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RESEARCH ARTICLE (PEER-REVIEWED)

System Dynamics Approach to Mitigating Skilled Labour Shortages in the Construction Industry: A South African Context

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Abstract

Skilled labour shortages in the construction industry are a major challenge in South Africa. The objective of this study is to assess the factors that cause skilled labour shortages, their effects on the construction industry and how the scenario can be improved. The study was conducted among industry professionals in the Eastern Cape Province of South Africa, using a survey method and conceptual System Dynamics (SD) modelling. Findings reveal thatinvestment, wage challenges, talent management, work environment, training, experience, and government policy are the important challenges relevant to skilled labour shortages. Inadequacy of skilled labour considerably impacts on the quality of work, productivity and scheduling. The causal loop diagrams reveal that enhanced investment in labour wages will strengthen the availability of skilled labourers. This will lead to higher productivity and vice versa. Investment in talent management and staff development programmes will improve the skilled labour pool. Moreover, a better work environment with improved health and safety will

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reduce the attrition of labourers caused by job dissatisfaction, which will in-turn reduce the skilled labour shortage in the industry.

Keywords

Construction industry; Skilled labour, Government policy; Skill development; Recruitment and retention; Wages

Introduction

Skilled labourersis one of the most important components of construction projects (Alzahrani and Emsley, 2013). Among other things, they perform the actual construction work, ensure the quality of construction, handle and use materials, plant and machinery, prepare the site for construction, manage the supply chain on project site and ensure the completion and delivery of the project (Alzahrani and Emsley, 2013). In other words, the actual burden of construction and quality of work are theresponsibility of the skilled labourers. Besides, the availability of skilled labourers and their competencies reflect the image of a company and provide competitive advantage. Skilled labourers are assets to a company and serve as the means for its continuous existence. Moreover, clients are always satisfied with high standard of work, which leads to the clients' continuous patronage. On the other hand, skilled labour shortages cause poor quality product and delay the delivery of projects;they also increase the cost of projects, engender client dissatisfaction, and damage company image. Therefore, lack of skilled labourers can be an impediment for the operation and successful completion of construction projects. In this context, arguments have emerged that companies should continuously seek ways to improve labourers' skills, because this will have positive impacts on their image (Tshele and Agumba, 2014).

Many researchers have investigated various issues relating to impediments tothe development of skilled labourers and the causes of skilled labour shortages. Some of the important issues include: lack of trade skills, poor distribution of labour and in experience of skilled labourers.The researchers have further explored how these factors link with project delivery time, cost and quality of work (Alwi and Hampson, 2003; Odeh and Battaineh, 2002; Sambasivan and Soon 2007; Satyanarayana and Iyer, 1996; Sweis et al., 2008). It has been established that lack of skills of labourerson construction projects are the major factors that adversely affect the project delivery time (Alwi and Hampson, 2003; Odeh and Battaineh, 2002; Sambasivan and Soon, 2007; Satyanarayana and Iyer, 1996; Sweis et al., 2008). Similarly, efficiency of various activities such as the operation of plant and machinery, supervision of unskilled labourer's activities, material handling on site, delivery of materials to site on schedule, appropriateness use of materials and equipmentare dependent on the labourers' competencies and skills (Alwi and Hampson, 2003). However, despite several investigationson labour shortages, the topic of how to mitigate the challenges of skilled labour shortages in developing countries is still unexplored in the South African context. In other words, studies on the interlinkage and interconnectedness among the factors that impede the development of skilled labourers in South Africa are scarce. Therefore, the objectives of this study are first toexamine the factors that lead to skill shortages and their implications,and secondto explore how these factors create interlinkages and causal feedback relationships among themselves to create skill shortages, and the strategies necessary to improve the scenario.

Skills Shortages and their Impacts on the Construction Industry

Skill shortages in any industry can lead to numerous problems such as high reliance onskilled migrant workers and higher wages leading to increased construction costs. This situation reflects badly on the industry and the nation. Significant amounts of hard currency are drained from the country, which would otherwise have been reintroduced into the economy with subsequent improvement in the standard of living of its citizens through job provision. Several scholars have tried to explore the causes of skill shortages in the construction industry; for example, Janse Van Rensburg et al. (2012) and Morton (2009). The Construction Industry Development Board (CIBD) (2007) identified that the unwillingness of the younger generation to take part in the construction industry because of its unattractiveness is a major reason for skill shortages(Saleh, 2008). They view the industry as physically challenging, unstable and extremely dangerous, as well as requiring them to move around (DOSH, 2010). In addition, wages paid to workers are low compared to those in other industry sectors. Similarly, it is argued that lack of construction activities, and the lackof skill development materials, mentors and funds, for potential workers contribute to skill shortages (Jasen, 2012).

