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Key factors for implementation of total quality management in construction Sector: A system dynamics approach

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ABSTRACT

Maintaining quality in construction projects is paramount to project success, achieved through techniques such as Total Quality Management (TQM). However, the key factors of TQM implementation in the construction industry of developing countries are not well explored. Accordingly, this paper evaluated the causative relationship and intricacies of TQM implementation in the construction sector of developing countries. A total of 28 key factors of TQM were captured through a literature review. Thereafter, 12 significant key factors were shortlisted. Lack of top management commitment, poor customer/client satisfaction, inadequate quality of education regarding TQM, and ineffective organizational quality culture emerged as impediments to implementing TQM in the construction sector. A Causal Loop Diagram (CLD) was developed to represent interrelations between the 12 shortlisted factors. In addition, a system dynamics model (SDM) was developed. The simulation results of the developed SDM indicated an increase in TQM implementation over the period under the defined system.

1. Introduction

The construction sector is complex, nonlinear, dynamic, and fragmented [13]. Causality is an important characteristic of this sector [1]. The construction industry significantly contributes to the economic growth and social development of developing countries [2]. Maintaining quality in the construction sector is the rudimentary element for achieving strategic competitiveness, employee empowerment, employee involvement, customer repetition, diminishing rework, continuous improvement, increasing productivity, enhanced budget performance, and comparatively more desirable schedule performance [3]. Different quality management techniques such as total quality management (TQM), six sigma, top-down and bottom-up approach, implementation of the international standard organization codes (ISO), cost of quality, Kaizen, etc., have been utilized for the management of construction project quality [4,5].

TQM is a quality management technique that aims for long-term success through customer satisfaction. The main impediments to implementing TQM in developing countries include the absence of top management commitment, inadequate expertise, low bidding contract award concept, undervalued education and training, lack of workers involvement, lack of workers empowerment, rigorous attitude and behavior, and rigid approach of executives towards quality management system (QMS) [6]. The contributing challenges of TQM implementation related to the work environment are an unproductive quality system, excessive paperwork, inadequate knowledge of the process requirements, and the high cost of implementing TQM in the construction sector [6].

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Regardless of the wider implementation of TQM in many developed countries, construction sectors in developing countries lag the quality-oriented performance. As a result, most construction projects are prematurely terminated or revised because of quality issues such as incompetent and ineffectual workmanship. Accordingly, the construction sectors of developing countries must map out a structural and strategic framework to consider quality standards, quality assurance, quality control, and enactment of TQM to compete with their competitors in developed countries [7]. Such steps would minimize the gaps in terms of construction quality performance in developed and developing countries.

TQM plays a significant role in the business goals and objective achievements of construction organizations [8]. TQM is imperative for the success of organizations focusing on delivering high-quality projects. Therefore, implementing TQM in construction promises many benefits [9]. This explorative work is aimed to investigate the key factors of TQM implementation in the construction sector of developing countries. For this purpose, the systems thinking (ST) approach is adopted. Two questionnaires (preliminary and detailed) were developed using Google Docs ® and shared with respondents in the construction sectors of developing countries. The data extracted from respondents assisted in the statistical analysis, determining shortlisted key factors and assessing the causal relationships among shortlisted key factors. First, the cumulative normalized score, including literature and the construction industry, was calculated based on the preliminary questionnaire. Subsequently, the relative importance index (RII) of the key factors was determined. Based on the RII values of screened-out relationships and interrelation polarity, either a direct (+) or indirect (-), the influence matrix (IM) was mapped out. This was achieved through a detailed questionnaire.

System dynamics (SD) is a simulation-based approach for sorting out real-world intricacies by using causal relationships and polarity among variables [10;34;35]. SD is used to explore the behavior of social systems over time. It has been successfully applied to the manufacturing and construction industries [11]. In the 1950 s, this approach was suggested by Forrester from the Massachusetts Institute of Technology. Since then, it has evolved into a separate subject [35]. It is based on the concept of ST. An SD model uses a feedback mechanism where the values are inserted based on expert opinion. The model was developed to implement TQM in the construction sector of developing countries following relevant studies [12]. The SD approach is used to develop stock and flow diagrams (SFDs) and causal loop diagrams (CLDs) based on their causal relationship. The SD model is developed using computer tools such as VENSIM® software. This approach uses the feedback mechanism to address the complexity resulting from the implementation of TQM in the construction sector of developing countries. This results in a TQM-based QMS that can improve the overall project performance of construction sectors [12].

The construction sector has an inherent complexity. Such complexity presents a key challenge to project managers handling construction projects [13]. Therefore, implementing TQM in the construction sector is challenging and requires much concentration by the senior managers. Furthermore, the concept of TQM in the construction sector is novel, and intricacies pertaining to its implementation are not addressed. Previous studies have only focused on the generic perspectives [14]. However, a conceptual TQM framework or SD-based model has not been presented to date. Such framework or SD model is required to address the challenges causing complexity in implementing TQM in the construction sector of developing countries. Accordingly, the current study uses an ST approach combined with the SD model to address the intricacy of TQM implementation in the construction sector. It has the following objectives:

1. To identify and shortlist the key factors for implementing TQM practices in the construction sector of developing countries.
2. To evaluate the interconnectivity, causal relationship, and polarity among the shortlisted key factors.
3. To develop an SD model to address complexities resulting from the implementation of TQM in the construction sector of developing countries.

The rest of the study is organized as follows. The study is organized into four sections starting with a detailed literature review followed by a research methodology. After the research methodology, results and discussions are explained in detail. Finally, the conclusion and future recommendations are presented.

2. Literature review

2.1. Total quality management (TQM)

Quality as an expression has extensive definitions and meanings. As elucidated by several authors, quality is associated with meeting aesthetics and operative and legal conditions [15]. From the perception of the construction sector, it can be outlined as a successful accomplishment of the deliverables as per the specification of the project within the identified time and budget [16].

Quality is the excellence or fineness of any process, product, or system and measured against recognized standards of merit for such items and the needs of the product's end-users and other stakeholders[17]. TQM is the outcome of a revolution in quality management techniques [18]. TQM has three main keywords: total, quality, and management. Total refers to the consideration of every-one, quality refers to meeting their demands, and management implies commitment from every-one. Thus, it is not an isolated process but a team approach to meet quality requirements [19;20]. Table 1 provides the definitions of TQM as explained by various authors.

The concept of TQM in the construction sector is novel, and the intricacies of its implementation have not been addressed so far. The generic perspective is explicated by various authors. However, a holistic conceptual framework or SD model is required for addressing key challenges causing complexity in implementing TQM in the construction sector. This is particularly important for

Table 1
An overview of existing definitions of TQM.

Definitions of TQM	Reference
TQM is an integrative firm-wide management philosophy that continuously improves the quality of the processes, products, and services by meeting or exceeding customer expectations to enhance customer satisfaction and organizational performance.	[3]
TQM is a way of managing people and business processes to ensure complete customer satisfaction at every stage. Customer satisfaction is one of the main objectives of TQM, which directs organizational efforts toward the goal of TQM. In addition, TQM enhances innovative processes in an organization through continual improvement, thus ensuring sustainable development.	[21]
TQM implementation has a momentous association with firms' performance.	[22]
TQM is defined as identifying and managing management of the company to generate desirable performance changes to promote quality, productivity, customer satisfaction, and profitability, which are the necessary activities required to attain quality within an organization.	[23]
TQM is a "systematic quality practice" for the management of the company to generate desirable change in the performance to promote "quality, productivity, customer satisfaction, and profitability."	[3]

the construction industry of developing countries. This has been targeted in the current study.

2.2. TQM in construction sector

Through TQM implementation in the construction sector, an improvement in organization status, extensive market share achievement, and more client satisfaction can be achieved [24]. In addition, construction TQM brings forth a conducive work atmosphere where all employees indulge in attaining construction quality performance, pivot on customer delight, and strive to ameliorate the overall efficiency and productivity of the construction projects [17].

There are various benefits of implementing TQM in construction. However, at the same time, certain barriers impede its adoption in construction. These benefits and barriers are subsequently explained.

2.2.1. Benefits of implementing TQM in the construction sector

TQM is considered a well-regarded approach to managing project quality. It has proven to minimize nonconformity, complexity, and non-linearity and achieve distinction. Moreover, rapid development and competition have made 'Quality' a strategic tool for increased profit margin and corporate profitability for businesses and companies around the globe [25].

Construction organizations must promote TQM initiatives to meet customer demands and provide superior value to the customer through the company's operations, quality understanding, and responses. Several studies suggested TQM as a means of strategic and competitive edge that can increase construction sector productivity and efficiency [7]. Organizations following TQM principles gain a strategic market edge over their competitors [26]. TQM starts from the top; thus, the workers within the company will exhibit excellent workmanship and higher quality-oriented work if the company's senior managers have a greater quality-oriented approach [27].

Implementing TQM in the construction sector presents various advantages such as enhanced budget efficiency, customer delight, better workers' job contentment, diminished rework, exquisite schedule and budget performance, better procurement, and greater participation in the bidding process [28]. Quality is the key criterion that determines the superiority or inferiority of the construction product or service. This needs an understanding of how a construction product meets its desired specification. Regarding the development of total quality culture in the construction sector of developing countries, one significant milestone is to create a qualified construction team of suppliers, main contractors, and petty contractors. They would be accountable for valuable quality practices and implementing a genuine QMS [29]. Similarly, raising quality awareness and improving the skill levels of the project team also help adopt and implement TQM.

2.2.2. Challenges in implementing TQM in the construction sector of developing countries

Applying any technique that challenges and modifies the traditional setups of the construction industry is not straightforward [30]. Despite the advantages of the TQM approach, its consideration in the construction sector is not straightforward due to complexities such as the lack of senior management interests, unskilled human resources, inadequate training, poor leadership support, and lack of technical workforce [31]. While the construction sectors may be willing to embrace TQM concepts to enhance their efficiency and minimize complexities, they still lag behind other industries such as manufacturing and service. The primary impediments to TQM adoption in construction are the inability to evaluate client demands precisely and convert this knowledge into a complete facility [17]. (See Fig. 1).

