigma (GLSS) in the Small and Medium Enterprise (SME) Indian ceramic industry. Focus was on the operational performance with identifications of the barriers which were responsible to reduce the performances of such industries. A comprehensive survey using a seven-point Likert scale was applied to collect the data among the different stake holders, thereafter PLS-SEM analytical method was used to know the important outcomes of the survey data. Total 12 barriers were identified from literature and expert's opinion and were required to make the relation among each other. Among different barriers, the operational complexity barrier (OCB) was treated as intermediate dependent barrier, and strategic prioritization and commitment barrier (SPCB) was treated as final crucial dependent variable. Total ten independent variables were directly related with OCB and indirectly related with SPCB via intermediates variable OCB. Cronbach's alpha values of the all barriers are in good agreement except OCB which have lower Cronbach's alpha (0.64). Other parameters like Composite reliability (rho_a), Composite reliability (rho_c) and Average variance extracted (AVE) are in good agreement with all barriers. Similarly, all observed variables are in line with their latent variables so as the path coefficient is also in good agreement for the hypothesis testing. The dependent variable OCB has strong correlations with MLB, PPDB and ROIUB, whereas moderate correlations with ATB, FB, OCSB and TIB variables. The weak relation is observed among ICB, RB, SPCB and SSCB variables. Hypothesis testing clearly approved the relation among independent and dependent latent variables and it was observed the most of the independent latent variables play vital role for the Operational Complexity Barriers. The study provides a complete evaluation of the barriers of GLSS implementation and a road map for ceramic manufacturers.

Keywords: GLSS; Barriers; PLS-SEM; Independent Variables; Dependent Variables; SMEs

1. Introduction

The emergence of sustainable manufacturing techniques is a response to growing concerns about environmental deterioration and the continuous quest for cost-effectiveness in industrial operations[1]. Green Lean Six Sigma (GLSS) is one strategy that promises both ecological responsibility and operational performance. However, the adoption of this integrated strategy is hindered by numerous barriers; especially in the ceramic production sector. Since the 1990s, company process reengineering has been a popular strategy for optimizing business processes, and GLSS has advanced in this direction[2]. The GLSS combines the Lean and Six Sigma processes with the goal of achieving environmental sustainability. Lean focuses on waste reduction and process efficiency, whereas Six Sigma seeks to reduce defects and process variability, hence improving quality[3-4]. When paired with Green, the concept encompasses environmental sustainability in addition to operational efficiency and quality.

Despite the obvious benefits, GLSS implementation is far from simple and frequently encounters opposition from numerous fronts. Previous research has identified various barriers to the implementation of a Lean-Green manufacturing system[5]. These barriers include legislative frameworks, financial resources, public perception, unclear returns on investment, and management commitment, among others. The significance of barriers is also emphasized in the context of green manufacturing[6]. These barriers are broad, encompassing environmental, social, and economic viewpoints, indicating the complexity of the problem and the magnitude of the required effort to overcome these barriers. Similarly, it has been recognized that integrating lean, green, and agile principles into modern industrial processes provides a viable path toward sustainability and resilience[7,8-11]. However, the intricate interplay of multiple elements that determine the successful integration of these techniques is not yet fully understood.

The ceramic sector has observed a rapid boost over last few years in India and around the world due to faster urbanization in place which leads to the demand for residential and commercial structures. Also, the Indian Government initiatives of 'Pradhan Mantri Awas Yojana', 'Smart Cities, and development of 'Industrial Corridors', road infrastructure, transportation, water supply and power generation has escalated demand for ceramic tiles, sanitary wares, insulators, bricks, refractories in the construction sector. Therefore there is continual economic growth and sustainable industrial development is observed in near future. At the same, the sector is facing environmental issues of waste generated due to high rejections during production, inventory, over production[12)], higher emission and energy consumption[13)]. The wastage is not only occurred during production, but also due to consumption of natural resources, solid waste disposal which cannot be recycled, and landfilling[14)]. Therefore, the sector is having sustainability issues. There are few studies on lean implementation, but have not addressed their environmental impact caused by the ceramic industry[15)]. The GLSS approach could be suitable and comprehensive approach in achieving sustainability objectives for ceramic industries manufacturing high-quality end products.

Consequently, it is crucial to comprehend the degree to which the above discussed barriers hinder the effectiveness of GLSS deployment, in ceramic manufacturing specially SMEs sectors. Diverse studies have presented theories and methods for comprehending sustainable production indicators, such as the influence of integrated lean, green, and social management systems[16-17)]. Leagile manufacturing, a blend of lean and agile principles, has been extensively researched in the automotive industry[18-20)]. It is essential to glean insights from these studies and implement them in the context of GLSS application in Indian Ceramic SMEs sector.

The purpose of this research is to expand upon these current frameworks and studies to provide thorough knowledge of the barriers that impede the proper deployment of GLSSs in the ceramic manufacturing industry which has not been observed in literature. These barriers can arise from a variety of sources, including organizational, technical, financial, regulatory, and cultural factors, and identifying them is a vital stage in the implementation process. This study has a secondary purpose of the categorization and subsequent mitigation of these barriers, which is made possible by a comprehensive understanding. In addition this study intends to examine their specific effects on the overall effectiveness of GLSS in ceramic manufacturing operations.

2. Literature Review

Today manufacturing industries are focusing on sustainability to remain competitive in global market. Now in days, manufacturing industries are having environmental challenges of greenhouse emission, climate change, and exhaustive use of resources and waste generation[21)]. Therefore, manufacturing industries are adopting innovative technologies and strategies to improve their operational performance so as to produce eco-friendly products for customer's satisfaction[22)]. Also, the environmental legislations[23)] and government policies (Perform, Achieve, Trade and Zero Effect Zero Defect) have forced organizations to reduce environmental impact and improve operational performance with sustainability[24)]. Literature reveals that GLSS is a holistic approach which integrates Lean for reducing waste and Six Sigma for reducing defects, and improved process performance can better facilitate the industries to achieve environmental goals of waste minimization, reduced emission and conservation of resource[22)]. However, the success of this environmental friendly approach is premised on an understanding of the different barriers towards implementation.

