Theoretical and Empirical Researches in Urban Management
Volume 17 Issue 2 / May 2022

# SYSTEM DYNAMICS MODEL LINKING DEMAND, EMPLOYMENT MOVEMENT BETWEEN SECTORS AND THE ECONOMY FOR THE SOUTH AFRICAN CONSTRUCTION SECTOR

**Kevin Jan DUFFY**
Institute of Systems Science, Durban University of Technology, Durban 4000, South Africa

**Obiora Cornelius COLLINS**
Institute of Systems Science, Durban University of Technology, Durban 4000, South Africa

**Thokozani SIMELANE**
Institute of Systems Science, Durban University of Technology, Durban 4000, South Africa;
Science and Technology, Africa Institute of South Africa, Human Sciences Research Council, Pretoria, South Africa

**Abstract**
Several factors can influence the dynamics in demand and supply of skills for all employment sectors. Here the variable drivers for construction sector employment are taken to involve the demand for employment, choice of employment and the state of the economy. A dynamical model based on longitudinal data obtained from the Construction Education and Training Authority (CETA) of South Africa is used to predict the dynamics of future employment trends in the construction sector of South Africa. This paper argues for a system dynamics approach as both a conceptual and methodological tool for predicting employment trends. The relationship between economic growth, demand and employment movement between sectors are shown to impact employment in the construction industry. Knowledge of how these factors impact employment could help policy makers in their efforts to reduce unemployment.
**Keywords**: Skills demand, Skills supply, System dynamics, Construction sector, Modelling.

## 1. INTRODUCTION

In any economy, there is a complex interaction between the demand and supply of people in a particular employment sector (Cosser, 2010; Keating, 2009). This complex interaction can present a non-linear relationship in matching demand and supply to industries (Keating, 2009). Several quantitative forecasting models to determine future employment needs for various industries in South Africa have been developed (LG SETA, 2015; Woolard, Kneebone, & Lee, 2003). In 2004 for instance, the United Kingdom's Warwick Institute for Employment Research and the Human Sciences Research Council undertook research that investigated the feasibility of developing quantitative forecasting models. This was intended to help determine future employment needs in South Africa (Woolard et al., 2003). The project was commissioned by the Department of Labour. From the study, within South Africa, multi-sectorial macroeconomic models that can be used to forecast employment are Partial-equilibrium Modelling, and Computable General Equilibrium Modelling based on a Social Accounting Matrix (Woolard, Kneebone & Lee, 2003). While these approaches were used to show sufficient skills in the country there has been concern raised about the availability and quality of data needed to develop models that can predict future demand and supply for employment sectors in South Africa's economy (Wilson, Woolard, & Lee, 2004).

It has been argued that a systems approach in the demand and supply of employment is necessary for implementing successful interventions (Arndt, 2006). The usefulness of systems thinking has been explored by various authors (Arnold & Wade, 2015; Kruss, McGrath, Petersen, & Gastrow, 2015; Mello, Gosling, Naim, Strandhagen, & Brett, 2017; Peters, 2014; Tura et al., 2019). Adams, Osmani, Thorpe, and Thornback (2017) reflect that 'there has been limited research on the application of circular economy principles in the built environment, within a whole systems context' but should help with understanding the dynamics involved.

While their argument for the 'circular economy in construction' draws on systems thinking more centrally, our focus is on systems dynamic modelling as a useful analytical lens in relation to the skills supply to the construction sector in South Africa. System dynamics modelling is concerned with building models of a complex nature and then experimenting with their behaviour to obtain an insight of the structure and behaviour of the system (Caulfield & Maj, 2001). This technique is used to study nonlinear behaviour of a complex system over time. It is an approach that captures the complexities involved in persistent problems where possible solutions lead to further complexities (Brent, Simelane & Clifford-Holmes, 2018; Brent & Simelane, 2018).

The construction sector employs about 9% of the South African workforce per year in its value chain. So, to investigate the dynamics of employment in the construction sector, a good knowledge of the dynamics in the other sectors is vital. This is because, what happens in other sectors of the economy has direct bearing on the construction sector. These other sectors include agriculture, mining, manufacturing, utilities, trade, transport, finance, business, community services, private household, social services, etc.