Some challenges related to the working environment in the construction industry are low-bid subcontracting, improper communication channels among different stakeholders, high initial cost, poor organizational quality culture, traditional quality policy, unclear strategic process quality management, lack of customer delight, discontinuous improvement of processes and techniques, and lack of time to ensure quality control, quality assurance, and QMS [32]. These hinder the implantation of TQM. Similarly, the challenges related to human beings are lack of attitude and behavior towards TQM, lack of expertise, poor teamwork and workmanship, and lack of top management commitment, employee training, involvement, and empowerment [6]. The anticipated research model to scrutinize the influence of TQM practices in construction projects is presented in Fig. 2. The model links the eight mentioned quality factors with organizational development in developing countries. Therefore, these must be catered for to pave the way for TQM implementation in the construction industry of developing countries.

These mentioned key challenges cause intricacy and complexity in implementing TQM in the construction sector of developing countries. Therefore, in view of enhancing the overall quality performance and productivity of construction projects, these key challenges must be addressed to reduce uncertainty and intricacy throughout the life cycle of a construction project in developing countries.

2.3. Systems thinking and dynamics

ST is based on feedback and causal relationships established between various system components. It includes "systematic" or "holistic thinking," dependent upon learning relationships and interconnections between apparently scattered constructs. ST consists of a mental model illustration of the problem (conceptual model), whereas SD comprises the mathematical recreation of the problem to elaborate on the past and comprehend the future. ST, including a CLD, analyzes complex problems drawn through feedback mechanisms [34]. The SD approach is a simulation technique for resolving real-life complications, illustrating associations among variables in real complex systems. The SD method encompasses three elements: system, computer, and SD model, as shown in Fig. 3. The model originates from the system (which is the focus of the study). The computer runs the model through trial and error to reach an optimum value or trend [35].

Construction projects comprise multiple feedback loops: positive and negative. Negative feedback loops prevent the system from realizing a certain goal, while positive feedback loops help achieve the goal. Moreover, different constituents of construction projects have nonlinear behavior, e.g., the productivity of labor over time [35]. Therefore, The SD model is required for assessing the quality performance of the construction projects and the implementation of TQM in developing countries to cater to this non-linearity and associated complexities.

The literature strengthens the perspective that rigorous organization of TQM is required to achieve success throughout the project's life cycle [7]. The employees in any organization must recognize they are working for a common objective and must contribute to implementing TQM effectively [36]. Implementing TQM demands a paradigm shift in organization quality culture to become a leading organization in the construction domain [37]. Previous studies also indicated that behavioral aspects of management style or human factors are mainly focused on acquiring organizational and quality management goals [38]. A few studies identified the relationship between TQM and organization performance [39]. In a nutshell, previous studies focused on shortlisting

Fig. 1. Organization Development Research Model [33].

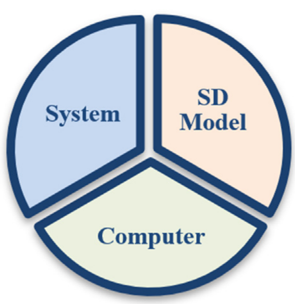

Fig. 2. System Dynamics Component [35].

critical success factors for implementing TQM but have not holistically structured their relative influence and associated causal relationships by defining systems thinking of TQM in construction.

The current study opts for a novel approach in the form of SD to address the complexity associated with implementing TQM in construction. The study aims to holistically define ST of TQM in construction using CLD and consequently develop an SD model to reflect the behavior of the defined system over time.

3. Research methodology

This study adopted a multi-stepped approach to achieve the objectives. The key steps are elaborated on below.

3.1. Literature retrieval and synthesis mechanism

After establishing the research gap, comprehensive literature was scrutinized from well-reputed journals, relevant books, and high-impact conference papers. While doing so, the articles published between January 1, 2012, to December 31, 2021, were studied. Fig. 3 shows the Preferred Reporting Items for Systematic reviews and meta-Analyses (PRISMA) diagram for the systematic literature review conducted in this study.

A total of 105 articles were identified as relevant to quality management in construction. These articles were identified using search repositories/databases such as Google Scholar, Research Gate, Web of Science, Scopus, and others. Further, these articles were screened based on their relevance to TQM. Accordingly, 50 relevant articles were identified. A full-text study of these 50 articles was carried out to scrutinize articles pertinent to our research objective. The number of shortlisted articles containing critical/contributing/key factors of TQM was 29. These final 29 articles were used to capture the most relevant contributing factors of TQM in construction. Twenty-eight key factors (18 related to organizational structure, ten humans related) were extracted from the literature. Content analysis was conducted to assign literature scores for each identified factor based on their ranking and frequency in the reviewed articles.

3.2. Data collection methods and tools

The surveys were conducted in two phases named a preliminary questionnaire survey and a detailed questionnaire survey.

3.2.1. Preliminary questionnaire survey

A preliminary survey was conducted using a questionnaire form generated in Google Docs®. The questionnaire consisted of two sections: basic details of respondents and a Likert-based ranking of factors. Likert scale (Low = 1, Medium = 3, High = 5) was provided to the respondents for ranking the key factors. Using the Likert scale, an industry score was assigned to each identified factor. Consequently, key factors were shortlisted using factor analysis on a weighting split of 60/40 (60 % field score, 40 % literature score) with a combined significance of 60 % and above [40].

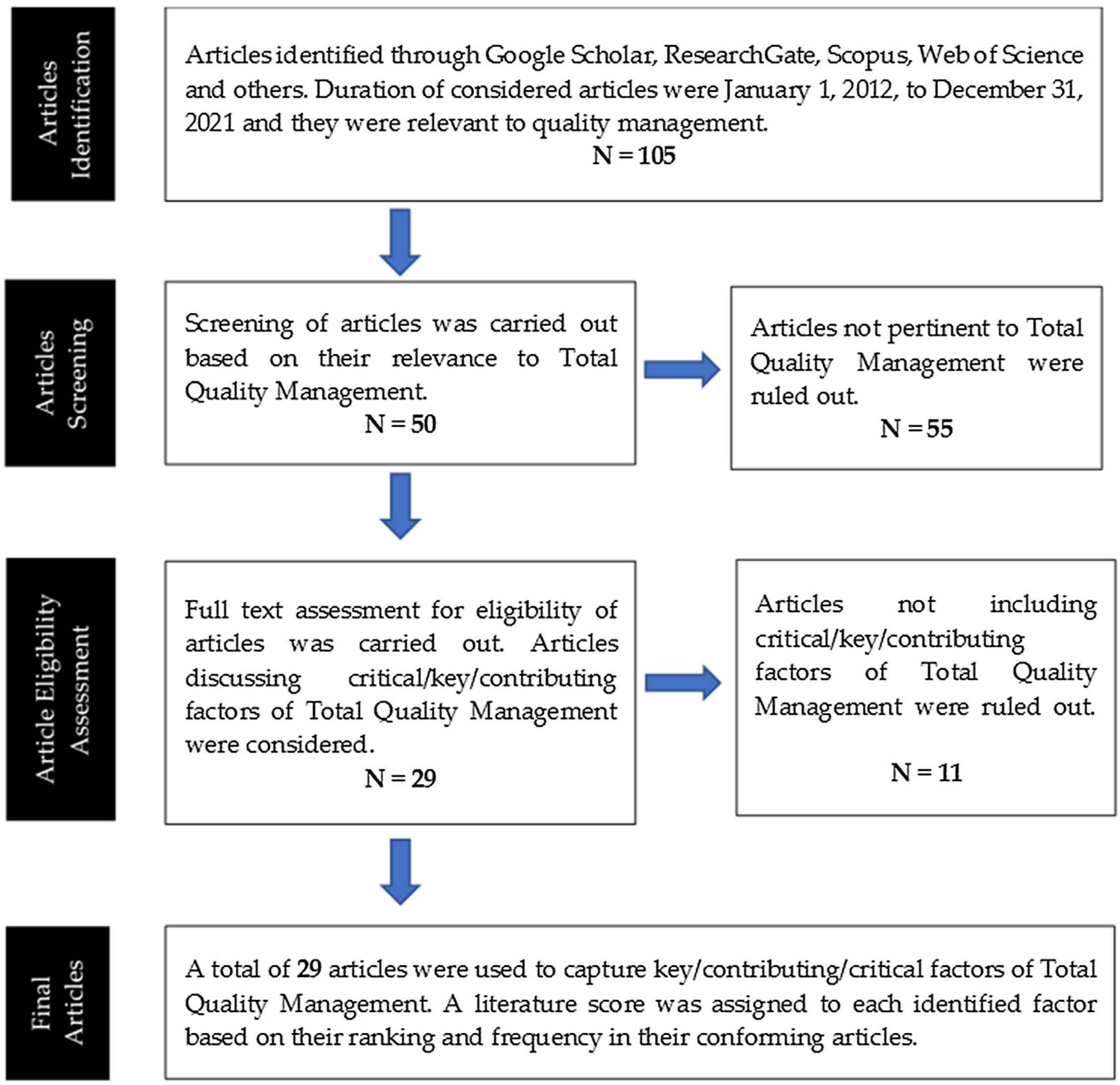

Fig. 3. PRISMA Diagram for Systematic Literature Review.

Sample Size: The optimum sample size was evaluated through equation (1) [41];

$$n = N/\left[1 + N(e)^2\right] \quad (1)$$

Here n = the anticipated sample size, e = probability of error (i.e., the desired precision, 0.05 % for 95 % confidence level), and the estimated responses from valuable respondents) required. As a result, the minimum sample size comes out to be 84. Data were collected from 107 respondents, out of which 84 responses were valid and 23 responses discarded. The respondents were industry professionals. The respondents were contacted through official emails and using social media platforms such as Linkedin®, Twitter®, and others.