Extensive and diverse research has been conducted on the challenges of green innovation projects, lean manufacturing, sustainability strategies, and lean supply chain management in the manufacturing industry. A study employed structural equation modeling to combine internal procedures and human resources for the implementation of lean manufacturing[25)]. They contend that the alignment of human resource (HR) policies and procedures with lean concepts can improve lean implementation effectiveness. In a similar vein, a study explored deeper into the enablers and barriers of sustainable manufacturing and concluded that an integrated approach to study these elements is essential for the industry's transition to achieve more sustainable practices[26-27)]. Another study examined the integration of lean manufacturing and six sigma with sustainability, emphasizing the necessity for future studies to design a model specifically addressing the issues[28)]. A researcher explored the interrelation between lean, six sigma and industry 4.0 technologies to provide right amount of informative data to strengthen these quality improvements approaches[29)]. Another researcher explored attempts to mainstream green product creation and integrate environmental sustainability into businesses[30)]. They investigated why and how businesses incorporate environmental sustainability into their plans, shedding light on the process and potential barriers. Similarly, a study offered a comprehensive evaluation of the current research on the drivers and barriers to green supply chain management adaptation[31)].

Some researchers focused on the deployment of hybrid lean-agile production methods in the automotive industry[32-34)]. Their discoveries led to a greater comprehension of how hybrid systems might circumvent conventional manufacturing limits. Drivers and constraints were examined for green manufacturing practices in Malaysian SMEs underscores the significance of understanding these aspects to promote sustainable practices in this sector[35)]. It was observed that integrated manufacturing has significant impact on manufacturing performance, which might be used to overcome implementation barriers. Thus it is essential to analyze barriers to have a better understanding and improve interpretation for successful implementation of GLSS in an industry.

Apart from many studies, there appear to be no studies suggesting the GLSS implementation barriers for SMEs particularly in ceramic manufacturing sector. A large number of ceramic industries are in the bracket of small and medium enterprises (SMEs) category which accounts for more than 50% of the total Indian market[36)]. In India, ceramic industries are dominated by the tile manufacturing and account the second largest producer in the world. The tiles market size was around USD 5.18 Billion in 2023 and is expected to grow at a CAGR of 9.1% from 2024 to 2030[37)]. This signifies the growth of the sector in India. While manufacturing variety of finished products, this sector consumes natural resources and produces waste during production process (pre-kiln, kiln and post-kiln operations).

The defective products cannot be recycled after firing in kiln and are discarded[30)]. The industries are finding challenges to dispose of these wastes which cause pollution to the environment and leads to 90% of energy wastage[38)]. Therefore it is an attractive area for the research to be carried out to realize the most efficient means to overcome these challenges with effective implementation of the GLSS. Though GLSS has effectively reduced the negative environmental impact, its implementation is not realized in SMEs due to several barriers. The SMEs presents many barriers on practical, theoretical, financial, and organizational levels, because these industries has limited understanding, and awareness of GLSS principles and practices[39)], Therefore, it is necessary to understand these barriers at their respective levels of implementation and must be eliminated as far as possible for effective performance of the organisations in manufacturing. Research on GLSS implementation in ceramic industries is not yet attempted. Therefore, the present research identifies the barriers to GLSS implementation in ceramic industries to help practitioners and management during implementation phase.

After extensive literature review, it was found that more research required for finding the GLSS applications in SMEs sector of India especially for Ceramic sector due to tackling of huge wastage which is cause of worry in respect to environment point of view. This research gap motivated to conduct the barrier identification for the ceramic sector of the Indian SMEs. The case study region was selected for the state of Rajasthan in India. PLS-SEM method was adopted to find the relation among factors responsible for barriers in LSS implementations. The PLS-SEM method is useful when the relation among latent variables is required specially when complex conditions were present.

3. Research Methodology

This study employs a quantitative research methodology based on partial least squares structural equation modeling (PLS-SEM) implemented in SmartPLS software[40-41)]. The selection of PLS-SEM was influenced by the need to examine numerous associations simultaneously, handle complex models with small to medium sample sizes, and make less severe data distribution assumptions[42)].

PLS-SEM study was selected for the present study due to its handling of complex relations among latent variables (graphically represented as circles) and observed indicators (graphically represented as rectangles in less data compare to other methods[43)]. PLS-SEM is more effective and useful when both formative and reflective constructs are included in research more than factor and regression analysis. Also PLS-SEM is useful when sample size is comparative small then other methods. PLS-SEM can handle both measurement and structural models for analysis which help to make the hypothesis testing more effective than other methods[44)].

This research targeted the stakeholders of a variety of small and medium-sized ceramic businesses in the state of Rajasthan in India. A survey of 600 stakeholders yielded a representative sample (both online and offline). The demographic information of the participants is presented in the Table 1. The purpose of the survey was to assess their perspectives, attitudes, and experiences related to the barriers to GLSS implementation. The survey questionnaire was created and validated with at most care to ensure that it captures the required data accurately. It contained numerous parts, each addressing a distinct set of GLSS variables. The questions were developed based on a review of the relevant literature and then revised through a pilot test to ensure their clarity and relevance. The response rate was approximately 53.3%, as a total of 320 legitimate responses were received out of 600 distributed surveys. A research suggested at least 100 observations to estimate SEM and 200 observations for reliable estimates, which is certainly met by our sample size of 320[45)]. This sample size is sufficient for PLS-SEM analysis because it exceeds the minimum recommendation for such a model. The data input were given into SmartPLS software for processing.

Table 1. Demographics of the participants selected for the present study.

Parameters	Section	Frequency	In %
Gender	Male	231	72.18
	Female	89	27.82
Age	22 to 30 Yr	57	17.81
	31 to 40 Yr	251	78.43
	More than 40 yr	12	3.75
Working Experience	0-2 Yr	62	19.37
	2 to 5 Yr	220	68.75
	More than 5 Yr	38	11.87
Education Qualifications	12^{th}	20	6.25
	Graduate	272	85.0
	PG	22	6.87
	Others	6	1.87
Type of Job	Technical	198	61.87
	Management	104	32.5
	Others	18	5.62

The PLS-SEM enabled the evaluation of the measurement model (outer model) to determine reliability and validity, followed by an examination of the structural model (inner model) to test the hypothesized associations. Checking the indicators' reliability, internal consistency reliability, convergent validity, and discriminant validity was part of the examination of the outer model. After confirming the reliability and validity of the measurement model, the structural model was evaluated based on criteria such as the coefficient of determination (R2), path coefficients, and significance levels. The results of the investigation were then evaluated to draw conclusions regarding the impediments to GLSS implementation among ceramic SME respondents.

The findings were then addressed in the context of the current literature, and implications for practice and future studies were proposed. This methodological output supports the study's dependability and validity, yielding findings that could inform future practices and research in the context of GLSS within ceramic SMEs.