One of the key factors that will play a significant role in skill supply in the construction sector is economic growth. Economic growth can have either a positive or negative influence on skills supply. There are several indicators that are used to determine the economic growth of a country. These indicators include Gross Domestic Product (GDP), unemployment rate, consumer price index, producer price index, interest rates, stock market, etc. For this study, we consider real GDP as an indicator for measuring economic growth rate. Real GDP is an indicator of all goods and services, valued and adjusted for inflation, from an economy each year.

Demand and supply of employment within South Africa's construction sector exhibits nonlinear behaviour, which is a character observed from complex systems. Thus, a system dynamic model can be used to provide useful insight into understanding the dynamics of the demands and supply of employment in South Africa's construction sector (Aiyetan & Dillip, 2018). Here a model is developed that includes key factors (parameters) for employment demand and supply in South Africa's construction sector. A Causal Loop Diagram (Figure 1) provides the conceptual framework of the model presented. The model includes the influence of the economy on employment in general and the construction sector, in particular. Using this model, the extents of these key factors are investigated and discussed.

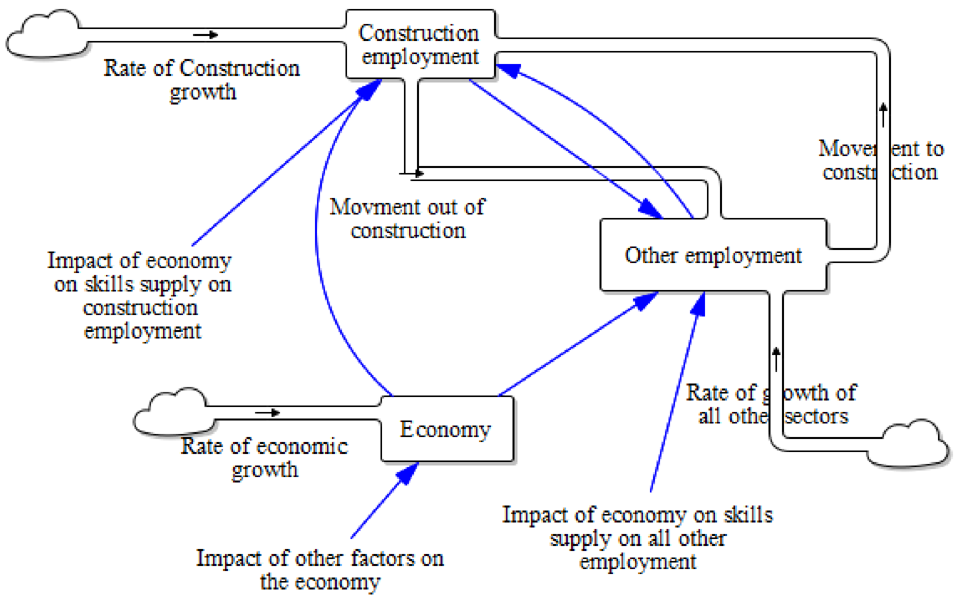


FIGURE 1 - MODEL OUTLOOK (CAUSAL LOOP DIAGRAM)

## 2. THE SOUTH AFRICA'S CONSTRUCTION SECTOR EMPLOYMENT MODEL

Employment dynamics of the construction sector is investigated in this study using the system dynamics model below mostly based on the Causal Loop Diagram in Figure 1.

$$\frac{dN_1(t)}{dt} = \sigma_1 N_1(t) + \frac{\rho_1 E(t)\, N_1(t)}{N_1(t) + N_2(t)} - \delta_{12} N_1(t) + \delta_{21} N_2(t),$$

$$\frac{dN_2(t)}{dt} = \sigma_2 N_2(t) + \frac{\rho_2 E(t)\, N_2(t)}{N_1(t) + N_2(t)} + \delta_{12} N_1(t) - \delta_{21} N_2(t),$$