There are adverse impacts of skill shortages on the construction industry. These needs to be mitigated towards the growth of the industry. Dainty, Cheng and Moore (2003) describe shortage of skill as beingcritical in the construction industry, becauseit results in poor quality of workas contractorsmight employ unskilled labourers to perform the tasks. Redoing of work results in cost increases as well as prolongs the project duration (Sambasivan and Soon, 2007). Consequently, the project may need rescheduling in response to disruptions and problems encountered. This phenomenon may adversely affect company's reputation, which can become a threat to the business (Aiyetan, Smallwood and Shakantu, 2014). Also, poor quality of work may attract late payments, caused by client dissatisfaction (Assaf and Al-Hejji, 2006).

So, the role of skilled labourers in the completion of projects has been proven to be highly significant (Alzahrani and Emsley, 2013). Studies have found various determinants that influence availability of skilled labourers, which include: remuneration/ wage, level of knowledge, training, leadership, motivation, commitment, belongingness, scheduling, supervision, coordination and communication between supervisors and labourers, communication skill, and adhering to health and safety aspects. (Durdyev and Mbachu, 2011; Enshassi et al., 2007a; , Enshassi et al., 2007b; Page, 2010; Tran, and Tookey, 2011). Although largely undermined, the skilled labour shortage determinants and their causal effects have significant implications for the success of the projects (Alzahrani and Emsley, 2013; Durdyev and Mbachu, 2011), therefore need further investigations.

Research Method

The study was conducted withthe use of a questionnaire survey anda structured interview, followed by System Dynamics (SD) modelling. The Eastern Cape Province of South Africa was selected for data collection. It is the second largest Province in the country with a population of 6.56 million and constitutes two of the largest cities of the country, namely Port Elizabeth and East London, in addition to six district municipalities. It is one of the important locations,but economically disadvantaged provinces compared to the more accessible provinces such as Gauteng and Western Cape. A significant number of construction projects are observed to underperform in different cities and as the province faces significant shortages of

skilled labourers to meet the increased demands of the construction industry. Therefore, it is essential to investigate the skilled labour shortage challenges and ways to resolve the issue.

A questionnaire survey was conducted among the building construction industry professionals in the Eastern Cape Province of South Africa, followed by interviews oftwenty (20) experts in the construction industry, to collect both quantitative and qualitative data. These are professionals belonging to registered companies with the Construction Industry Development Board (CIDB), the recognize Board of Construction and Project Managers of the country.The survey sample consisted of fifty (50) contracting firms available in the Easter Cape Province. All the 50 firms were surveyed and fifty (50) professionals from these companies were identified. The survey was conducted by using a pretested questionnaire with one questionnaire for each contracting firm. The questionnaires were administered via post and the questionnaire included skilled labour attributes, determinant variables and their impact on construction industry. Thirty (30) fully filled questionnaires were returned, representing a response rate of 60%. Responses from 20 respondents were not received because of various reasons such as unwillingness to take part in the survey, lack of time and interest.

The respondents were selected based on a number of criteria such as their direct engagement with construction projects, engagement with skilled labourers, and engagement with construction and managerial activities. The respondents include professionals at the middle and higher management level. About 30.3% of the respondents had a minimum qualification of Bachelor of Technology, followed by 26.0% having a minimum qualification of Diploma in Construction Management. Some of the respondents were registered with their professional bodies. About 85% of the respondents had relevant work experience of six years and above. It was also found that respondents' organizations have been involved with over 16 projects on average, which reflects the suitability of the respondents and their organizations for the survey. Data on the perceptions of different variables were collected by using a five-point Likert scale, in which 1 indicated least important, 2 indicated somewhat important, 3 denoted fairly important, 4 meant very important and 5 indicated most important. Statistical analyses were performed on the collected data. Mean scores and standard deviations were computed to assess the factors contributing to shortages of skilled labourers, the effects of skilled labour shortages and strategies to improve the situation. Moreover, Z tests were conducted to check the veracity and variabilities in the responses.

In addition to the questionnaire survey conducted, opinions were sought from twenty experts who are professionals from construction industry, namely: project management consultants, human resource professionals, academicians and researchers in the field of construction. In selecting the experts, first a profile search of relevant people from different organisations was made. Then a shortlisting was done to select experienced respondents. After initial contacts, semi-structured qualitative interviews on the interlinkages among the variables related to skill shortages and remedial measures were conducted with the experts.