3.2.2. Detailed questionnaire survey

A detailed questionnaire survey was conducted to determine the polarity and strength of relationships amongst factors shortlisted through the Preliminary Questionnaire Survey. It is composed of 132 causal relationships and the associated polarities. Using the significant interrelations and their polarities, an IM was developed. The development of an IM or impact matrix is an initial step toward ST and systems modeling [46]. IM encompasses interrelationships of significant factors and their polarities to develop the CLD. The quantitative values in IM that reflect the strength of influence are later normalized and used to develop equations in the subsequent systems dynamics model (SDM).

3.2.2.1. Sample size. The optimum sample size was evaluated through equation (1) [41];

As a result, the minimum sample size comes out to be 121. Thus one hundred twenty-one experienced respondents were asked to rank causal relationships on the Likert scale in conjunction with direct or indirect polarity. Respondents were asked to give their feedback in a grid format (combined level of influence and polarity) using the detailed questionnaire.

3.2.2.2. Respondent's detail and demographics. Data was accumulated from 174 respondents, out of which 53 were invalid, and 121 factual responses were utilized for further analyses. The respondents were contacted through their official emails and social media such as LinkedIn, Twitter, and others. Regarding qualifications, 34 % of respondents had a bachelor's degree, 61 % had master's degree, and 5 % had a doctoral degree. The professional experience of 64 % of the respondents ranged from 1 to 5 years, and 22 % had 6 to 10 years of experience. Similarly, 6 % of respondents had 11 to 15 years of extensive experience, and 8 % of informants had more than 20 years of professional experience. Regarding the designation of respondents, most respondents had jobs such as construction managers and project managers, followed by quantity surveyors, construction designers, architects, and consultants. The demographics of the respondents are shown in Table 4, along with the frequencies of responses.

In terms of organization type, 35 % of the respondents were from contractor organizations, while 15 % were from client domains. Further, 35 % of the respondents were consultants, while 2 % were specialty contractors. The remaining 13 % were from the academic domain, and 3 % were project managers, as shown in Fig. 4a.

In terms of statistics, 62 of the respondents were from Pakistan, 11 were from India, 6 from Bangladesh, 2 from Qatar, 6 from South Africa, 5 from Iran, 4 from Algeria, 2 from Azerbaijan, 2 from Tanzania, and 3 from Iran and 1 from Siri Lanka, etc. Thus, all respondents belonged to developing countries, as shown in Fig. 4b.

3.2.2.3. Data reliability and Consistency check. The Cronbach's Alpha test was conducted to check the reliability and internal consistency of data. Its benchmark value is 0.7; the higher the value, the more reliable and internally consistent the data will be. Cronbach's Alpha value was 0.9 in the current study, which indicated that the data is sufficiently reliable and internally consistent, as shown in Tables 5 and 6 [45].

3.3. CLD development and SD approach

IM was used to craft the CLD to reflect ST of TQM in construction. Experts were engaged who verified the developed CLD to

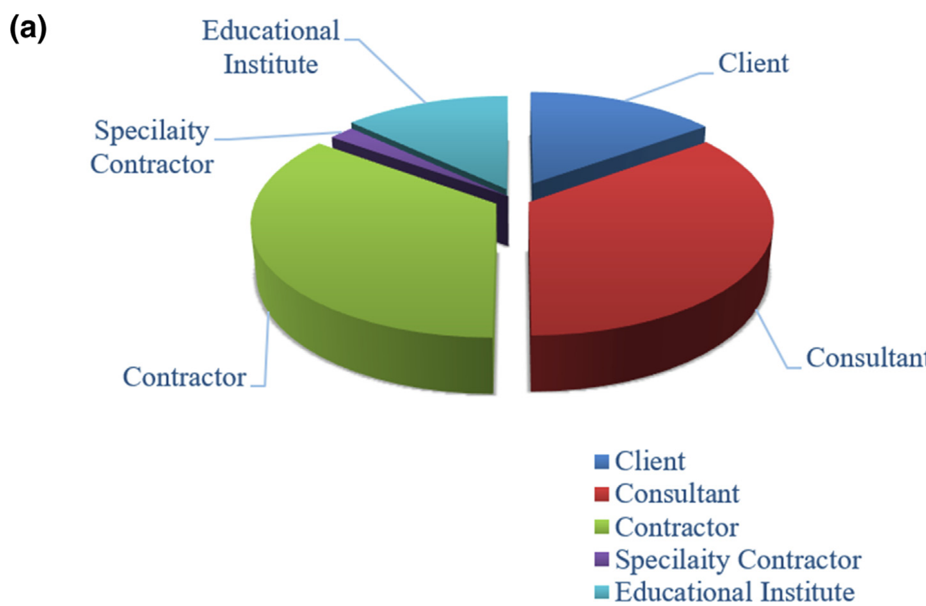

Fig. 4a. Organization types of respondents.

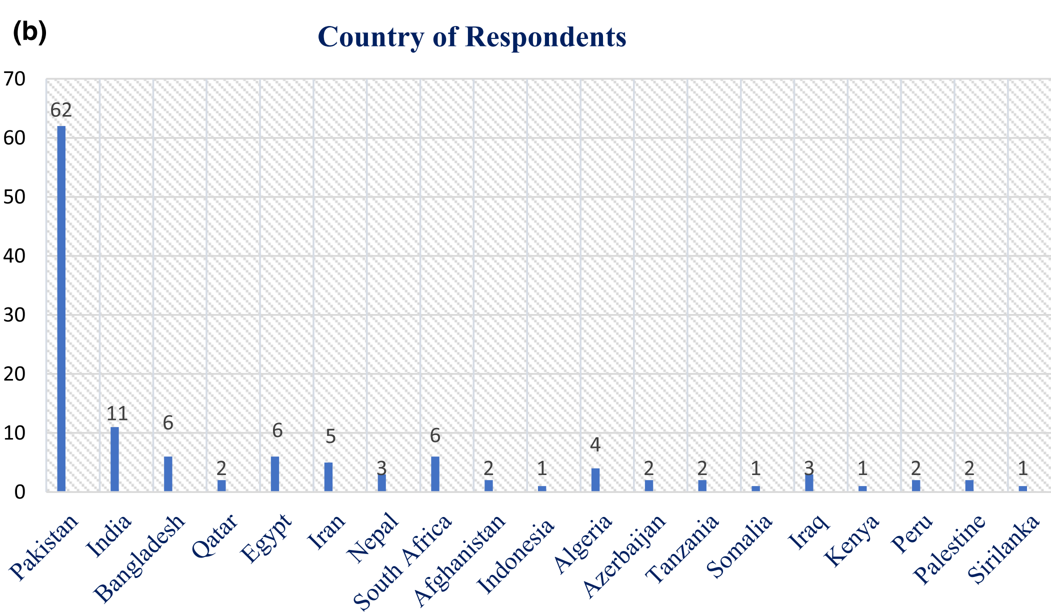

Fig. 4b. Detailed survey: Regions of respondents.

ensure its meaningfulness, logic, and relevance to the construction industry. Thereafter, an SDM was developed through Vensim® software using CLD. The model encompassed a total of three stocks. An additional stock named TQM was introduced, and the three stocks mentioned above were merged to visualize the system's combined effect on TQM. The equations for stocks and variables were developed based on normalized RII scores. The model was simulated over five years to visualize each stock's behavior and overall system of TQM in construction.

3.4. Validation

The SDM developed in this study aimed to address the complexity resulting from implementing TQM in the construction sector of developing countries. To achieve this, it is important to validate the model. Therefore, four tests were conducted to validate the SDM [49]: Boundary Adequacy Test, Structure Verification Test, Parameter Verification, and Extreme Condition Verification. The schematic representation of the complete research methodology is shown in Fig. 5.

4. Results and discussions

4.1. Results - preliminary questionnaire survey

Respondents were asked about the significance of each factor on a Likert scale (from 1 to 5). Then, these scores were combined to get the final ranking of key factors. The weighting split used in this respect is 60/40 (60 % score dedicated to the construction industry and 40 % to literature). The Simple Majority Principle was used for shortlisting the factors having a combined significance (literature and industry) of 60 %. As a result, twelve key factors were shortlisted [40].

Based on Table 2 and the cumulative frequency chart for key factors of TQM, shown in Fig. 6, the key factors were highlighted (60 % of significance as the break-off point). Twelve key factors,