$$\frac{dE(t)}{dt} = \alpha E(t) + \Lambda E(t)^2.$$

For this model, the total number of employments in all the sectors is partitioned into two variables $N_1(t)$ and $N_2(t)$. The variable $N_1(t)$ represent the number of employments in the construction sector at time t and $N_2(t)$ represent the number of employments in all other sectors at time t. The dynamics of $N_1(t)$ and $N_2(t)$ are influenced by many factors, but we consider only the major factors. One major factor is the rate of growth in employment which is linked in some way to population growth and the economy of the country. $\sigma_1$ and $\sigma_2$ represent the growth in the construction sector and all other sectors, respectively, that creates the demand for employment in those sectors. The supply of people with skills will depend on the economic growth of the country as well as the current employment needs. E(t) represents a measure of economy growth for the country which in this study we model on real GDP. The rate of change in real GDP is captured by α. Any other factors that impact the economy are represented by Λ. The parameters $\rho_1$ and $\rho_2$ represent the effects of the economy on the proportional supply of skills to $N_1(t)$ and $N_2(t)$, respectively. Individuals can change employment for several reasons. In the model $\delta_{12}$ is the rate at which individuals move from $N_1(t)$ to $N_2(t)$ and $\delta_{21}$ is the rate at which individuals move from $N_2(t)$ to $N_1(t)$. Analysis of this model is used to determine the possible future dynamics of demand and supply of skills in the construction sector.

## 3. MODEL PARAMETER ESTIMATIONS

Parameters estimates were obtained by fitting the model to employment data from the South African Construction Educations and Training Authority (CETA) and real GDP data for South Africa from World Economics (2020) for the period 2010 to 2018. The data are normalized using decimal scaling to enable model fitting and analysis. The data and each model fit for each of employment in the construction sector, other sectors, and real GDP in US dollars, from 2010 to 2018, are given in Figure 1.

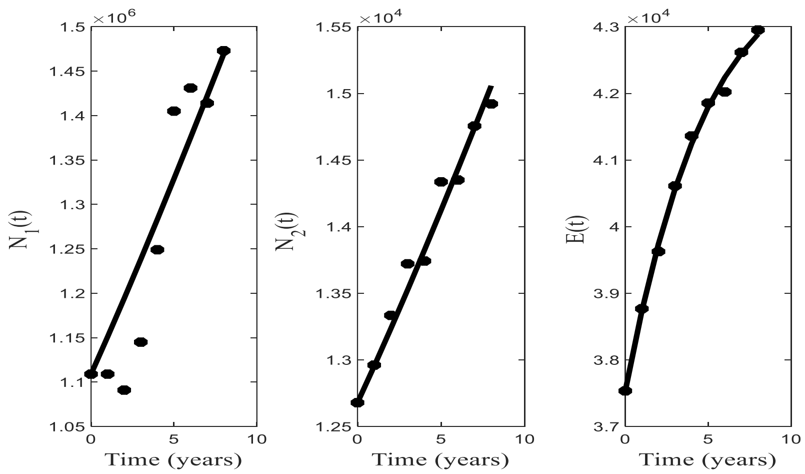


FIGURE 1 - EMPLOYMENT DATA (POINTS) FIT TO THE MODEL (LINES) FOR THE CONSTRUCTION SECTOR AND OTHER SECTORS, AND REAL GDP (US DOLLARS), FROM 2010 TO 2018. UNITS FOR N1 AND N2 WERE THE NUMBER EMPLOYED IN THAT YEAR.

The parameter values obtained are: $\sigma_1 = 0.0257$, $\sigma_2 = 0.0043$, $\rho_1 = 0.0091$, $\delta_{12} = 0.0505$, $\delta_{21} = 0.0033$, $\rho_2 = 0.0058$, $\alpha = 0.2375$, $\Lambda = -0.5400$. Using these estimated parameters, the



Theoretical and Empirical Researches in Urban Management
Volume 17 Issue 2 / May 2022

model can be used to make future predictions on the possible dynamics of employment in the construction sector. Such predictions are crucial for planning and development of better policies that can lead to the creation of employment resulting in sustainable economic growth.

## 4. RESULTS

Using the estimated parameter values we consider the possible future dynamics of employment in the construction sector. To consider the effects of the primary drivers (demand and supply of skills, economic growth etc.) we look at the effect on the dynamics when the parameters are varied. For each scenario, one parameter is varied and all others remain unchanged (the fitted values). Note that our predictions are a guide in that the model predictions, while not necessarily completely accurate, can give some useful insight into the future dynamics of the system.

### *4.1. Effect of demand in the construction employment*

Different levels of demand for construction employment are considered by changing the parameter for growth in the construction sector $\sigma_1$ (Figure 2). As expected, greater demand creates more employment. However, of interest is the fact that as the rate is increased the effect become increasingly nonlinear.