Following the survey, SD modelling method (Sterman, 2000) was adopted to develop conceptual models and stock flow modelsto establish the causal feedback mechanisms among the factors contributing to skilled labour shortages, effects of skilled labour shortages and strategies for reducing skills shortages.SD principle assists in eliciting and displaying information in a conceptualmodel to understand the phenomenon clearly, without any complex quantitative analysis. (Lee, Choi and Park 2005; Montibeller and Belton 2006; Park et al., 2013). Based on the principles suggested by Von Bertalanffy (1974), the construction industry was taken as a system having a complex set of subsystems, which needs to perform in a coordinated manner to achieve the desired outcome of reduction of skill shortages.

Investigations regarding various aspects of construction and applications of SD to evolve solutions have been taken up by several scholars since the last four decades. Some examples of SD applications in construction are: Cooper (1980, 1993), Abdel-Hamid (1984); Ford and Sterman (1998, 2003); Rahmandad and Hu (2010); Owens and Leveson (2011) and Parvan, Rahmandad and Haghani (2012, 2013). Also, Lyneis and Ford (2007) provided a detailed discussion regarding SD applications on various aspects of construction delays and rework. Further, Han, Love and Peña-Mora (2013), based on their case study, suggested that as construction projects are known to involve complex, inter-dependent, uncertain and labour-intensive work, SD models can assist project managers to understand the dynamics of how construction process works and its intricate relationship with labour, cost and schedule. As construction projects are getting increasingly complex and dynamic in which skilled labourers play an important role, there is a need to investigatethe issue of skilled labour shortages in the industry in a more holistic way to understand the system conceptually and thereby deriving mechanisms to develop policy interventions.

According to Olaya (2012) and Sterman(2000), unlike many mechanistic systems or physical modelling, SD is based on the principle of operational thinking with a feedback mechanism of information-decision-action and influence on the environment. This feedback mechanism offers the dynamic hypotheses with unique explanatory power to diagnose the problems and visualise the behaviour of the system under different scenarios. The aim of this investigation was to develop quantitative SD model and simulate to develop policy scenarios, the scope of this paper is however limited to the development of conceptual models and stock flow diagrams.In this study therefore, first causal feedback relationships among the causes and consequences of skilled labour shortages were developed. Next, one-way causalities and their polarities (positive influence or negative influence) were developed and then feedback relations were checked. Based on the causal feedback relations among the variables, causal loop diagrams (CLD) were created and then reinforcing (positive or strengthening) or balancing (oscillating, self-regulating or disturbing) mechanisms were ascertained. Furthermore, by using the various causal loop diagrams, a stock-flow diagram was developed by integrating the stock variables, rate variables, flows and auxiliary variables. Although mathematical simulation model is not in the current scope of the study, it is noted that the stock variable(s) were initialised based on the current state (value) and the rate variables (flow rates), flow rate fractions and auxiliaries were calculated by using historical statistical data that were derived from the various authentic organisations such as Statistic South Africa and government organisations or companies. Moreover, the equations for various variables (such as rate variables and auxiliaries) were developed from the historical statistical data or from the cross-section data (from the survey).

Findings

Before the interlinkage and causal relationships among various variables were developed to build causal loop diagrams (CLD), the importance of various variables under the three important aspects such as factors causing skilled labour shortage, effects of skilled labour shortages on the construction industry and strategiesto improve the availability of skilled labourers in construction industry were established. The importance of the various variables was established by concurrent use of the mean scores obtained from the Likert scale evaluations, evidences from literature and opinions of the experts. The evidence from the literature and expert opinions were sought to strengthen the findings from the Likert scale evaluations. The factors which are found to have negligible impact have been ignored in

the development of CLDs and stock flow diagrams. While developing the CLDs and SD stock flow diagram, the construction industry was considered as the system and its various components such as production, investment, work environment, talent management as sub systems.

FACTORS CAUSING SKILLED LABOUR SHORTAGES

The factors contributing to skilled labour shortages are presented in Table 1. There are six factors which significantly contribute to skilled labour shortages, which are: investment, labour wage challenges, talent management, condition of working environment, training and experience, and government policy. The Likert scale evaluations indicate the mean scores of the factors range between 2.5 and 3.1. The low standard deviation (ranging between 0.085 and 0.31) and high Z probabilities (ranging between 0.81 and 0.88) associated with the factors reveal that there is low variability among the responses and therefore the aggregate responses are acceptable. Since the Likert scale evaluations indicate that all these factors have a mean score ranging between 2.5 to 3.1 (Table 1), premised upon the other two aspects of the evaluation such as expert opinion and evidences from literature, the significance of these factors have been decided on three levels such as very important, fairly important and somewhat important. Consequently, it is found that investment, wage challenges and talent management are the factors, which are very important contributors to shortages of skilled labourers. Furthermore, work environment, and training and experience also play a fairly important role in the shortage of skilled labourers. However, the government policy, which is an exogenous factor is found to be somewhat important.