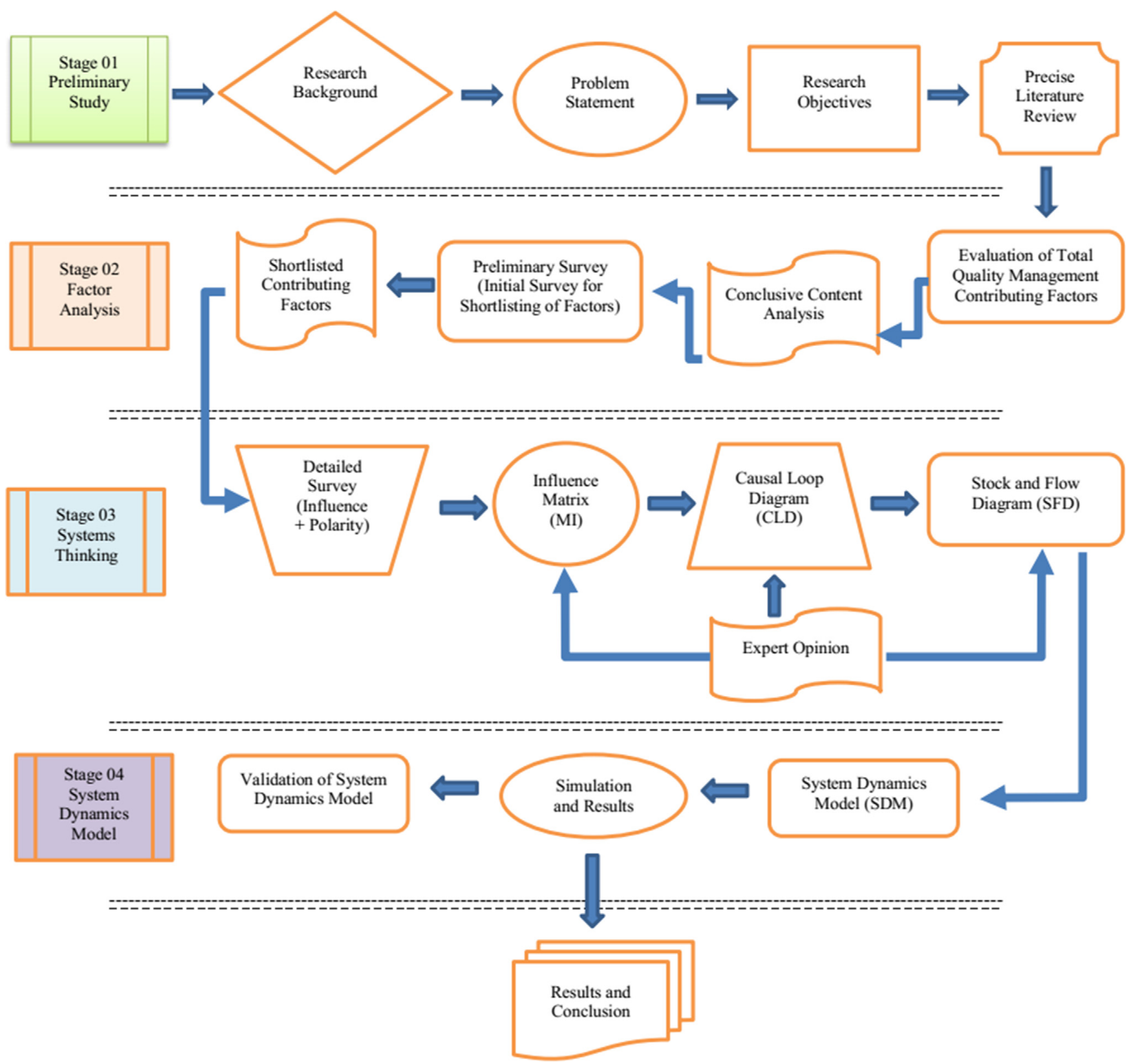

Fig. 5. Research Methodology.

Table 2
Ranking based on the total cumulative normalized score by using a 60/40 ratio.

Sr.No .	Key Factors of TQM	Total Score 60/40	Cumulative Normalized Score	Key References
1.	Top Management Commitment	0.0732	0.0732	[42;43;37;44;33;41;27]
2.	Customer Satisfaction	0.0649	0.1381	[43;42;37;44;33;28;38;23]
3.	Quality of Education Regarding TQM	0.0511	0.1893	[42;43;38;27]
4.	Organization Quality Culture	0.0470	0.2363	[42;43;38;41;27]
5.	High Initial Cost	0.0449	0.2813	[33;38]
6.	Continuous Improvement	0.0449	0.3262	[44;28;38;23]
7.	Employee Training	0.0445	0.3707	[43;44;33;38;41;27]
8.	Employee Involvement	0.0430	0.4138	[37;44;33;28;38;27]
9.	Employee Empowerment	0.0438	0.4577	[43;37;44;28;38;27]
10.	Appropriate Communications Medium	0.0408	0.4985	[43;37;33;38;41;27]
11.	Attitude and Behavior Towards TQM	0.0346	0.5331	[37;44;38;23;27]
12.	Low Bid Subcontracting	0.0339	0.5671	[37;28;38]
13.	Leadership	0.0325	0.6197	[42;43;37;38];
14.	Supplier Quality Management	0.0317	0.6314	[43;44;38];
15.	Process Improvement	0.0290	0.6605	[44;28;38];
16.	Human Resource Management	0.0290	0.6896	[43;28;38;41;27];
17.	Supplier Relationship	0.0284	0.7180	[42;43;37;44;28;38]
18.	Expertise & Resources	0.0284	0.7464	[37;44;38]
19.	Employee Satisfaction	0.0271	0.7736	[44;28;38;23;27]
20.	Benchmarking	0.0271	0.8008	[28;38]
21.	Strategic Quality Improvement	0.0271	0.8280	[43;44;33;38]
22.	Excessive Paper Work	0.0269	0.8549	[37;44;38;23]
23.	Process Quality Management	0.0263	0.8813	[43;37;44;38]
24.	Quality Policy	0.0259	0.9072	[37;38]
25.	Time to Implement TQM	0.0253	0.9326	[37;28;38;41;27]
26.	Teamwork	0.0247	0.9573	[42;43;38]
27.	Resources	0.0242	0.9816	[43;38;41]
28.	Financial Management	0.0193	1	[37;28;38]

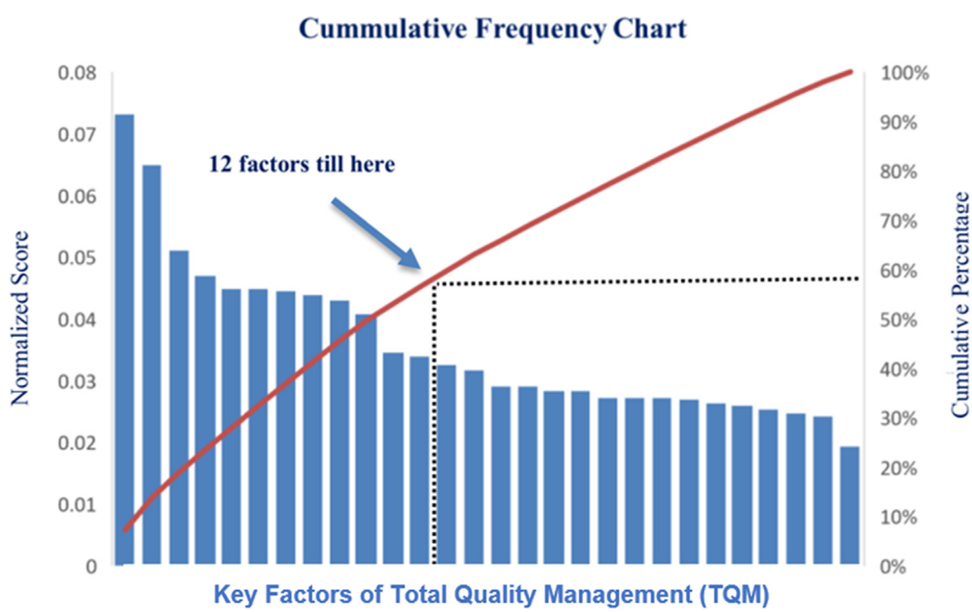

Fig. 6. Cumulative Frequency Chart for Key Factors of TQM.

possessing cumulative normalized scores until 60 %, were shortlisted for further analysis [40].

Table 3 shows the detailed breakdown of the key shortlisted factors coded as F1,2,3…12. The normalized literature score, normalized industry score, the total score (60/40), cumulative normalized total score, and ranking (60/40) are shown in Table 3. Top management commitment, customer satisfaction, quality of education regarding TQM, organization quality culture, and the high initial cost were key factors.

4.2. Result - detailed questionnaire survey

The correlation between impacting and the impacted factors and their polarities determined through the Detailed Questionnaire Survey is shown in Table 7. According to Table 7, the shortlisted key factors, causal relationship, and polarity are either direct or indirect. The correlation between impacting and impacted factors are considered to determine the RII of key factors. The correlations with a mean value greater than or equal to 3.75 are taken

Table 3
Ranking of factors based on 60/40 weighting split and combined significance of 60%.

Code	Key Factors of TQM in the Construction Sector	Normalized Literature Score	Normalized Industry Score	Total Score 60/40	Cumulative Normalized Total Score	Ranking (60/40)
F1	Top Management Commitment	0.11363	0.04629	0.0732	0.07323	1st
F2	Customer/ Client Satisfaction/Focus	0.09297	0.04629	0.0649	0.13819	2nd
F3	Quality of Education Regarding TQM	0.07231	0.03703	0.0511	0.18934	3rd
F4	Organization Quality Culture	0.06198	0.03703	0.0470	0.23636	4th
F5	High Initial Cost	0.05681	0.03703	0.0449	0.28131	5th
F6	Continuous Improvement	0.05681	0.03703	0.0449	0.32626	6th
F7	Employee Training	0.05578	0.03703	0.0445	0.37079	7th
F8	Employee Involvement	0.05268	0.03703	0.0430	0.41385	8th
F11	Employee Empowerment	0.04028	0.04629	0.0438	0.45775	9th
F12	Appropriate Communications Medium	0.04648	0.03703	0.0408	0.49856	10th
F14	Attitude and Behavior Towards TQM	0.03099	0.03703	0.0346	0.5331	11th
F18	Low Bid Subcontracting	0.01549	0.04629	0.0339	0.5671	12th

Table 4
Respondent demographics and frequency of responses.

Profile	Frequency	Percentage
Total responses = 121		
Title of Job		
Project Manager	20	16 %
Construction Manager	35	29 %
Site In-charge/Execution	5	4 %
Architect	12	10 %
Construction Design Consultant	25	21 %
Quantity Surveyor	14	12 %
Consultant	10	8 %
Qualification		
Bachelors (B.Eng./B.Sc.)	41	34 %
Master (M.Sc.)	74	61 %
Doctorate (PhD/D.Eng.)	6	5 %
Professional Experience		
0 to 5 years	75	64 %
6 to 10 years	27	22 %
11 to 15 years	8	6 %
16 to 20 years	6	4 %
21 and above	5	4 %

Table 5
Cronbach's Alpha Benchmark Values

The Relationship between Cronbach's alpha Value and Internal Consistency	
Cronbach's alpha Value (α)	Internal Consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

Table 6
Reliability Statistics.