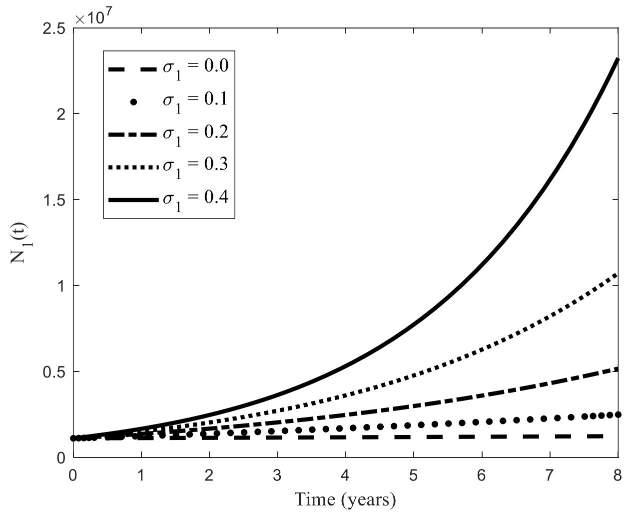


FIGURE 2 - GRAPH SHOWING THE EFFECTS OF THE RATE OF CONSTRUCTION SECTOR GROWTH ($\sigma_1$) ON THE NUMBER OF EMPLOYED IN THE CONSTRUCTION SECTOR (N1).

### *4.2. Effects of the economy on the employments in the construction sector*

Economic growth is one of the major factors that determines the employment rates in any country. The importance of the economy is illustrated in Figure 3 where economic growth rate ($\alpha$) is varied. A threshold value for economic growth results in a constant economy (approximately $\alpha = 0.2$). In this case construction employment increases at a linear rate. Above this threshold the economy increases to a new constant and employment increases at a greater nonlinear rate. Below this threshold the economy declines to a new constant and the rate of an increase of employment is also affected.

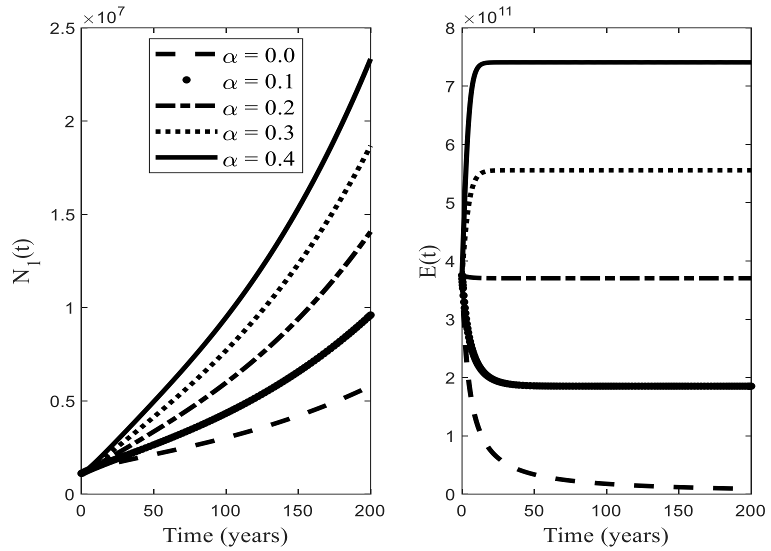


FIGURE 3 - PLOT SHOWING THE EFFECTS OF GROWTH RATE OF REAL GDP ($\alpha$) ON REAL GDP (US DOLLARS) AND ON THE NUMBER OF EMPLOYED IN THE CONSTRUCTION SECTOR (N1). LEGENDS ARE THE SAME.

By varying the proportional effect of the economy on the number of existing employment ($\rho_1$) shows the importance of this factor (Figure 4). If there is no effect of the economy on construction employment, then construction employment remains constant. Also, as the rate is increased the effect become increasingly nonlinear.