Table 1 Factors contributing to skilled labour shortages

Factors	Mean Score (MS)	Standard deviation	Z value	Z probability	Evidence from literature	Expert discussion	Remark
Government policy	3.10	0.130	1.19	0.88	Daniels (2007)	×	Somewhat Important
Training and experience	3.00	0.085	1.17	0.87	Noe et al. (2013), Wu, et al. (2015)	××	Fairly Important
Satisfaction of Working Environment	2.96	0.150	1.12	0.86	Abrey& Smallwood (2014), Danso (2012), Kahya (2007)	××	Fairly Important
Investment	2.70	0.110	1.04	0.84	Guddi et al. (2012)	×××	Very important

Table 1 continued

Factors	Mean Score (MS)	Standard deviation	Z value	Z probability	Evidence from literature	Expert discussion	Remark
Talent management	2.60	0.210	0.96	0.82	Huang &Tansley (2012), Garavan et al. (2012)	×××	Very important
Wages challenge	2.50	0.310	0.88	0.81	Guddi et al. (2012)	×××	Very important

(Note: ×××: very important, ××: Fairly Important, ×: Somewhat important) Since no factors was found to be singled out as the most important and the factors which are least important were not considered, the analysis were limited to three levels in terms of relative importance.

EFFECTS OF SKILLED LABOUR SHORTAGES ON THE CONSTRUCTION INDUSTRY

Table 2 presents the effects of skilled labour shortages on the construction industry in the EasternCape Province of South Africa. Based on the Likert scale evaluations, the mean scoresof all the factors range between 3.28 and 3.70. The standard deviations (range between 0.005 and 0.150) of the factors are low and Z probabilities (range between 0.89 and 0.92), associated with the responses are high, indicate high consistency and low variability among the responses and therefore are acceptable. Consequently, factors such as quality of the work/ rework, company reputation, construction delay, productivity, scheduling (Re) and cost (overrun) are affected by skilled labour shortages.However, based on the cumulative evaluations of the expert opinion and evidence from the literature, it was found that skilled labour shortages significantly impacton the quality of work/ rework and productivity, followed by construction delay and scheduling (rescheduling). However, cost and company reputation are only somewhat affected.

Table 2 Effects of skilled labour shortage

Effects of shortage of skilled labour	Mean Score (MS)	Standard Deviation	Z value	Z probability	Evidence from literature	Expert discussion	Remark
Quality of the work/ Rework	3.70	0.150	1.42	0.92	Oke et al. (2018), Rasool et al. (2011) & Tshele&Agumba (2014)	×××	Very important
Company Reputation and image	3.61	0.045	1.43	0.92	Tshele&Agumba (2014)	×	Somewhat important

Table 2 continued

Effects of shortage of skilled labour	Mean Score (MS)	Standard Deviation	Z value	Z probability	Evidence from literature	Expert discussion	Remark
Construction Delay	3.60	0.090	1.40	0.91	Tshele&Agumba (2014), Rasool et al. (2011) &Oke et al. (2018)	××	Fairly important
Productivity	3.50	0.005	1.39	0.91	Oke et al. (2018), Rasool et al. (2011) &Tshele&Agumba (2014)	×××	Very important
Scheduling (Re)	3.38	0.058	1.33	0.90	Aiyetan (2015)	××	Fairly Important
Cost (Overrun)	3.28	0.103	1.27	0.89	Oke et al. (2018), Rasool et al. (2011) &Tshele&Agumba (2014)	×	Somewhat important

(Note: ×××: very important, ××: Fairly Important, ×: Somewhat important) Since no factors was found to be singled out as the most important and the factors which are least important were not considered, the analyses were limited to three levels in terms of relative importance.

STRATEGIES TO IMPROVE THE AVAILABILITY OF SKILLED LABOURERS IN CONSTRUCTION INDUSTRY

Table 3 indicates strategies that can be considered for reducing skills shortages or improving the availability of skilled labourers in the construction industry in the Eastern Cape Province of South Africa. It reveals that for all seven factors evaluated,mean scores of six factors range between 3.20 and4.10. Skill development programme wasfound to be the most important strategy with a mean score of 4.10. The standard deviations of the factors were found to be low (ranging between 0.066 and 0.229) and Z probabilities associated with the responses were observed to be high (ranging between 0.88 and 0.94). So, the responses obtained from the respondents are consistent and are therefore acceptable. However, following the concurrent evaluations, it was found that skill development programmes (CPD and Training) and investment on wages are the very important strategies that should be augmented to improve the skilled labour shortages in the study area. Also, factors such as recruitment and retention policy (incentives and rewards) and improvement of work environment (health and safety) could fairly assist in the improvement of the situation. Furthermore, an extension of the retirement age, attracting the young generation and apprenticeships and experiences, though are less important factors, can influence the improvement of skilled labour shortage situation to a certain extent.