Cronbach's Alpha	Number of Items
0.9	132

for further analysis and mapping out the CLD. Causal relations showing an RII value greater or equal to 0.75 or having a mean value of 3.75<=m=<5 are used for further analysis [47].

4.3. The influence matrix

The influence matrix was mapped out in accordance with the results, interpretation, and analysis of the preliminary and detailed questionnaire survey. In Table 8, impacting factors are presented on the x-axis, and impacted factors are presented on the y-axis. The causal relationships with a mean value greater or equal to 0.75 are considered and illustrated, respectively. The positive sign and the normalized relative importance index indicated direct polarity, and the negative sign and normalized relative importance index exhibited indirect polarity.

4.4. Causal loop Diagram

A CLD was developed according to the interrelationships having a mean influence value ranging from 3.75=<m<=5. The CLD is formulated based on expert opinions to make it logical and meaningful. The following step was to ensure that feedback loops revolved in the same direction. Some of the interrelations were overlooked that was going away from the system [48]. The CLD is constituted of four reinforcing and two balancing loops as shown in Fig. 7. Each loop is elaborated subsequently.

4.4.1. Knowledge of TQM (Reinforcing loop R1)

Reinforcing loop R1 (as shown in Fig. 8) extrapolated that as top management commitment amplifies, it encourages employee involvement and strongly influences continuous improvement of construction projects. Furthermore, the quality performance of construction organizations is improved due to concurrent continual improvement and refined quality of knowledge regarding TQM. Thus, this loop reinforces prompt and robust influence and is marked as a reinforcing loop (R1).

4.4.2. Employee collaboration towards quality policy making (Reinforcing loop R2)

Reinforcing loop R2 (as shown in Fig. 9) deduced that increased senior management commitment coupled with employee participation in policy and decision-making leads to relentless improvement of construction projects. Furthermore, as continuous improvement progressively escalates, communication channels among dominant stakeholders, i.e., client, consultant, and contractor, are improved. Thus, the quality performance of construction projects and TQM implementation are spontaneously increased.

4.4.3. Effective communication and coordination mechanism (Reinforcing loop R3)

Fig. 10 represents reinforcing loop *R*3 which implies that a significant uplift in executive management commitment increases employee professional training and development of technical expertise. Thus, continuous improvement can be influenced positively. Appropriate communication medium has a pivotal role in the success or failure of any thriving construction organization. Therefore, it is an indispensable prerequisite to reveal the most appropriate communication channels within a construction project

Table 7
Correlation of Impacting Factors and Impacted Factors.

Sr. No.	Impacting Factor	Impacted Factor	Mean	Polarity
1	Customer/ Client Satisfaction/Focus	Top management commitment	3.99	+
2	Low Bid Subcontracting	Initial Cost	3.96	+
3	Quality of Education Regarding TQM	Top management commitment	3.84	+
4	Poor Organization Quality Culture	Quality of Education Regarding TQM	3.76	–
5	Low Bid Subcontracting	Attitude and Behavior Towards TQM	3.76	–
6	Initial Cost	Customer/Client focus/Satisfaction	4.12	–
7	Continuous Improvement	Quality of Education Regarding TQM	3.78	+
8	Employee Training	Continuous Improvement	4.04	+
9	Top Management Commitment	Employee Training	4.19	+
10	Top Management Commitment	Low bid subcontracting	3.81	–
11	Employee Empowerment	Top management commitment	3.89	+
12	Employee Involvement	Continuous Improvement	3.88	+
13	Top Management Commitment	Employee Involvement	3.90	+
14	Continuous Improvement	Employee Empowerment	3.76	+
15	Appropriate Communications Medium	Top management commitment	4.32	+
16	Continuous Improvement	Appropriate communications medium	3.88	+
17	Attitude and Behavior Towards TQM	Poor Organization Quality Culture	3.90	–

Table 8
Influence Matrix Established from Correlation of Impacting Factor and Impacted Factors.

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
V1	1	0.80	0.77						0.78	0.86		
V2		1			−0.82							
V3			1	−0.75		0.76						
V4				1							−0.78	
V5					1							−0.79
V6						1	0.81	0.78				
V7	0.84						1					
V8	0.78							1				
V9						0.75			1			
V10						0.78				1		
V11											1	0.75
V12	−0.76											1

V1: Top Management Commitment V2: Customer Client Satisfaction/focus V3: Quality of Education Regarding TQM V4: Poor Organization Quality Culture V5: Initial Cost V6: Continuous Improvement V7: Employee Training V8: Employee Involvement V9: Employee Empowerment V10: Appropriate Communication Medium V11: Attitude and Behavior Towards TQM V12: Low Bid Subcontracting; Y-Axis = Impacted Factor, X-Axis = Impacting Factor.

to certify quality-oriented performance and underpinning of TQM. As effective communication and coordination mechanisms are developed, the quality performance of construction projects is rapidly improved. Therefore, this loop is considered to have a volatile, robust, reinforcing impact.

4.4.4. Effective Employee Empowerment (Reinforcing loop R4)

Fig. 11 represents reinforcing loop R4 which infers that an increase in top management commitment leads toward advancing employee professional training and uninterrupted improvement of construction projects. Furthermore, as the continuous improvement of construction procedures and operations increases, employees' quality-focused attitude and morale boost, reducing rework and fostering the TQM concept. Hence, this loop carried a slow but strong impact and was identified as a reinforcing loop.

4.4.5. Reluctant Attitude towards adaptation (Balancing loop B1)

Balancing loop B2 (as shown in Fig. 12) concluded that top management has an inverse relationship with low bid subcontracting. As top management commitment increases, low bid subcontracting decreases gradually. Low bid subcontracting is a corner-cutting contract awarding mechanism based on the preference of the lowest cost vendor. This method can compromise the overall quality of the project. As low bid subcontracting is reduced, the attitude and behavior of the client/customer towards TQM are amplified. Accordingly, the poor organization quality culture is reduced. As poor organizational quality trends are reduced, the quality of education, training, and quality practices in implementing TQM is increased. Hence, loop B1 carries a strong and fast influence that is self-balancing.

4.4.6. The cost of cutting corners in the construction sector (Balancing loop B2)

Self-balancing loop B2 (as shown in Fig. 13) deduced that as top management commitment increases, low bid subcontracting decreases leading to higher initial costs. As upfront cost increases, customer satisfaction and focus decrease. Customer delight can be achieved if anyone in the organization from either the lowest or highest position takes part wholeheartedly in completing the project while optimizing cost and taking time management into account. Since top management commitment is directly proportional to customer delight, this commitment increases customer client satisfaction and interest in TQM increases. Consequently, loop B2 carries a strong and fast influence that is self-balancing.

4.5. Stock and flow Diagram

The SFD (Fig. 14) is developed based on the CLDs presented in Section 4.4. Top management commitment, quality of education regarding TQM, and continuous improvement were the three stocks in the model. An additional stock (TQM) was incorporated into the model to observe the convergence of the existing three stocks. The key factors were linked with these stocks, and the model was simulated accordingly.

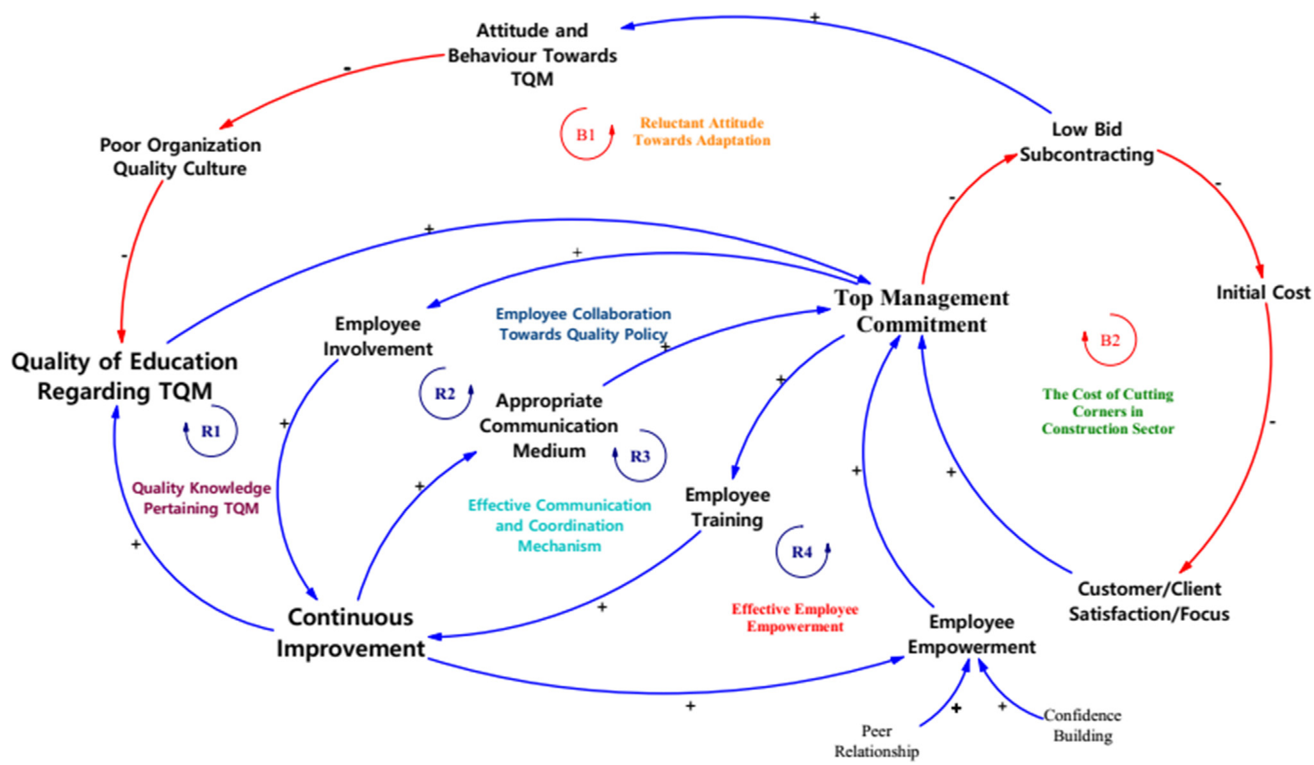

Fig. 7. Causal Loop Diagram (CLD).