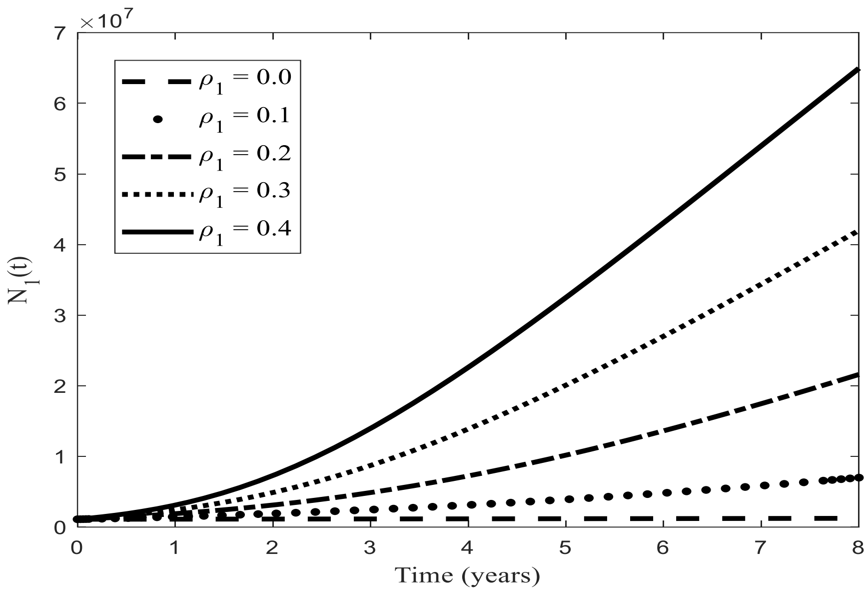


FIGURE 4 - PLOT SHOWING THE EFFECTS OF ECONOMIC GROWTH ($\rho_1$) ON THE NUMBER OF EMPLOYED IN THE CONSTRUCTION SECTOR (N1).



Theoretical and Empirical Researches in Urban Management
Volume 17 Issue 2 / May 2022

### *4.3 Effects of rate of change of employment in the construction sector*

The effects of career changes from the construction sector to other sectors and vice versa are considered in Figure 5. As expected, the rate at which individuals change employment has an impact on the construction sector. The rate that people leave construction employment ($\delta_{12}$) can have a large effect with a threshold at which there is no effect (approximately $\delta_{12} = 0.3$) below and above which employment rises or declines to a new constant value. On the other hand, the rate at which individuals change employment from other sectors to the construction sector ($\delta_{21}$) increases the number of employments in the construction sector.

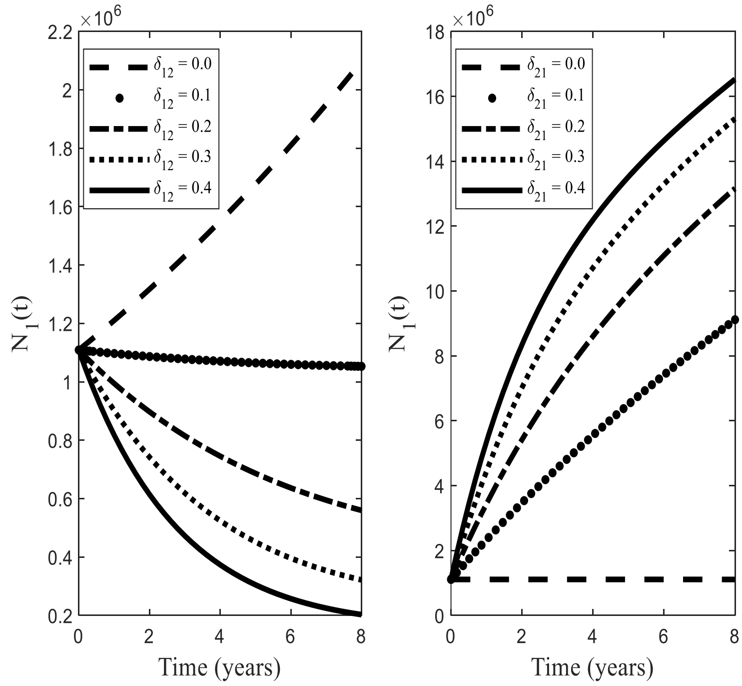


FIGURE 5 - PLOT SHOWING THE EFFECTS ON THE NUMBER EMPLOYED IN THE CONSTRUCTION SECTOR (N1) FOR A RATE OF CHANGE OF EMPLOYMENT FROM THAT SECTOR TO OTHER SECTORS AND VICE-VERSE.

### *4.4 Combining more than one factor.*

Combining effects will obviously also result in different employment rates. As an example, it is interesting to consider the rate of growth of the construction industry ($\sigma_1$) with the rate that construction employees leave the sector ($\delta_{12}$) because each of these has a marked effect. Simulations for varying both these parameters show how these two factors can cancel each other out. In Figure 6 low values of $\sigma_1$ and high values of $\delta_{12}$ result in employment stagnation. Only either high value of $\sigma_1$ or low values of $\delta_{12}$ result in increased employment with a combination of these effects being optimal.