The majority of respondents in this survey were male, accounting for nearly 70% of the total, indicating a gender imbalance among ceramic SME stakeholders. Approximately sixty percent of the respondents were between the ages of 32 and 40, constituting a sizeable share of the total. This age range represents a mature workforce with likely familial obligations, which may influence their perspectives and responses. In terms of educational background, the majority of participants possessed at least a master's degree. Seventy-five percent of respondents claimed to possess a bachelor's degree or higher, indicating a high level of formal education among the stakeholders. The framework selected for the PLS-SEM based study is show in Fig. 1, in which all required latent variables connected with its dependent variable are shown. All these variables are identified using literature review and expert opinion.

4. Measurement Model of the Present Study

The measurement model is a major component of the partial least squares structural equation modeling (PLS-SEM) method used in this study on Green Lean Six Sigma (GLSS). The measurement model is the key integral which helps to make the authenticity of the data collected using survey format. This relates the individual measurement items to their corresponding latent variables and serves as the foundation for structural equation modeling (SEM). This section demonstrates the theoretical basis and statistical analysis used to establish the reliability and validity of the applied measurement model. In contrast to prior research, which utilized the lavaan package of the mathematical programming software R for SEM analysis, this work employs SmartPLS software[46]. SmartPLS is renowned for its capacity to manage both sophisticated models and lower sample sizes, which makes it a good fit for our sample of 320 valid survey replies. As a result, SmartPLS software was utilized to analyze the measurement model, ensuring a robust and reliable analytic procedure and validating the efficacy of PLS-SEM in determining the application and ramifications of GLSS in ceramic SMEs. The study used the well-structured survey instrument after pilot study of 50 experts which approve the observed indicators for the participants. In this, total 320 participants filled the survey form for observed indicators. The participants include; experts, managers, engineers, vendors, company owners and research professors. In pilot study, experts were identified on the basis of the expertise required for SMEs ceramic sector and all these experts were from the state of Rajasthan in India. Statistical measures such as Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity confirmed the adequacy of the data for factor analysis.

4.1 Latent Variables

According to Fig. 1, the conceptual model for this study on Green Lean Six Sigma (GLSS) consists of twelve latent variables. These variables are multidimensional by their very nature and cannot be measured with a single observed variable. Therefore, numerous observed items were used to evaluate each latent variable in our conceptual model. During the construction of our model, the authors have separated the latent variables into two groups: independent and dependent variables as shown in Fig. 2. It is crucial to note that a model with such a large number of variables was needed for capturing the intricate interplay between the numerous factors affecting GLSS implementation. Consequently, with the aid of SmartPLS software, this study was able to gain a comprehensive understanding of the dynamics at play, enabling a comprehensive and nuanced investigation of GLSS in the context of ceramic SMEs. The barrier constructs and measured parameters for the present study are shown in Table 2. Based on the experts' opinions, the research questions were designed. The research questions and hypothesis selected for the present study is presented in the Table 3, whereas all required research questions were discussed along with the related hypothesis. Same was approved by using PLS-SEM method.

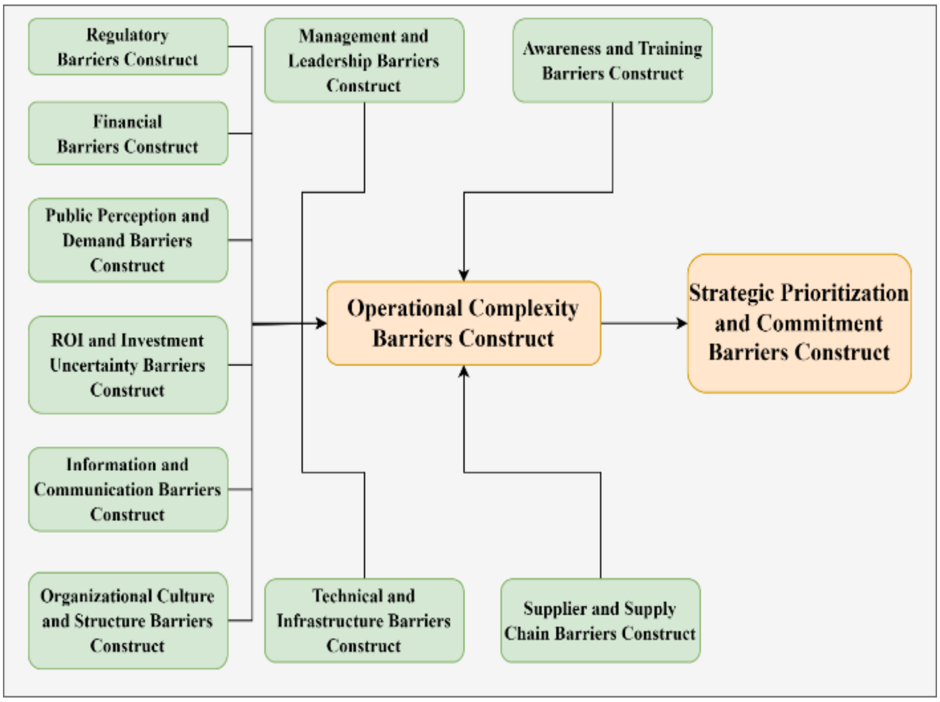

Fig. 1: Framework for PLS-SEM study for GLSS based study.