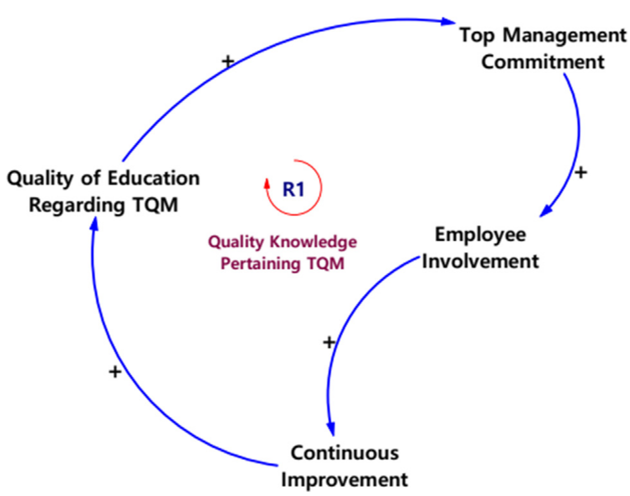

Fig. 8. Reinforcing Loop R1.

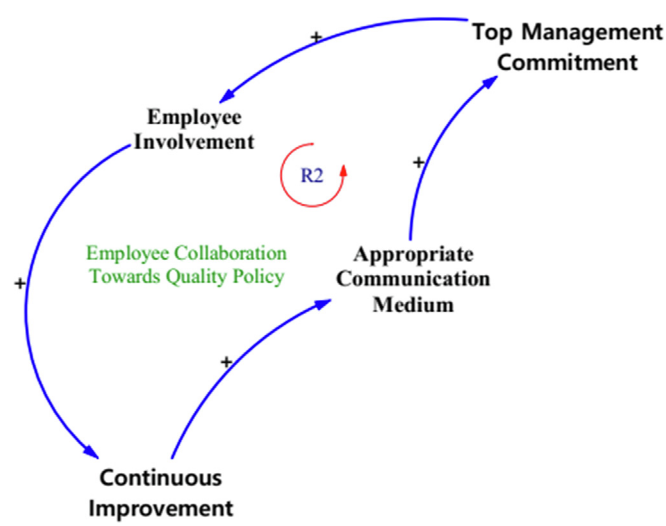

Fig. 9. Reinforcing Loop R2.

4.6. System dynamics model

Based on the CLD and SFD, the SD model of the current study is developed. The RII of key factors is calculated based on the mean value presented in Table 9. If the nature of queries was not unique and unrelated, the mean value was chosen over the mode value [35]. Consequently, 17 causal relationships were established with RII greater than or equal to 0.75. Equation (2) was used to calculate the mean value.

$$\text{Mean Value} = (1*\text{Low} + 3*\text{Medium} + 5*\text{High})/\text{Number of respondents} \tag{2}$$

Multiple equations were developed through normalized mean influence for inflows and outflows of all stocks. These are given in equations (3) to (10) below.

$$TMCinflow = 0.06*V2 + 0.057*V3 + 0.058*V9 + 0.065*V10 + 1*V1 \tag{3}$$

$$TMCoutflow = 1*V1 \tag{4}$$

$$QOERegardingTQMinflow = -0.056*V4 + 0.057*V6 + 1*V3 \tag{5}$$

$$QOERegardingTQMoutflow = 1*V3 \tag{6}$$

$$CIinflow = 0.058*V8 + 0.061*V7 + 1*V6 \tag{7}$$

$$CIoutflow = 1*V6 \tag{8}$$

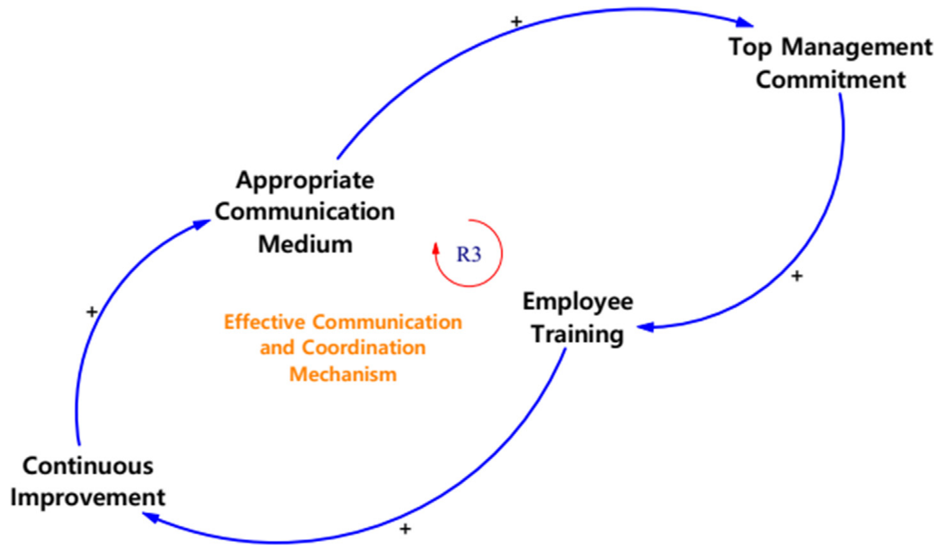

Fig. 10. Reinforcing Loop *R3*.

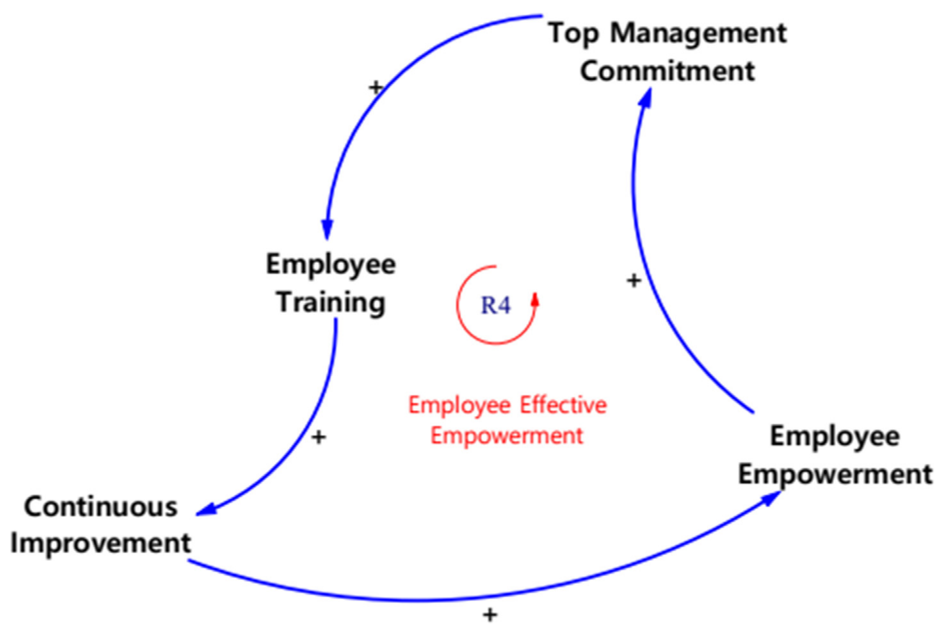

Fig. 11. Reinforcing Loop R-4.

$$TQMinflow = V6 + V3 + V1 + 1.00 * TQM \quad (9)$$

$$TQMoutflow = 1.00 * Totalqualitymanagement \quad (10)$$

Where TMC means Top Management Commitment, QOE means Quality of Education, CI means Continuous Improvement, V1 represents Top Management Commitment, V2 represents Customer Client Satisfaction/focus, V3 represents Quality of Education Regarding TQM, V4 represents Poor Organization Quality Culture, V6 represents Continuous Improvement, V7 represents Employee Training, V8 represents Employee Involvement, V9 represents Employee Empowerment and V10 represents Appropriate Communication Medium.

Based on the CLDs, SFDs, and equations (1)–(9), the SD model for the current study is developed, as shown in Fig. 15.

4.6.1. Simulation and results

This simulation represented the behavior of the complex integrated systems and the three stocks (top management commitment, quality of education regarding TQM, and continuous improvement). These stocks were simulated distinctly over five years in VENSIM software. Subsequently, an additional stock expressed as TQM was also simulated to deduce the impact of all three stocks, which were converged on it, as shown in Fig. 16.

The graph in Fig. 16 inferred that TQM implementation amplifies as top management commitment, continuous improvement, and quality knowledge of TQM strengthens. As top management commitment increases, employee integrity and allegiance towards continuous quality performance improvement magnify. Top-tier commitment is directly proportional to the constant improvement of the project. Further, the quality of education about TQM supports fact-based decision-making that leads to process improve-

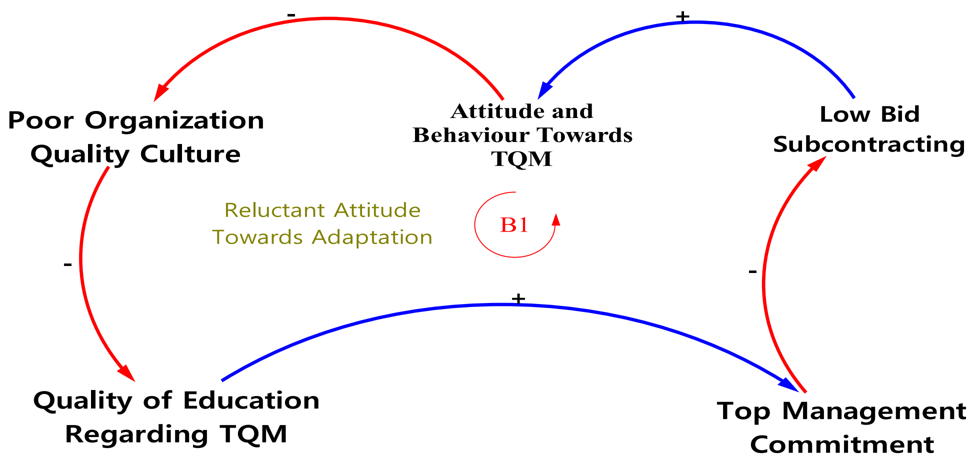

Fig. 12. Balancing Loop B-1.