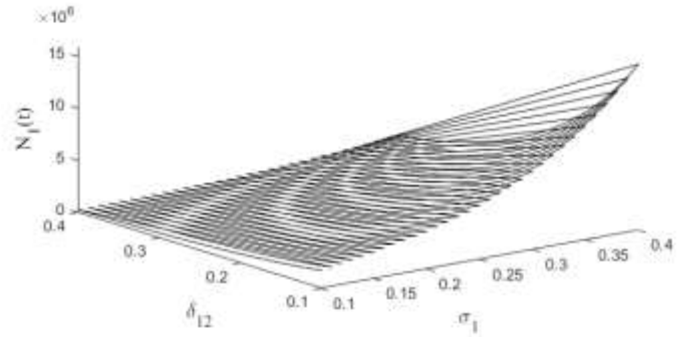


FIGURE 6 - PLOT SHOWING THE EFFECTS ON THE NUMBER EMPLOYED (N1) FOR CHANGES IN CONSTRUCTION GROWTH ($\sigma_1$) AND EMPLOYEES LEAVING THE CONSTRUCTION SECTOR ($\delta_{12}$).

## 5. DISCUSSIONS

As expected, demand, economic growth and movement between sectors have an influence on the extent of construction employment in South Africa. Here we use a simple model relating these factors and data on employment trends and economic growth are used to fit the parameters of the model. Demand is assumed to be related to construction sector growth and economic growth is based on data for real GDP. Scenario predictions using simulations of the model for increasing parameters individually are used to investigate the extent of each factors influence.

Model simulations with increasing construction sector growth result in increasing construction employment and these increases are nonlinear for high enough growth. These results confirm the emphasis of many governments on stimulating the economy by developing construction projects. In South Africa the government uses infrastructure investment to help reduce unemployment, decrease income inequality, and realise sustainable economic growth and development (Mosenogi, 2016). Construction can stimulate an increase in lower-income and middle-income wealth (Lopes, 2022). Creation of employment stimulated by construction projects can increase household incomes and bridge inequality in the economy (Mosenogi, 2016). Although direct influences of construction on income generation have been shown to be more apparent in the early phases of development linked to increases in urbanization and demographic growth (Bon, 1992; Lopes 2022). However, our results show that the greater the stimulation of construction the larger the effect on employment with nonlinear growth in employment if the rate is high enough. Thus, regardless of the stage of economic development the importance of the construction sector is supported.

The simulations show an interesting interrelationship between economic growth and employment. First, economic growth which stabilizes at a particular rate result in a steady increase in construction employment. Secondly, as the rate of economic development increases construction employment increases are more and more nonlinear. The data for real GDP from 2010 to 2018 in South African shows a logistic trend for economic growth. Logistic trends are observed in many processes in biology, engineering, demographics, and economics. These processed involve growth with saturation due to limiting factors. In economics, logistic trends resulting from limited resources are a common condition of socio-economic development (Kwasnicki, 2013). Thus, logistic models, as used here, are often used successful to describe these types of trends.

The extent of the effect on employment is also shown to be important. As this effect becomes stronger the growth of employments also become non-linear. However, it is hard to see how this factor could be manipulated as the relationship would depend on the circumstance involved. What is ignored in the model is the potential feed-back of the construction industry on the economy and this could be important.

Change of employment from one sector to another is very common. Factors that drive people to change their employment include finances, working environment, proximity to home etc. Here we explore the effects of a rate of change of employment from the construction sector to the other sectors and vice versa. As expected, rates of people changing employment into or from the construction sector has an impact on those employments. If these rates match the construction sector growth the employment remains constant. For higher rates of people leaving construction employment the overall number employed decreases and as rates of entering construction increase the number employed increase. What is important is that none of these trends go to zero, each tends to a revised constant employment. Thus, persons altering employment does not extinguish the industry.

These factors will vary together and the combined effects are also important. For example, considering the rate of growth of the construction industry together with the rate that construction employees leave the sector can balance one another. Thus, in recession years where the construction sector might be stagnant policies and incentives to encourage employee retention could be used. Simulations such as developed here could guide such efforts. Further research, by us or others, on the cost/benefit analysis on these type of initiatives should be developed.