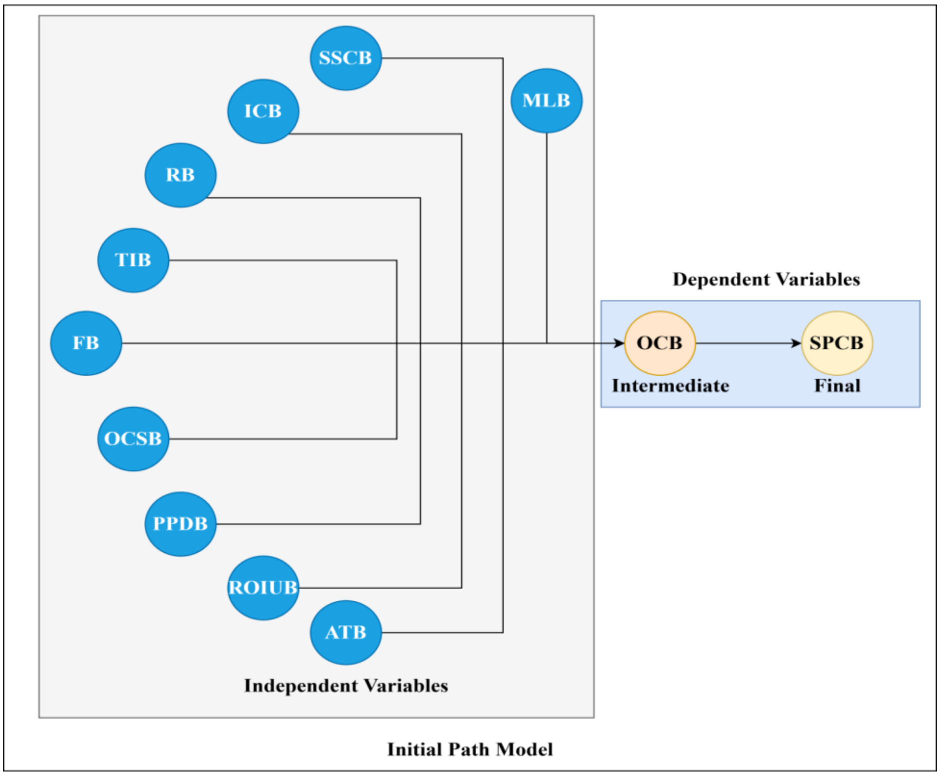

Fig. 2: Initial path model selected for present study.

Table 2. Barriers responsible for the adoption of GLSS in ceramic SMEs.

Barriers	Description	Parameters
Regulatory Barriers Construct (RB)	Absence of a concrete regulatory framework encouraging sustainable practices	The current environmental regulations in our region encourage us to adopt green practices
		Our organization closely monitors the updates on environmental regulatory framework
	Instability in the formulation of future environmental laws	Future legislative instability hinders our willingness to adopt sustainable operations
		Our organization is concerned about possible changes in future environmental legislation
Financial Barriers Construct (FB)	Insufficient or inconsistent state incentives to implement green practices	Government incentives play a crucial role in our decision to implement green practices
		Financial incentives from the government would encourage us more toward sustainability
	The misconception that green, lean six sigma implementation requires prohibitive investment	Our organization views green lean six sigma as a high-cost initiative
		Cost concerns limit our ability to implement green lean six sigma
	Budget limitations restricting the transition to sustainable operations	Financial constraints limit our ability to transition to sustainable operations
		Limited budget is a major barrier to adopting green lean six sigma in our organization
Public Perception and Demand Barriers Construct (PPDB)	Public and industry peers' indifference toward environmental concerns due to inadequate exposure	There is significant awareness among our peers about the importance of sustainable practices
		Public awareness about the environmental issues influences our decision to adopt green practices
	Inadequate demand from customers for environmentally friendly, reconfigurable products	There is sufficient demand for our environmentally friendly products
		Customer demand for sustainable products drives our decision to implement green lean six sigma
ROI and Investment Uncertainty Barriers Construct (ROIUB)	Ambiguity regarding the return on investment from sustainable practices	The unclear ROI from sustainable practices affects our decision to adopt them
		Our organization believes in the financial benefits of green lean six sigma
	High technological uncertainty associated with green initiatives	Organizational resistance to change affects our likelihood of adopting sustainable systems
Operational Complexity Barriers Construct (OC)	Challenges in the conceptualization and execution of Green Lean Six Sigma Approach (GLSS) across product, process, supply chain, and system	Complexity in executing GLSS affects our rate of green lean six sigma implementation
		Our organization finds it challenging to integrate GLSS in our supply chain
	Challenges in evaluating the performance of sustainable systems	Our organization is open to changes that enhance sustainability
Management and Leadership Barriers Construct (MLB)	Management difficulties in steering the shift toward sustainable operations	Management complexities hinder our adoption of sustainable operations
		Our management finds it difficult to steer the organization toward sustainability
		Our top executives prioritize sustainability in our operations
	Absence of effective leadership promoting the transition to sustainable practices	Top management commitment is crucial for the successful implementation of green lean six sigma
		We have effective leaders who promote sustainability in our organization
		Lack of effective leadership discourages us from adopting green lean six sigma
Awareness and Training Barriers Construct	Insufficient education, awareness, and incentive programs for employees	Our employees are well educated and aware of sustainable practices

(ATB)	High initial learning curve associated with the adoption of new sustainable systems	We provide training to our employees on green lean six sigma
Technical and Infrastructure Barriers Construct (TIB)	Insufficient technical resources and supporting infrastructure for the green lean six sigma	Availability of technical resources greatly influences our transition to green lean six sigma
	Overreliance on traditional methods and technologies	Our organization has sufficient infrastructure to support green lean six sigma
Organizational Culture and Structure Barriers Construct (OCB)	An organizational culture that does not foster or encourage sustainable practices	Our organizational culture does not facilitate changes toward sustainable practices
	Suboptimal organizational structure limiting the effective implementation of green practices	The organizational structure in place hampers the implementation of green practices
	Organizational resistance to paradigm shifts	There is significant resistance within our organization toward altering its structure to accommodate sustainability practices
Supplier and Supply Chain Barriers Construct (SSCB)	Our suppliers show limited commitment toward sustainable practices	Our suppliers show limited commitment toward sustainable practices
	We struggle to retain employees who are well-versed in sustainable practices	We struggle to retain employees who are well-versed in sustainable practices
	We face difficulties in integrating sustainable practices into our supply chain	We face difficulties in integrating sustainable practices into our supply chain
Information and Communication Barriers Construct (ICB)	We lack access to updated information about sustainable practices	We lack access to updated information about sustainable practices
	Our organization faces challenges in maintaining effective communication channels for sustainability initiatives	Our organization faces challenges in maintaining effective communication channels for sustainability initiatives
	We encounter issues in aligning with international environmental standards and compliance	We encounter issues in aligning with international environmental standards and compliance
Strategic Prioritization and Commitment Barriers Construct (SPCB)	Our top executives show low prioritization toward sustainable practices due to lack of understanding or negative predispositions	Our top executives show low prioritization toward sustainable practices due to lack of understanding or negative predispositions
	Our organization struggles with interdepartmental collaboration for implementing sustainable operations	Our organization struggles with interdepartmental collaboration for implementing sustainable operations
	Our organization has limited understanding of the long-term benefits of adopting sustainable practices	Our organization has limited understanding of the long-term benefits of adopting sustainable practices

Table 3. Research questions and hypotheses for the present study.