CONCEPTUAL CAUSAL LOOP DIAGRAMS FOR SKILLED LABOUR SHORTAGES

Based onthe findings discussed in the preceding sections, causal feedback relations for skilled labour shortages, and strategies for improving the scenariowere developed. The CLDs are

Table 3 Strategies for reducing skills shortages

Strategy	Mean Score (MS)	Standard Deviation	Z score	Z probability	Evidence from literature	Expert discussion	Remark
Skill development programmes (CPD and Training)	4.10	0.229	1.55	0.94	Tshele & Agumba (2014)	×××	Very important
Investment on wages	3.70	0.066	1.45	0.93	Tshele & Agumba (2014)	×××	Very important
Recruitment and Retention policy (Incentives and rewards)	3.40	0.343	1.22	0.88	Aiyetan (2015)	××	Fairly Important
Work environment (Health and safety)	3.38	0.066	1.33	0.91	Abrey & Smallwood (2014)	××	Fairly Important
Extension of the retirement age	3.30	0.098	1.28	0.90	Aiyetan (2015)	×	Somewhat important
Attracting the young generation	3.25	0.118	1.25	0.89	Aiyetan (2015)	×	Somewhat important
Apprenticeships and experiences (Work Integrated learning)	3.20	0.139	1.22	0.88	Tshele & Agumba (2014)	×	Somewhat important

(Note: ×××: very important, ××: Fairly Important, ×: Somewhat important) Since no factors was found to be singled out as the most important and the factors which are least important were not considered, the analyses were limited to three levels in terms of relative importance.

presented in Figures 1 to 3. The CLDs were developed based on the findings of the discussions with experts in an iterative manner to frame the causal feedback relations,amend, correct and validate them based on the real phenomena occurring in the field. The CLDs are presented in three major conceptual SD models and consist ofbalancing loops (B) indicating the causation of skilled labour shortages and reinforcing loops (R) presenting the strategies to improve the skilled labour shortage scenario. Figure 1 presents the CLD that relates investment, productivity and skilled labourer availability in the construction industry of the Eastern Cape province. If the investment is not adequate as is the current situation, it leads to poor labour wages, which influence the availability of skilled labourers in the construction industry negatively due to either few people opt for the profession or higher attrition rate as people leave the profession or the province in search of better paying jobs. This phenomenon is represented by the B1. This situation gets exacerbated as the lack of skilled labourers in the industry or on projects results in challenges in the project delivery such as delay, rework or cost overrun leading to negative or lesser contribution to the investment situation in the industry or projects because of poor productivity- represented by B1A. Thus, B1A complements B1 and aggravates the skilled labour shortage situation. However, productivity remains the vital

factor, which is dependent on the availability of skilled labourers. Therefore, if the investment is increased in the labour wage sector, it will reinforce the availability of skilled labours, leading to higher productivity and investment through a feedback relationship represented by CLD R1. Higher productivity also positively influences the labour wages leading to higher availability of skilled labours because of either reduction in attrition rate or more people opting for this profession (R1A). Furthermore, R1A reinforces R1. Consequently, the phenomenon R1 (R1A) balances the disruption caused by B1 (B1A) and assists in the reduction of skilled labour shortages.