Overall, our simulations show the extent of linkages between construction sector growth, economic development, and choice of employment. Overall, construction employment can be stimulated by a healthy climate of sector growth, economic development and the choice of employment focused on construction. This paper argues for a system dynamics approach as a conceptual and methodological tool for predicting employment trends. Result can assist in making policy decisions for reducing unemployment in South Africa, especially in the construction sector.

## ACKNOWLEDGEMENT

The management of the Construction Educations and Training Authority (CETA) and the resources they provided enabled the successful completion of the study. This research was funded in part by The National Research Foundation of South Africa (Grant Number 131604).

## REFERENCES

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017, February). Circular economy in construction: current awareness, challenges and enablers. In *Proceedings of the Institution of Civil Engineers-Waste and Resource Management* (Vol. 170, No. 1, pp. 15-24). Thomas Telford Ltd.

Aiyetan, O. A., & Das, D. (2018). System dynamics approach to mitigating skilled labour shortages in the construction industry: A South African context. *Construction Economics and Building*, *18*(4), 45-63.

Arndt, H. (2006). Enhancing system thinking in education using system dynamics. *Simulation*, *82*(11), 795-806.

Arnold, R. D., & Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia computer science*, *44*, 669-678.

Bon, R. (1992). The future of international construction: secular patterns of growth and decline. *Habitat international*, *16*(3), 119-128.

Brent, A., & Simelane, T. (Eds.). (2018). *System dynamics models for Africa's developmental planning*. Pretoria: Africa Institute of South Africa (AISA).

Brent, A., Simelane, T., & Clifford-Holmes, J. (2018). Introduction to system dynamics as a decision-support tool for developmental planning. In A. Brent & T. Simelane (Eds.), *System Dynamics Model for Africa's developmental planning*. Pretoria: Africa Institute of South Africa (AISA).

Caulfield, C. W., & Maj, S. P. (2001, October). A case for systems thinking and system dynamics. In *2001 IEEE International Conference on Systems, Man and Cybernetics. e-Systems and e-Man for Cybernetics in Cyberspace (Cat. No. 01CH37236)* (Vol. 5, pp. 2793-2798). IEEE.

Cosser, M. (2010). The skills cline: higher education and the supply-demand complex in South Africa. *Higher Education*, *59*(1), 43-53.

Lopes, J. (2022). Construction in the economy and in national development. In Ofori, George (ed.) Research Companion to Construction Economics. p.104-125.

Keating, J. (2009). Matching supply of and demand for skills: International perspectives. *Australian Bulletin of Labour*, *35*(3), 528-560.

Kruss, G., McGrath, S., Petersen, I. H., & Gastrow, M. (2015). Higher education and economic development: The importance of building technological capabilities. *International Journal of Educational Development*, *43*, 22-31.

Kwasnicki, W. (2013). Logistic growth of the global economy and competitiveness of nations. *Technological Forecasting and Social Change*, *80*(1), 50-76.

LG SETA. (2015 ). *Skills demand and supply in South Africa, with focus on the water sector*. Retrieved from Council for Scientific and Industrial Research (CSIR) Pretoria:

Mello, M. H., Gosling, J., Naim, M. M., Strandhagen, J. O., & Brett, P. O. (2017). Improving coordination in an engineer-to-order supply chain using a soft systems approach. *Production Planning & Control*, *28*(2), 89-107.

Mosenogi, J. M. (2016). An impact analysis of construction sector on economic growth and household income in South Africa. *Journal of Management & Administration*, *2016*(1), 128-137.

Peters, D. H. (2014). The application of systems thinking in health: why use systems thinking?. *Health research policy and systems*, *12*(1), 1-6.

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P. (2019). Unlocking circular business: A framework of barriers and drivers. *Journal of cleaner production*, *212*, 90-98.

Wilson, R., Woolard, I., & Lee, D. (2004) Developing a national skills forecasting tool for South Africa. Institute for Employment Research, University of Warwick, Coventry, UK. Pretoria: DoL/HSRC

Woolard, I., Kneebone, P., & Lee, D. (2003). Forecasting the demand for scarce skills, 2001-2006. *Human resources development review*, 458-474.

World Economics (2020). Real GDP South Africa, http://dev.worldeconomics.com/GrossDomesticProduct/Real-GDP/South%20Africa.aspx, accessed on 26 March 2022..