Research Questions	**Null Hypothesis**	**Alternative Hypothesis**
1. What are the effects of regulatory and financial barriers on the adoption of the Green Lean Six Sigma Approach (GLSS)?	H0_1: Regulatory and financial barriers have no significant effect on the adoption of GLSS.	Ha_1: Regulatory and financial barriers have a significant effect on the adoption of GLSS.
2. How does public perception and demand influence the operational complexity and strategic prioritization associated with the GLSS?	H0_2: Public perception and demand do not significantly influence the operational complexity and strategic prioritization associated with the GLSS.	Ha_2: Public perception and demand significantly influence the operational complexity and strategic prioritization associated with the GLSS.
3. What impact do management and leadership barriers have on the operational complexity and strategic prioritization in implementing GLSS?	H0_3: Management and leadership barriers do not significantly impact the operational complexity and strategic prioritization in implementing GLSS.	Ha_3: Management and leadership barriers significantly impact the operational complexity and strategic prioritization in implementing GLSS.
4. How does the level of awareness and training affect the successful implementation of GLSS within an organization?	H0_4: The level of awareness and training does not significantly affect the successful implementation of GLSS within an organization.	Ha_4: The level of awareness and training significantly affects the successful implementation of GLSS within an organization.

5. How does the organizational culture and structure impact the implementation and strategic prioritization of GLSS?	H0_5: The organizational culture and structure do not significantly impact the implementation and strategic prioritization of GLSS.	Ha_5: The organizational culture and structure significantly impact the implementation and strategic prioritization of GLSS.
6. How does the availability of technical resources and infrastructure affect the implementation and strategic prioritization of GLSS?	H0_6: The availability of technical resources and infrastructure does not significantly affect the implementation and strategic prioritization of GLSS.	Ha_6: The availability of technical resources and infrastructure significantly affect the implementation and strategic prioritization of GLSS.
7. What role do supplier and supply chain barriers play in the operational complexity and strategic prioritization of GLSS implementation?	H0_7: Supplier and supply chain barriers do not significantly influence the operational complexity and strategic prioritization of GLSS implementation.	Ha_7: Supplier and supply chain barriers significantly influence the operational complexity and strategic prioritization of GLSS implementation.
8. How does the availability and access to updated information and effective communication channels affect the implementation of GLSS?	H0_8: The availability and access to updated information and effective communication channels do not significantly impact the implementation of GLSS.	Ha_8: The availability and access to updated information and effective communication channels significantly impact the implementation of GLSS.
9. How does the level of employee engagement and dedication influence the operational complexity and strategic prioritization in GLSS adoption?	H0_9: The level of employee engagement and dedication does not significantly influence the operational complexity and strategic prioritization in GLSS adoption.	Ha_9: The level of employee engagement and dedication significantly influences the operational complexity and strategic prioritization in GLSS adoption.
10. How does the lack of commitment from suppliers and limited integration of sustainable practices affect the implementation and strategic prioritization of GLSS?	H0_10: The lack of commitment from suppliers and limited integration of sustainable practices do not significantly affect the implementation and strategic prioritization of GLSS.	Ha_10: The lack of commitment from suppliers and limited integration of sustainable practices significantly affects the implementation and strategic prioritization of GLSS.

5. Result and Discussion

In present Green Lean Six Sigma (GLSS) study, a normality check using SmartPLS has been performed to ensure that the dataset followed normal distribution assumptions. SmartPLS generated skewness and kurtosis statistics, with transformations applied as needed. Initial path model selected for the present study is shown in appendix along with all relations among latent variables were show in detail.

According to path diagram shown in Fig. 3 and Fig. 4, there were two dependant latent variables, in which first dependant variable Organizational Culture and Structure Barriers Construct (OCB) was connected with all independent latent variables, but this dependant variable OCB was also interconnected with final and most crucial dependent variable Strategic Prioritization and Commitment Barriers Construct (SPCB). The path coefficient relationship with dependant variable OCB and all independent latent variables are presented in Table 4. The interconnection relationship among OCB and SPCB variables with all ten independent variables are presented in Table 5. All ten independent variables and final crucial latent variables SPCB via OCB latent variables has also mentioned in the said table. According to Table 4, the path coefficients shows the relation among independent variable and dependent variables.

Table 4. Path coefficients for the GLSS.

Independent and Dependent variables Relation	Path coefficients
ATB -> OCB	0.07
FB -> OCB	-0.044
ICB -> OCB	-0.012
MLB -> OCB	0.36
OCB -> SPCB	0.209
OCSB -> OCB	-0.071
PPDB -> OCB	0.048
RB -> OCB	-0.04
ROIUB -> OCB	0.435
SSCB -> OCB	-0.052
TIB -> OCB	0.124

This research revealed significant positive relationships between Organizational Culture and Structure Barriers (OCB), and Awareness and Training Barriers (ATB), Management and Leadership Barriers (MLB), Public Perception and Demand Barriers (PPDB), the Role of Institutions in Unethical Behavior (ROIUB), and Technical and Infrastructure Barriers (TIB). Adjusting these variables can improve Organizational Culture and Structure Barriers. A negative association was found between OCB and behavioral factors, individual counterproductive behavior, organizational counterproductive safety behavior, routine behavior, and

Supplier and Supply Chain Barriers (SSCB), suggesting that these variables may weaken OCB. Notably, the path coefficient between ROIUB and OCB (0.435) highlights the significant role of institutions in unethical behavior as a strong predictor of OCB. The significant association between OCB and Strategic Prioritization and Commitment Barriers (SPCB) (path coefficient = 0.209) indicates that improving OCB can enhance SPCB. This analysis identifies potential intervention areas for enhancing OCB, emphasizing institutional roles in unethical and moral-legal behavior, and suggests measures to counteract the negative impacts of counterproductive and routine behaviors.

The PLS-SEM analysis is extended to evaluate the total effects of the independent variables on both OCB and SPCB. This exploration helps us understand the overall influence that each of the variables exerts on the outcomes, whether directly or indirectly. The total effects are presented in the Table 6. The Table 5 shows the indirect effect of the variables. The direct effect of the independent variables and dependent variables (intermediate and final both) were correlated in Table 6. The ROIUB has the greatest total influence on Organizational Culture and Structure Barriers (OCB) (0.435), followed by MLB (0.36), confirming our prior findings that these factors are powerful predictors of OCB. The fact that their total effects on SPCB are likewise substantial, with ROIUB at 0.091 and MLB at 0.075, demonstrates the impact of these factors on both OCB and SPCB. The combined detrimental effects of FB, ICB, OCSB, RB, and SSCB on OCB are consistent with previous findings. These effects are also mirrored in their effect on SPCB. Indicating the interventions to counteract these detrimental influences should target both OCB and SPCB.

Table 5. Indirect effect for the GLSS barriers.