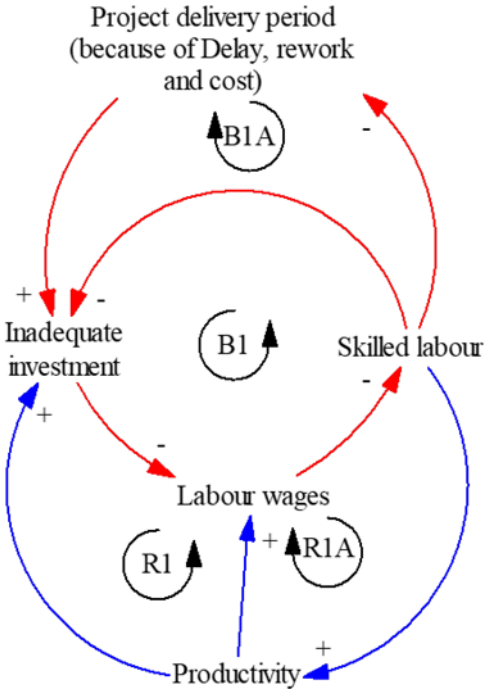

Figure1: CLDs among investment, productivity and skilled labour

It was further found that training and experience play an important role in the development of skills. However, the lack of adequate training programmes negatively impacts the availability of skilled labour pools in the construction industry. As observed by B2 in Figure 2, poor training and lack of experience cause poor development of skills. Lack of skills does not add to the availability skilled labour pools, thereby creating shortages of skilled labourers. However, talent management is found to be one of the major factors that can be vital for augmenting the skilled labour pool. For instance, as shown by R2, if talent management is conducted in the construction industry through an appropriate recruitment and retention policy, staff development programmes and investments in these aspects, it will definitely augment the skilled labour pool, and availability of skills in the industry through the causal feedback relationships (see Figure 2).

As illustrated in Figure 3, it was found that the work environment also impactson the availability of skilled labourers in an organisation or the industry in general. The work environment causes job satisfaction or dissatisfaction among labourers and influences their decision to remain or leave the organisation or industry. It wasalso observed in the

construction industry of the Easter Cape province that the attrition of labourers is largely influenced by the lack of job satisfaction, which reduces the available skilled labourers through

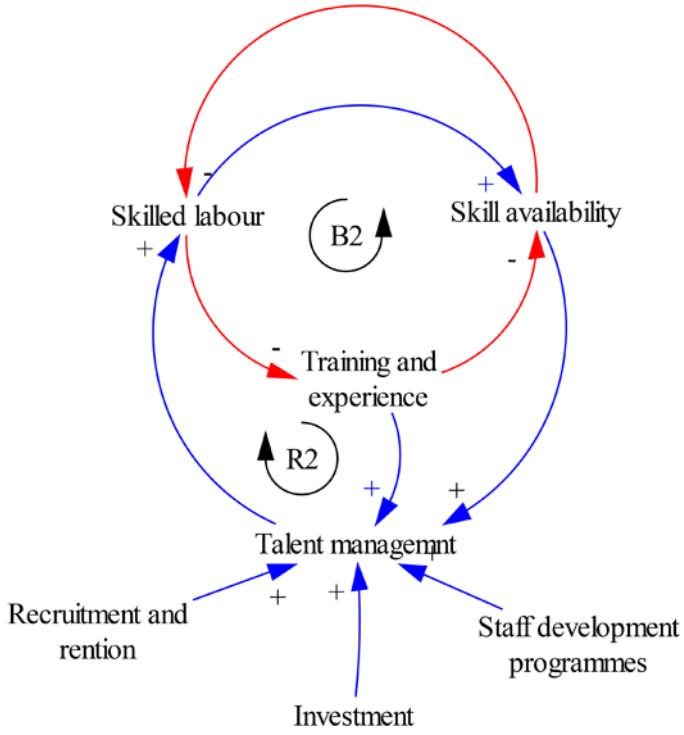

Figure 2 CLDs among skilled labour, talent management and training and experience

the feedback mechanism B3. However, if the work environment is improved through a good health and safety policy, investmentsfor enhancing working conditions, aided by a government policy, that leads to increased labour satisfaction, resulting in the reduction of attrition of labourers, which will consequently enable the reduction of shortages of skilled labourers in the industry through a feedback relationship R3 (Figure 3). Thus, a better work environment is vital to reduce labour dissatisfaction and consequently the reduction of shortages of skilled labourers due to attrition. However, while the development of an appropriate health and safety policy and investment to enhance work environment are internal to the construction industry and are endogenous factors, the government policy is external to the industry and is an exogenous factor and therefore can have a delayed influence.

STOCK FLOW DIAGRAM FOR SKILLED LABOUR SHORTAGES

Figure 4 presents the stock flow model representing skilled labour shortages. The model was built using different variables such as stocks, rates, auxiliary variables and constants. The various variables used in the model development are presented in Table 4. There is one stock variable in the model, thenumber of skilled labourers, which is dependent on rate variables such as skilled labour inflow rate and attrition rate. While the skilled labour inflow rate influences positively and adds to the labour pool, the attrition rate has a negative influence leading to the outflow of labours thereby balancing the labour stock in the system. The other variables presented in the Table 4 such as productivity, labour wages, investment, talent

management, work environment, delay and rework are auxiliary variables. All these variables have been considered as endogenous variables and internal to the construction industry. It is