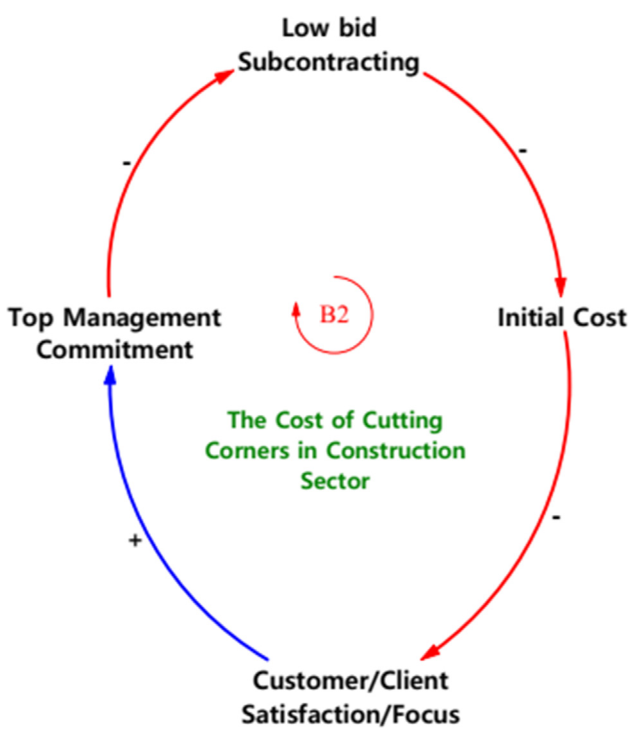

Fig. 13. Balancing Loop B-2.

ment of construction projects. This overwhelming trend in the graph leads toward exponential quality improvement and implementation of TQM in the construction sector of developing countries.

The behavior over time graph (BOTG) of low bid subcontracting, shown in Fig. 17, implies that low bid subcontracting exponentially decreases over time. Thus, low bid subcontracting is inversely proportional to senior management commitment. The concept of low-bid subcontracting cuts corners and ultimately jeopardizes the quality of the construction project. As superior commitment is amplified, constancy of purpose and organization-wide process improvement is inevitably achieved. Thus, customer delight and associated construction quality performance are achieved. Consequently, the BOTG of low bid subcontracting and high initial cost declined over five years in the current simulations.

Fig. 18 shows that the implementation of TQM in the construction sector of developing countries has inevitably magnified over five years. Employee mutual reciprocity, training, and collaboration lead to relentless improvement and influence the overall project quality performance of construction projects in developing countries. Furthermore, the profound TQM knowledge contributes to construction process improvement, revamping quality policy, fact-based decision making, employee prerogative, pre-eminent quality culture, averting cutting corners, and pulling off customer delight.

4.7. Model validation

As mentioned in section 3.4, four tests were conducted to validate the System Dynamics model (SDM) [49]: Boundary Adequacy Test, Structure Verification Test, Parameter Verification, and Extreme Condition Verification which are explained below.

A boundary adequacy test was conducted to endorse the three constituents. These include assessing whether all significant insights are endogenous to the system, whether the behavior of model change is significant when boundary conditions are changing and whether policy recommendations change when the boundary is extended. All variables are endogenous in the present model except two exogenous, i.e., peer relationships and confidence building. Consequently, after simulation, the behavior of the model and policy recommendations does not alter when boundary conditions are altered.

A structure verification test was conducted to certify that the structure of SDM is consistent and logical. In the present SDM, all the key variables are evaluated through a comprehensive literature review and cross-checked by experts in the construction sector. The resultant CLD is mapped out through final causal relationships combined with polarities and further modified through experts' opinions. Therefore, the SDM is meaningful, logical, and accurately represents the construction industry system of developing countries. This practice complies with the effort carried out by Qudrat-Ullah and Seong [49].

The parameter verification test deduced that the mathematical functions incorporated in SDM were generated and relied on two essential components: causal strength and polarity of interrelations. Moreover, experts in the construction sector evaluated both causal strength and polarity of final interrelations. Thus, it is safe to deduce their reliability.

The entire exogenous variables were assigned unity value and simulated under extreme conditions during the extreme condition test. The outcomes demonstrated that model behavior is logical as TQM amplified exponentially under the given system, as illustrated in Fig. 17 [35].

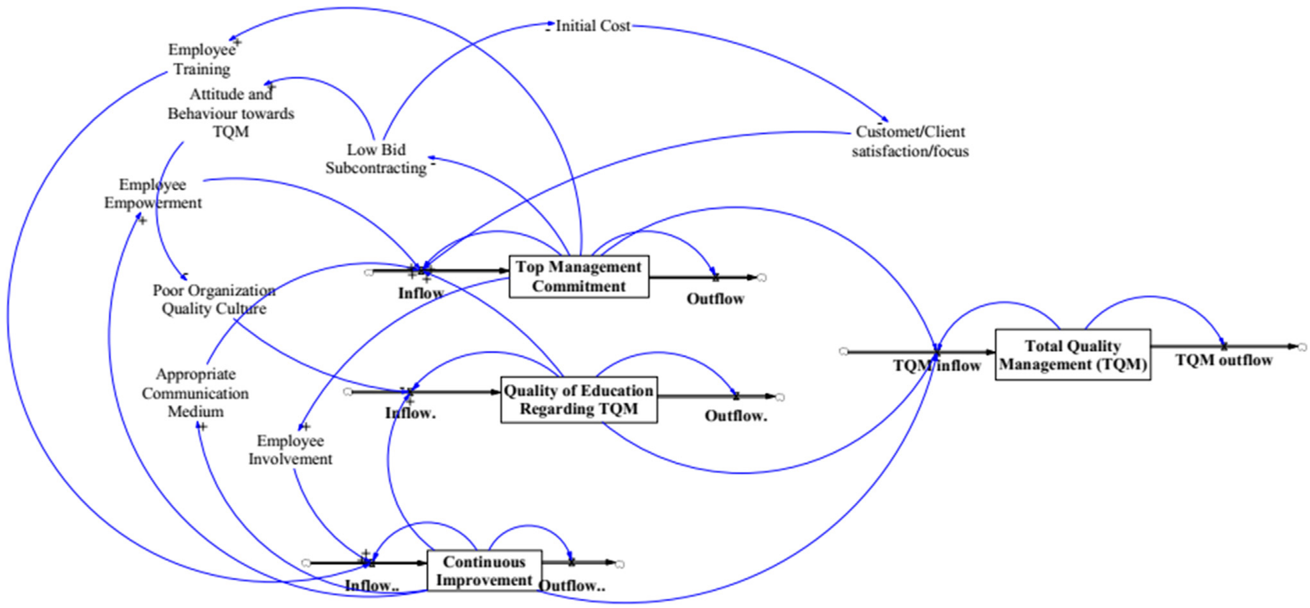

Fig. 14. Stock and Flow Diagram (SFD).

Table 9
Correlation, Polarity, and Relative Importance Index of Finalist Causal Relationship.

Sr. No.	Impacting Factor	Impacted Factor	Mean	RII	N. RII	Polarity
1	Client Satisfaction/Focus	Top Management Commitment	3.99	0.80	0.060	Direct
2	Low bid subcontracting	Initial Cost	3.96	0.79	0.059	Direct
3	Quality of Education Regarding TQM	Top Management Commitment	3.84	0.77	0.057	Direct
4	Poor Organization Quality Culture	Quality of Education Regarding TQM	3.76	0.75	0.056	Indirect
5	Low bid subcontracting	Attitude and Behavior Towards TQM	3.76	0.75	0.056	Direct
6	Initial Cost	Customer/Client focus/Satisfaction	4.12	0.82	0.062	Indirect
7	Continuous Improvement	Quality of Education Regarding TQM	3.78	0.76	0.057	Direct
8	Employee Training	Continuous Improvement	4.04	0.81	0.061	Direct
9	Top Management Commitment	Employee Training	4.19	0.84	0.063	Direct
10	Top Management commitment	Low Bid Subcontracting	3.81	0.76	0.057	Indirect
11	Employee Empowerment	Top Management Commitment	3.90	0.78	0.058	Direct
12	Employee Involvement	Continuous Improvement	3.88	0.78	0.058	Direct
13	Top Management Commitment	Employee Involvement	3.90 s	0.78	0.058	Direct
14	Continuous Improvement	Employee Empowerment	3.76	0.75	0.056	Direct
15	Appropriate Communications Medium	Top Management Commitment	4.32	0.86	0.065	Direct
16	Continuous Improvement	Appropriate Communications Medium	3.88	0.78	0.058	Direct
17	Attitude and Behavior Towards TQM	Poor Organization Quality Culture	3.90	0.78	0.058	Indirect

Overall, this study developed a simulation-based systems dynamics model to address TQM implementation causality in the construction sector of developing countries. This holistic ST approaches provided a framework for TQM implementation in the construction sector and improved overall productivity and quality performance of the construction sector, as witnessed in the simulation ns. Furthermore, the SDM simulated under the defined system and BOTG of all three stocks revealed an exponentially increasing trend over time, showing the potential to adopt and implement TQM. Thus, if adopted and applied to real construction projects, the proposed model would ameliorate quality performance. Accordingly, the overall efficiency and effectiveness of construction projects in developing countries can be improved. This is in line with Ullah et al. [4], who highlighted that applying quality management techniques in developing countries like Pakistan can significantly improve the project performance and success of the construction industry.