Independent and Dependent variables Relation	**Specific indirect effects**
FB -> OCB -> SPCB	-0.009
PPDB -> OCB -> SPCB	0.01
SSCB -> OCB -> SPCB	-0.011
ROIUB -> OCB -> SPCB	0.091
TIB -> OCB -> SPCB	0.026
OCSB -> OCB -> SPCB	-0.015
RB -> OCB -> SPCB	-0.008
ATB -> OCB -> SPCB	0.015
ICB -> OCB -> SPCB	-0.003
MLB -> OCB -> SPCB	0.075

The total favorable effects of ATB, PPDB, and TIB on OCB are relatively less pronounced, but they also extended to SPCB, albeit to a lesser extent. This suggests that although these variables are less influential than ROIUB and MLB, they still have a substantial effect on the outcomes. Intriguingly, the total effect of OCB on SPCB is relatively high (0.209), indicating that interventions aimed at enhancing OCB can also have a substantial positive effect on SPCB. This research provides a full understanding of the intricate interactions between factors. The findings highlight the importance of variables such as ROIUB and MLB in fostering organizational citizenship behavior, and safe and productive citizenship behavior. The Table 7 presents a correlation matrix for all variables in the research, summarizing the associations between each pair of variables.

Table 6. Direct effect of the GLSS.

Independent and Dependent variables Relation	**Total effects**
ATB -> OCB	0.07
ATB -> SPCB	0.015
FB -> OCB	-0.044
FB -> SPCB	-0.009
ICB -> OCB	-0.012
ICB -> SPCB	-0.003
MLB -> OCB	0.36
MLB -> SPCB	0.075
OCB -> SPCB	0.209
OCSB -> OCB	-0.071
OCSB -> SPCB	-0.015
PPDB -> OCB	0.048
PPDB -> SPCB	0.01
RB -> OCB	-0.04
RB -> SPCB	-0.008
ROIUB -> OCB	0.435
ROIUB -> SPCB	0.091
SSCB -> OCB	-0.052
SSCB -> SPCB	-0.011
TIB -> OCB	0.124
TIB -> SPCB	0.026

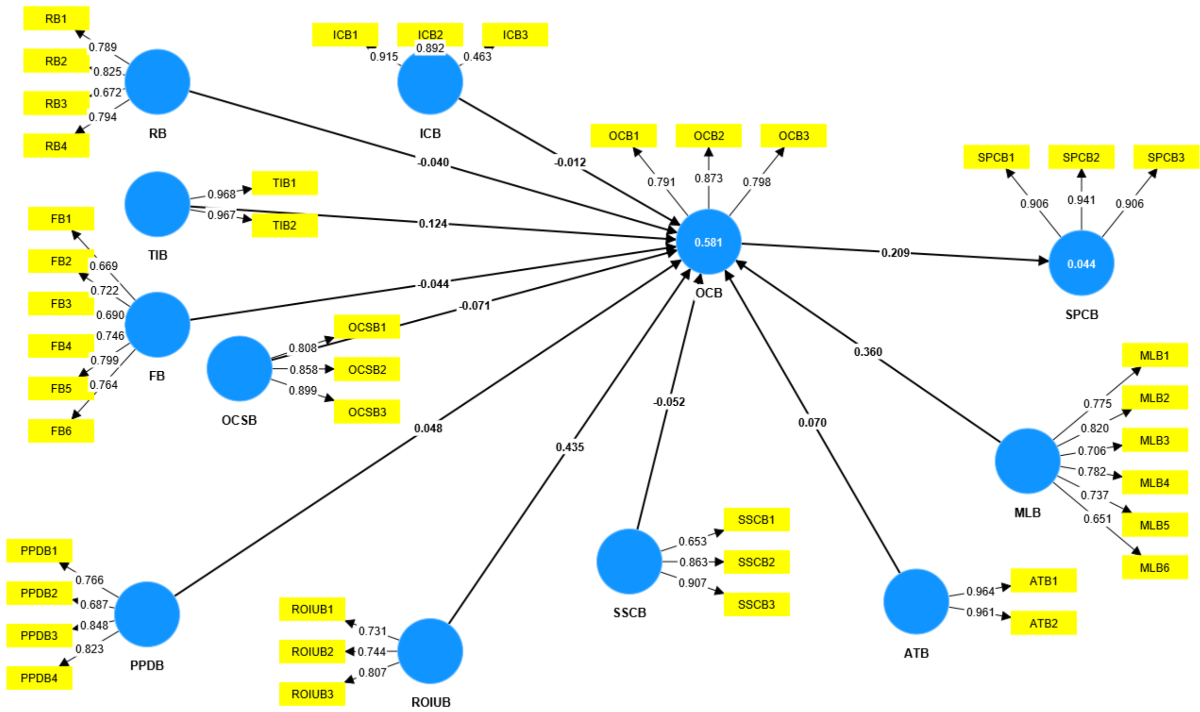

Fig. 3: Path coefficients for barriers.