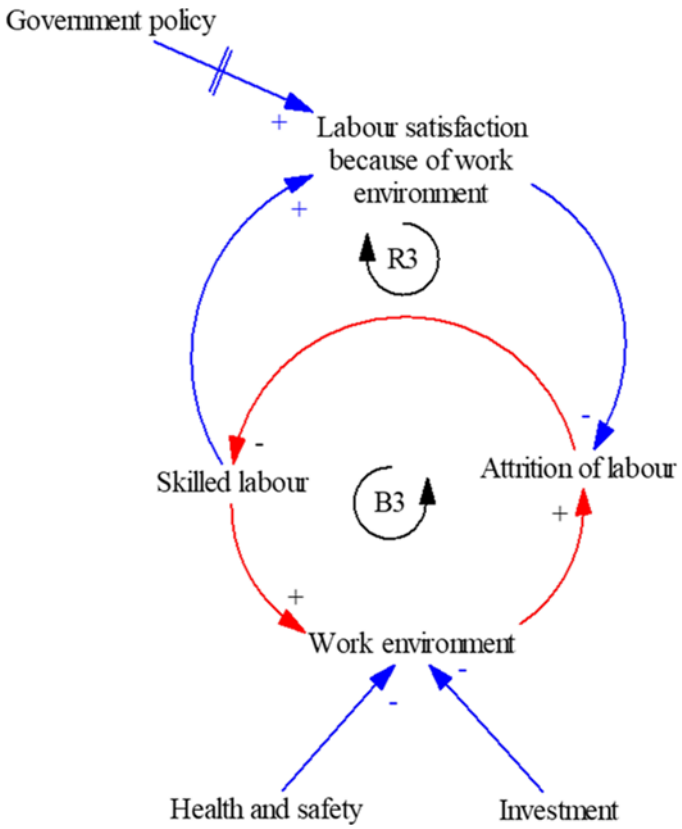

Figure 3 CLDs among skilled labour, work environment and attrition of labour

envisaged that the positive influences of these auxiliary variables increase the labour inflow rate, while their reduction influences the inflow rate negatively or increases the attrition rate. Furthermore, government policy is also observed to influence the stock through an indirect influence on the working condition, health and safety, labour wages and staff development programmes. This is as an exogenous variable to the construction industry, influences through information flow and is envisaged to have a delayed effect on the stock variable. The stock variable, skilled labourers, is dependent on the cumulative effects of the rate variables and both endogenous and exogenous auxiliary variables. As seen in the stock flow diagram, these variables work through a feedback system and develop system behaviours such as, increase or decrease in skilled labourers in the construction industry under the various policy intervention scenarios related to investment, talent management, work environment and government policyboth independently and in combination. The functional model for estimating the stock of skilled labour is as follows:

Skilled labour (SL)= f (ISL, NSLR, LWR, WER, TMR, GPI, IAR)

The model equation for estimating the skilled labour stock is given in equation 1 (Eq.1).

$$\text{Skilled Labour (SL)} = \text{Initial skilled labour pool (ISL)} + \int_{to}^{t} ISL * NSLR * (LWR + WER + TMR + GPI - IAR) * dt \quad \text{.....(Eq.1)}$$

The rates and auxiliary variables influencing the rates are presented on Table 4.

Table 4 Variables used for stock flow modelling

Variable	Type	Unit	Remark
Skilled labour (ISL)	Stock	Numbers	Skilled labour pool in the construction industry
Skilled labour inflow (NSLR)	Rate	Per cent (fraction)	Normal physical flow
Attrition rate (IAR)	Rate	Per cent (fraction)	Normal physical flow
Actual productivity	Auxiliary	Amount	
Change in productivity	Auxiliary	Amount	
Estimated productivity	Auxiliary	Amount	
Current labour wages	Auxiliary	Amount	
Perspective labour wages	Auxiliary	Amount	
Labour wage ratio (LWR)	Auxiliary	ratio	Perspective wage/current wage
Current talent management	Auxiliary	Index	
Perspective talent management	Auxiliary	Index	
Talent management ratio (TMR)	Auxiliary	Ratio	Perspective talent management index/current talent management index
Current investment Fraction	Auxiliary	Fraction	
Investment in staff development programme	Auxiliary	Amount	Perspective
Investment in retention and incentives	Auxiliary	Amount	Perspective
Current health and safety	Auxiliary	Index	
Current work environment	Auxiliary	Index	
Perspective work environment	Auxiliary	Index	
Investment on work environment	Auxiliary	Amount	Perspective

Table 4 continued

Variable	Type	Unit	Remark
Contribution of work environment ratio (WER)	Auxiliary	Ratio	(Perspective work environment policy index+ investment on work environment)/ current work environment index
Contribution of actual share of productivity to skilled labour	Auxiliary	Ratio	
Normal rate of production	Auxiliary	Per cent (Fraction)	
Delay	Time	Index	
Rework	Time	Index	
Government policy (GPI)	Auxiliary	Index	Information flow with delay