Many researchers have focused on critical/key contributing factors of TQM in its implementation [42;43;44], but a holistic approach to see how all of these critical/key factors behave in a system was missing so far. Further, the complexity associated with individual factors is amplified at the systems level. This research aimed to address the complexity resulting from implementing TQM in construction by defining its system of key factors and reflecting behavior over time of the defined system. An SDM was developed in this study that aims to improve the current state of the art of TQM. Thus this study and humbly contributing to the literature in the form of key factors of TQM implementation in construction also provides a practical step towards TQM implementation at a holistic level in the industry through the developed SDM.

The main advantage of the SD approach is that rather than addressing individual contributing factors of TQM, it has holistically considered the system of TQM in construction, thereby

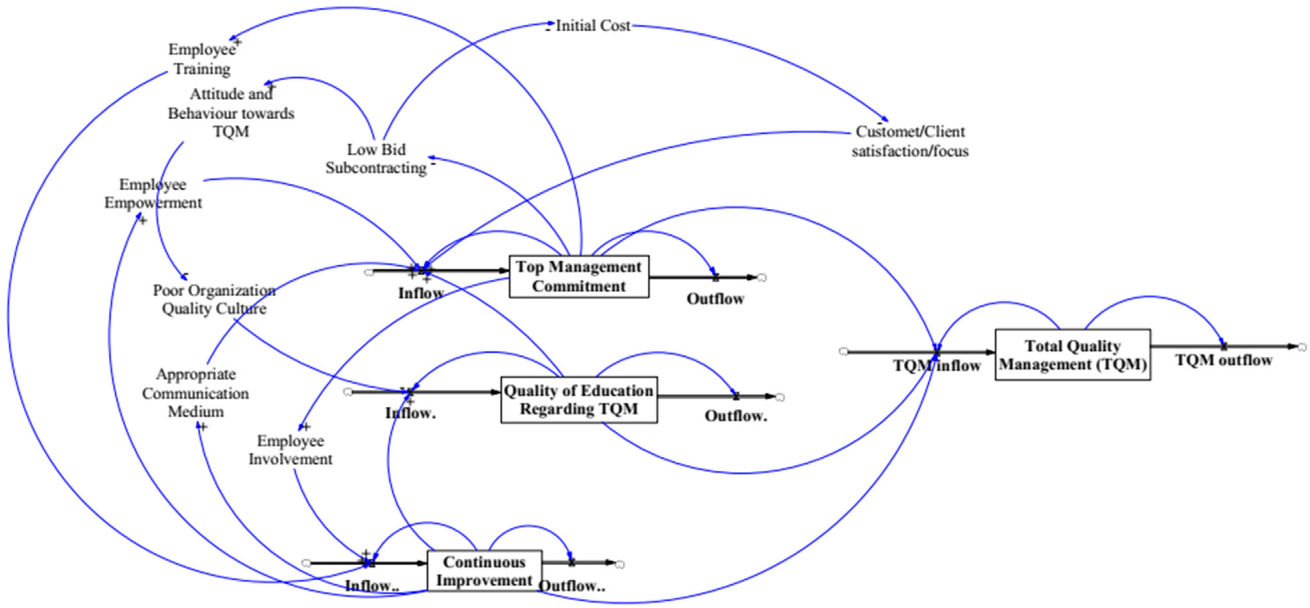

Fig. 15. System Dynamics Model.

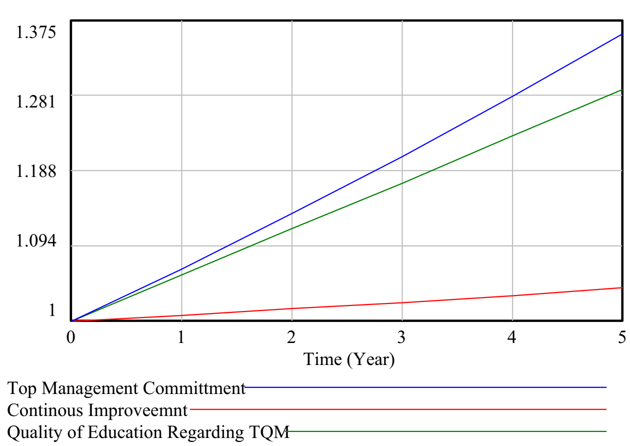

Fig. 16. Simulation Graph (Behavior Over Time Graph of Stocks).

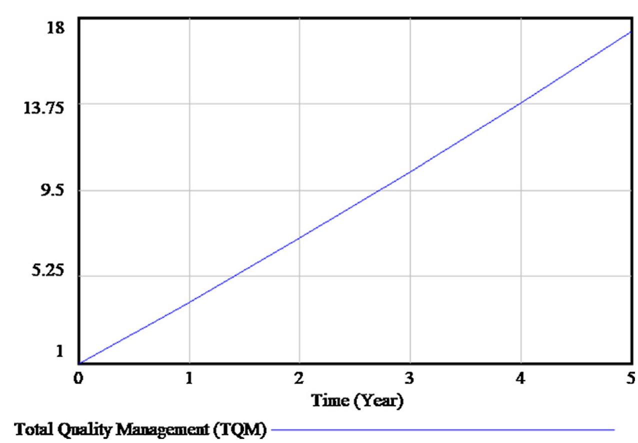

Fig. 18. Simulation Graph (BOTG of TQM).

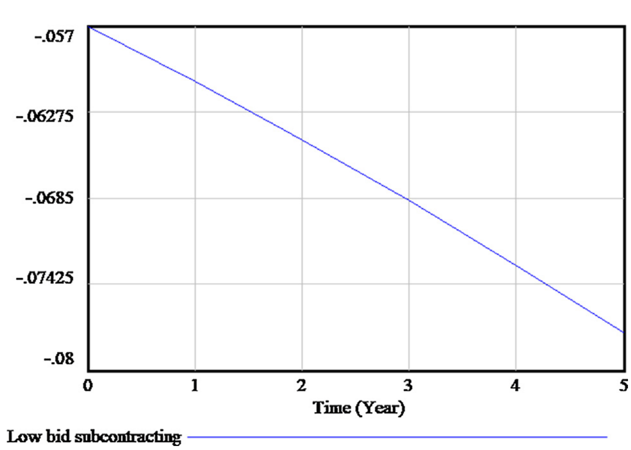

Fig. 17. Simulation Graph (BOTG of Low Bid Subcontracting).

addressing complexity associated with implementation at a much larger scale. This can be adopted and implemented by the relevant organizations.

The study can provide construction practitioners with information and knowledge through ST and the developed SDM, which can be pivotal in developing policies/guidelines for effective TQM implementation in construction. The holistic approach used in this work can help understand the system of TQM at a much larger scale and pave the path for its implementation. Furthermore, the developed SDM will create a sustainable environment suitable for TQM implementation in construction by addressing the inherent complexity. Such reduced complexities will also improve the chances of project success in the construction industry.

5. Conclusion

Despite the diversity and novelty of construction projects, the utilization of sophisticated quality management methods such as TQM is lower. This study aimed to address the intricacy and causality resulting from implementing TQM in the construction sector, especially in developing countries, using the ST approach.

A comprehensive literature review was conducted and initially identified twenty-eight key factors. Next, a preliminary survey was conducted, and respondents were asked to rank key factors on a Likert scale. As a result, top management commitment, customer/-client satisfaction, quality of education regarding TQM, organization quality culture, and high initial cost have been highlighted as the top five key factors of TQM implementation in the construction industry of developing countries.

A detailed survey was conducted to evaluate the causal relationship between strength and polarity. Subsequently, the RII of each shortlisted causal relationship was determined. Based on construction field experts' opinions, the CLD was mapped out. Seventeen significant shortlisted causal relationships with a mean value ranging from 3.75<=m<=5 were used in the CLD. Expert opinions and valuable suggestions were also incorporated to make the CLD logical, significant, and relevant to the need and demands of the construction sector of developing countries.

The SFD was developed to connect causal relationships and polarity and subsequently used to develop the SDM. Top management commitment, continuous improvement, and quality of education regarding TQM and the TQM (converging stock) were specified as four notable stocks of this SDM. The combination of influence matrix, CLD, and SFD assisted in developing the SDM simulated through VENSIM® software over five years. Over time, the existing three accumulated stocks under the influence of reinforcing interrelationships illustrated exponentially increasing behavior of the TQM as the converging stock.

The graph of key factors, including low bid subcontracting, poor organization quality culture, and initial cost, exhibited trends over time, negatively complemented by attitude and behavior towards TQM. Subsequently, the TQM graph illustrated ascending behavior over time as all three stocks converged on that point. This reflected that TQM implementation would increase as the years pass under a well-defined system, so the quality of construction projects and overall performance will improve in developing countries.

The findings of this study pave the way for creating a strategy/policy or quality-oriented environment, which is more feasible for TQM implementation and enhances the quality performance of construction projects in developing countries.

5.1. Limitation and future research

This study is limited to developing countries. Further, the developed SDM is not applied to any real-time project/case study. Therefore, future research can explore the application of SDM to real projects/case studies in both developed and developing countries to compare the results and advance the body of knowledge.

CRediT authorship contribution statement

Hassan Riaz: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Khurram Iqbal Ahmad Khan:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Fahim Ullah:** Validation, Resources, Data curation, Writing – review & editing, Supervision, Project administration. **Muhammad Bilal Tahir:** Validation, Data curation, Writing – review & editing. **Muwaffaq Alqurashi:** Resources, Data curation, Project administration, Funding acquisition. **T. Badr Alsulami:** Resources, Data curation, Project administration, Funding acquisition.

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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