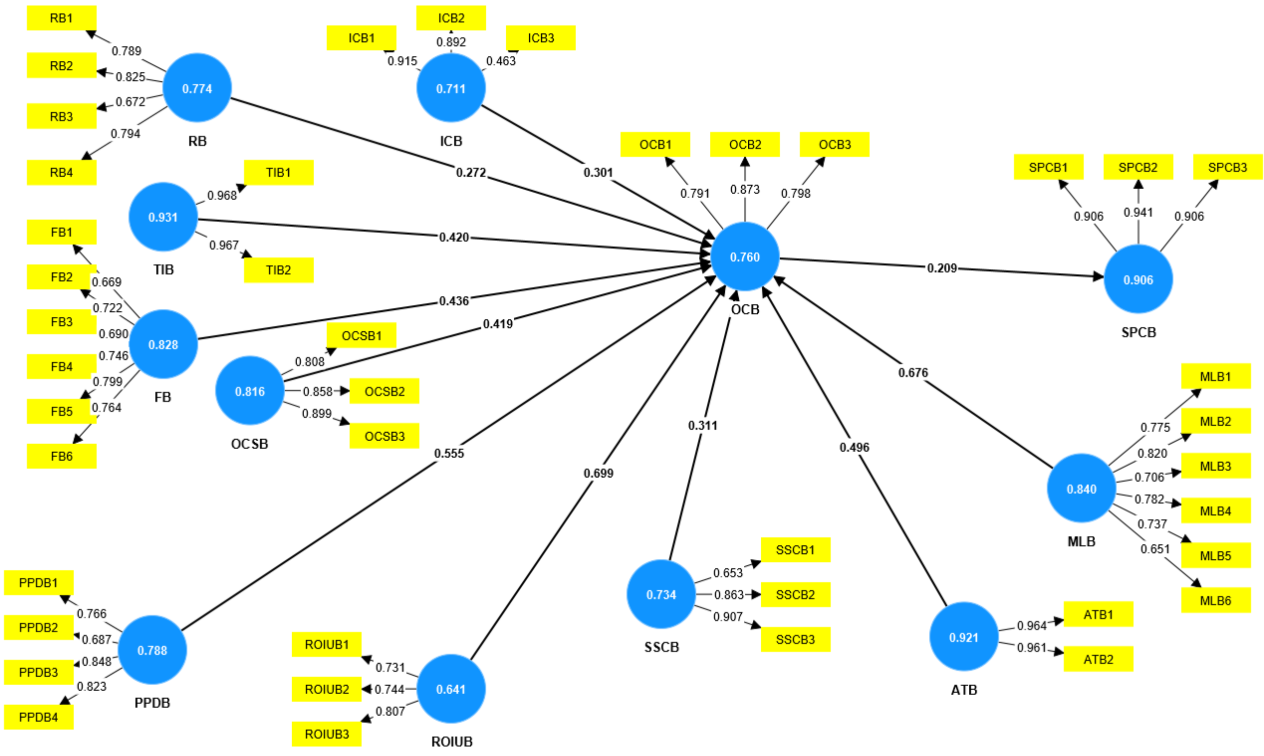

Fig. 4: Path coefficients for barriers on the basis of cronbach's alpha.

Table 7. Correlations among the latent variables.

	ATB	FB	ICB	MLB	OCB	OCSB	PPDB	RB	ROIUB	SPCB	SSCB	TIB
ATB	1	0.544	0.537	0.637	0.496	0.624	0.474	0.458	0.537	0.28	0.517	0.489
FB	0.544	1	0.488	0.54	0.436	0.452	0.635	0.668	0.591	0.292	0.435	0.386
ICB	0.537	0.488	1	0.414	0.301	0.451	0.389	0.496	0.408	0.315	0.798	0.368
MLB	0.637	0.54	0.414	1	0.676	0.577	0.619	0.387	0.678	0.282	0.458	0.456

	ATB	FB	ICB	MLB	OCB	OCSB	PPDB	RB	ROIUB	SPCB	SSCB	TIB
OCB	0.496	0.436	0.301	0.676	1	0.419	0.555	0.272	0.699	0.209	0.311	0.42
OCSB	0.624	0.452	0.451	0.577	0.419	1	0.442	0.368	0.467	0.155	0.616	0.693
PPDB	0.474	0.635	0.389	0.619	0.555	0.442	1	0.345	0.668	0.272	0.368	0.466
RB	0.458	0.668	0.496	0.387	0.272	0.368	0.345	1	0.392	0.289	0.469	0.317
ROIUB	0.537	0.591	0.408	0.678	0.699	0.467	0.668	0.392	1	0.31	0.411	0.42
SPCB	0.28	0.292	0.315	0.282	0.209	0.155	0.272	0.289	0.31	1	0.267	0.211
SSCB	0.517	0.435	0.798	0.458	0.311	0.616	0.368	0.469	0.411	0.267	1	0.454
TIB	0.489	0.386	0.368	0.456	0.42	0.693	0.466	0.317	0.42	0.211	0.454	1

The correlation coefficients range from -1 to 1, with positive values indicating that as one variable increases, so does the other. All relationships in this example are positive. The strongest correlation is between the ICB and SSCB (0.798), suggesting a strong positive link, meaning that gains in the ICB are significantly associated with improvements in the SSCB among ceramic SME manufacturers. MLB and ROIUB also show a strong association with OCB (0.676 and 0.699, respectively), indicating their significant impact on organizational citizenship behavior. Increased MLB and ROIUB values are expected to significantly increase OCB. OCB also has a notable association with SPCB (0.209), implying a positive but relatively weak link. Conversely, the correlation between OCSB and SPCB (0.155) is the lowest, indicating a weak relationship. FB and RB showed a strong association (0.668), suggesting that changes in feedback pathways may impact role behaviors in ceramic SMEs. However, it is important to note that correlation does not imply causality, and future research should explore the causal links between these variables more deeply.

The Table 8 displays the reliability and validity data for each latent variable in the study, including Cronbach's alpha, composite reliability (rho_a and rho_c), and average variance extracted (AVE).

Table 8. Construct reliability and validity among the latent variables.

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
ATB	0.921	0.922	0.962	0.927
FB	0.828	0.833	0.874	0.537
ICB	0.711	0.838	0.817	0.616
MLB	0.84	0.849	0.883	0.558
OCB	0.76	0.775	0.861	0.675
OCSB	0.816	0.82	0.891	0.733
PPDB	0.788	0.798	0.863	0.614
RB	0.774	0.792	0.855	0.596
ROIUB	0.641	0.654	0.805	0.58
SPCB	0.906	0.906	0.941	0.842
SSCB	0.734	0.738	0.853	0.664
TIB	0.931	0.931	0.967	0.936

The Cronbach's alpha values are used to determine the internal consistency of the scale's components. A greater Cronbach's alpha suggests that the components within a scale are internally consistent. In this study, all variables except for ROIUB had Cronbach's alpha values greater than the suggested minimum of 0.7, indicating acceptable internal consistency. Composite reliability (rho_a and rho_c) also provides a measure of internal consistency or reliability. These measurements consider the variance and inaccuracy of the indicator variables. All variables in this instance above the generally accepted criterion of 0.70 indicated adequate reliability.

The average variance extracted is utilized to measure the amount of variance captured by the construct relative to the measurement error variance. The criterion for AVE is at least 0.5, which indicates that at least 50% of the volatility of the indicators must be accounted for. In this instance, all variables except FB (0.537) match this criterion, showing a high level of convergent validity. The TIB and ATB have the highest reliability and validity statistics (Cronbach's alpha: 0.931 and 0.921; composite reliability (rho_a): 0.931 and 0.922; composite reliability (rho_c): 0.967 and 0.962; AVE: 0.936 and 0.927), indicating that the items within these constructs are highly interrelated and share a high proportion of variance.

The heterotrait–monotrait ratio (HTMT) is a metric for evaluating the discriminant validity of a measurement model. Compared to cross-loadings and the Fornell–Larcker criterion, the Fornell–Larcker criterion is a more rigorous and robust way to verify discriminant validity. In general, the HTMT threshold value is between 0.85 and 0.90, and values beyond these thresholds indicate a lack of discriminant validity between the components. The HTMT analysis is presented in Table 9 for all 12 variables including independent and dependent variables.