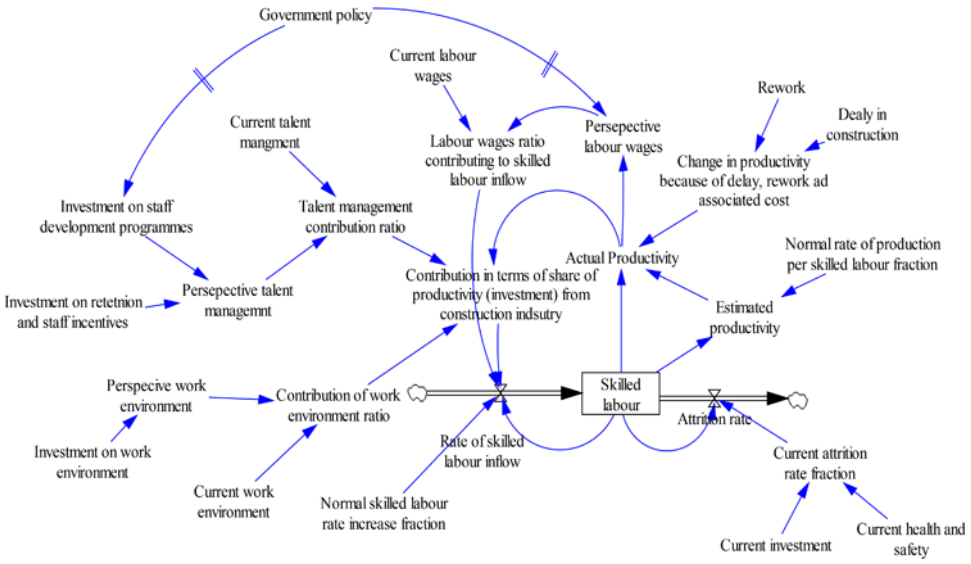

Figure 4 Stock flow diagram for skilled labour shortages

It is noteworthy that the structure of the stock flow diagram forms the basis for mathematical model, which can be used for the quantification and behaviour analyses under different scenarios. However, the scope of the paper is limited to the development of stock flow diagram and the development of the quantitative model, simulation and scenario analyses will be discussed in another paper.

Conclusion

Shortages of skills in the construction industry, particularly in South Africa at regional level, is a challenge that is being increasingly experienced. The identification and assessment of various factors contributing to skill shortages, effects of skill shortages and strategies to improve

the availability of skilled labourers are of paramount importance. This study utilised system dynamics approach to model the contributors, effects of labour shortages and the influence of intervention strategies. The study was conducted in the context of the construction industry in the Eastern Cape Province of South Africa and using a survey method to collect data essential for modelling. SD modelling principle was adopted to develop conceptual models and CLDs to understand the reasons behind skill shortages, and the dynamic relationships, which could assist in evolving possible policy/ strategic interventions to improve the availability of skilled labourers in the construction industry.

Findings suggest that investment, wage challenges, talent management, work environment and training and experience play an important role in the shortage of skilled labourers. Government policies also impacts the situation in an indirect way. The shortage of skilled labourers affects significantly the quality of work, causing rework and low productivity, followed by construction delays. The CLDs indicate that increased investment in the labour wage will reinforce the availability skilled labours, leading to higher productivity, which will in turn positively influence the higher availability of skilled labours by either reducing the attrition rate or attracting more people to construction workforce. Also, talent management in the construction industry through appropriate recruitment and retention policy, staff development programmes and investment in these aspects will augment the skilled labour pool, and the availability of skills in the industry. Further, if the work environment is improved through a policy of health and safety and investment in enhancing working condition, aided by a government policy, there might be a reduction in the attrition of labourers,caused by job dissatisfaction, which consequently will enable reduction of shortages of skilled labourers in the industry.

The study has certain limitations. The study was conducted using the data from the Eastern Cape Province. The study is also based on limited survey samples because of the limited availability of construction firms at the regional level. Also, strategies were developed based on CLDs. However, the performance of the strategies can only be evaluated through quantitative modelling and by developing simulated scenarios under different policy and strategic interventions, which is the further scope of the research. Further studies by considering the construction industries in other provinces are necessary in order to generalise the findings at a national level. Nevertheless, at its current state, the study established the factors contributing to the shortage of skilled labourers and their effects on the construction industry at a regional level. Moreover, the causal feedback mechanisms provides the interlinkages among various variables and their implications based on which appropriate strategies can be developed to reduce the shortage of skilled labourers in the construction industry at a regional level in South Africa. Also, the stock flow diagram and model equation for the stock offered a platform for the development of a quantitative model and simulated scenarios to understand the behaviour of the construction industry sector with regards to skilled labour shortages in South Africa.

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