The majority of pairs of constructs in the measurement model exhibit good discriminant validity, as the HTMT values are below the 0.85 or 0.90 limits. This indicates that each pair of constructs captures distinct phenomena and is distinct from the others. The ICB-SSCB (1.041), MLB-ROIUB (0.921), and OCB-ROIUB (0.921) are examples of pairs of constructs for which the HTMT value surpasses the acceptable threshold (0.982). This shows that these conceptions lack discriminant validity, indicating that they may not capture separate notions. Several other pairings of constructs have HTMT values that are close to the top limit, including FB-RB (0.836), FB-ROIUB (0.821), and PPDB-ROIUB (0.958).

Table 9. HTMT analysis.

	ATB	FB	ICB	MLB	OCB	OCSB	PPDB	RB	ROIUB	SPCB	SSCB	TIB
ATB												
FB	0.619											
ICB	0.657	0.619										
MLB	0.732	0.645	0.481									
OCB	0.587	0.54	0.346	0.834								
OCSB	0.718	0.543	0.578	0.698	0.523							
PPDB	0.557	0.771	0.477	0.76	0.71	0.549						
RB	0.536	0.836	0.646	0.47	0.347	0.455	0.418					
ROIUB	0.697	0.821	0.535	0.921	0.982	0.651	0.958	0.552				
SPCB	0.306	0.341	0.345	0.321	0.244	0.179	0.318	0.341	0.4			
SSCB	0.623	0.559	1.041	0.575	0.405	0.78	0.477	0.627	0.593	0.327		
TIB	0.528	0.435	0.428	0.518	0.497	0.798	0.544	0.361	0.548	0.229	0.544	

To evaluate the validity of a reflective measurement model, the Fornell–Larcker criterion is widely applied and the results are presented in Table 10 for both independent and dependent variables. It examines discriminant validity by comparing the square root of the average variance extracted of each construct to its correlations with all other constructs. For discriminant validity, the square root of the AVE (diagonal values in the table) must be greater than the off-diagonal values in the respective rows and columns.

Examining the Fornell–Larcker criterion table reveals that the diagonal elements (representing the square root of the AVE) for each construct (ATB, FB, ICB, MLB, OCB, OCSB, PPDB, RB, ROIUB, SPCB, SSCB, and TIB) are greater than their respective off-diagonal elements.

6. Conclusion

The objective of this research was to examine the implementation of green lean six sigma methodology in ceramic SMEs using PLS-SEM model. A sample of 320 validated replies was used in the study where significant latent variables influencing the application of the GLSS in these businesses was identified.

Table 10. Fornell Larker analysis.

	ATB	FB	ICB	MLB	OCB	OCSB	PPDB	RB	ROIUB	SPCB	SSCB	TIB
ATB	0.963											
FB	0.544	0.733										
ICB	0.537	0.488	0.785									
MLB	0.637	0.54	0.414	0.747								
OCB	0.496	0.436	0.301	0.676	0.822							
OCSB	0.624	0.452	0.451	0.577	0.419	0.856						
PPDB	0.474	0.635	0.389	0.619	0.555	0.442	0.783					
RB	0.458	0.668	0.496	0.387	0.272	0.368	0.345	0.772				
ROIUB	0.537	0.591	0.408	0.678	0.699	0.467	0.668	0.392	0.761			
SPCB	0.28	0.292	0.315	0.282	0.209	0.155	0.272	0.289	0.31	0.917		
SSCB	0.517	0.435	0.798	0.458	0.311	0.616	0.368	0.469	0.411	0.267	0.815	

TIB	0.489	0.386	0.368	0.456	0.42	0.693	0.466	0.317	0.42	0.211	0.454	0.967

As demonstrated by Cronbach's alpha, composite reliability, average variance extracted, the heterotrait–monotrait ratio, and the Fornell–Larcker criterion, our analysis revealed that the latent variables in our model possessed excellent internal consistency reliability, convergent validity, and discriminant validity.

Further, the path coefficients revealed the varied degrees of influence that the independent variables had on Organizational Culture and Structure Barriers and then on Strategic Prioritization and Commitment Barriers. Variables such as MLB and ROIUB, which have strong positive effects on OCB, were of great interest. The subsequent examination of the cumulative effects of these variables on both OCB and SPCB corroborated these connections. The correlation matrix aided in visualizing the degree of correlations between the constructs, allowing for a thorough grasp of how one variable interacts with the others. Combined with the HTMT and Fornell–Larcker analyses, this strengthened the distinction between each construct, hence enhancing the validity and dependability of our findings.

The current research has provided important insights into the dynamics of GLSS implementation in ceramic SMEs. It is hoped that the findings will not only contribute to the academic literature on the topic but also provide industry stakeholders with a clearer understanding of the important elements impacting the successful implementation of the GLSS. It emphasizes the significance of particular behaviors, such as management leadership, and the perceived return on investments as major drivers in developing corporate citizenship behavior, which, in turn, improves strategic performance and competitiveness. Despite these findings, there are limitations to this study, and additional research is required to expand and deepen our understanding of GLSS adoption in other SME sectors.

7 Practical Implications and Limitations

The findings of this study have several practical implications for stakeholders in ceramic SMEs seeking to implement GLSS. By identifying key latent variables such as MLB and ROIUB, the study underscores the importance of leadership and financial incentives in fostering of OCB and improving Strategic Prioritization and Commitment Barriers. Industry leaders can leverage these insights to design targeted strategies for GLSS adoption, focusing on enhancing managerial involvement and demonstrating tangible returns from sustainable practices. The results also provide a roadmap for developing training programs, resource allocation, and policy frameworks that address critical barriers and promote a culture of continuous improvement. Additionally, SMEs can use the validated constructs from this study as benchmarks to assess their readiness and effectiveness in implementing of GLSS in their organizations to improve the productivity.

7.1 Limitations of the present study

Despite its contributions, the study has several limitations that warrant consideration;

Geographic and Sector Scope: The research focuses exclusively on ceramic SMEs, which may limit the generalizability of the findings to other industries or regions.

Cross-Sectional Design: The study employed a cross-sectional survey, which captures data at a single point in time and may not fully reflect the evolving nature of GLSS adoption and its long-term impact.

Sample Size Constraints: Although the sample size of 320 respondents is robust, it may not adequately represent all stakeholders within the ceramic SME sector.

Subjective Measures: Data was collected through self-reported surveys, which can introduce bias due to participants' subjective perceptions and interpretations.

Exclusion of External Factors: The study primarily examined internal organizational factors, potentially overlooking external influences such as market dynamics, regulatory changes, and economic conditions that can impact GLSS adoption.

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