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CONSTRUCTION OUTPUT MODELLING: A SYSTEMATIC REVIEW

ABSTRACT

Purpose: Construction economics scholars have emphasised the importance of construction output forecasting and have called for increased investment in infrastructure projects, due to the positive relationship between construction output and economic growth. However, construction output tends to fluctuate over time. Excessive changes in the volume of construction output have a negative impact upon the construction sector, such as liquidation of construction companies and job losses. Information gleaned from extant literature suggests that fluctuation in construction output is a global problem. Evidence indicates that modelling of construction output provides information for understanding the factors responsible for these changes.

Methodology: An interpretivist epistemological lens is adopted to conduct a systematic review of published studies on modelling of construction output. A thematic analysis is then presented and the trends and gaps in current knowledge are highlighted.

Findings: It is observed that interest rate is the most common determinant of construction output. Also revealed is that~~,~~ very little is known about the underlying factors stimulating growth in the volume of investment in maintenance construction works. Further work is required to investigate the efficacy of using non-linear techniques for construction output modelling.

Originality: This study provides a contemporary mapping of existing knowledge relating to construction output and provides insights into gaps in current understanding that can be explored by future researchers.

Keywords: Construction output, forecasting, modelling, systematic review, text mining.

INTRODUCTION

The construction industry produces a nation's infrastructure ~~to~~ in order to support economic growth. For several decades, research has demonstrated that the construction industry is also one of the main drivers of economic growth (Turin, 1978; Dang and Low, 2011; Chiang et al., 2015). Because of~~to~~ this causal relationship between construction sector activities and economic growth, academics and practitioners have called for increased investment in construction projects (Anaman and Osei-Amponsah, 2007; Kofoworola and Gheewala, 2008). H~~–h~~owever, such investment has not always resulted in economic prosperity and~~.~~ ~~T~~there are two main reasons for this observation. First, there may be a~~the~~ lack of local capacity to meet the increased demand for new construction projects (cf. Bhalla and Edmonds, 1983; Lewis, 1984). Second, an unplanned increase in investment creates a fluctuation in construction output, which has a negative impact upon the construction sector (Ofori et al., 1996).

Construction output is one metric used for~~in~~ measuring the volume of construction investment. The fluctuation of construction output is a topical area of interest within the field of construction economics and several models have been developed to identify the factors which affect its volume. This interest stems from the impact of construction output on employment, property prices and construction costs (Jin and Zeng, 2004; Zheng et al., 2012; Saks, 2008; Soo and Oo, 2014). Due to the negative impact that fluctuations in construction output have on the economy, Ng et al. (2009) suggest that econometric models should be developed to predict future changes in construction output volume. If a model is capable of accurately predicting the volume of construction output, then the critical determinants can be manipulated to produce the desired output. For instance, the impact of intervention strategies could be evaluated in a controlled laboratory (i.e. the model) before implementation. The outcome of model-based studies would provide evidence-based knowledge for minimising the impact of changes i~~i~~n construction output volume. Although an accurate forecast of an event is essential, it is difficult to achieve this in the real world (Makridakis et al., 2009). The occurrence of a natural disaster would result in drastic changes in the volume of investment in construction works. The huge uncertainty associated with economic and business activities can also affect the accuracy of model forecasts.

Construction output modelling research is targeted at either 'explanation' (see Anaman and Osei-Amponsah, 2007) or 'forecasting' (see Jiang and Liu, 2014). Typically, models ~~are~~ developed for construction output forecasting are based on empirical evidence of the existing relationship between construction activities and the economy (see Riggleman, 1933; Lewis, 1960). Based on the foregoing, socio-economic variables (such as population and interest rates) are used as predictors of construction output. Thus, researchers strive to identify the 'best' set of socio-economic variables to explain or predict movements in the volume of construction output.

Research rationale

The empirical knowledge-base required to drive an academic discipline is generated through research. According to Runeson (2011), the process of knowledge creation passes through three distinct phases: description, explanation and prediction. At the description phase, studies are designed to describe an event in construction practice. Riggleman (1933) describes the fluctuations in the volume of construction output from 1875 to 1932. Subsequently, many studies have examined the relationship between the variations in the volume of construction output and the economy (Turin, 1978; Bon and Minami, 1986). Findings emanating from the description phase inform the choice of variables included in explanatory and prediction models developed in the second and third phases of knowledge creation. Professor Ranko Bon (1992) conducted several studies aimed at understanding the relationship between construction activities and the economy (i.e. explanatory phase). The outcome of these studies informed the hypothesis which states that at an advanced stage of development, the volume of new construction work would reduce and the amount of maintenance construction would be expected to increase~~grow~~ due to the needs of ageing infrastructure (*ibid*). Consolidation of the results from explanatory research leads to the emergence of theories, which then provide a sound base for the development of forecasting models.

Modelling-oriented studies are either used to explain the relationship between two theoretical constructs (e.g. the link between the construction industry and the economy) or for forecasting (see Shmueli and Koppius, 2011). For example, Chiang et al. (2015) report on the development of a model for evaluating the relationship between 'construction output' and the 'economy', and find that a bi-causal relationship exists between the two constructs. In contrast, Sing et al. (2015) use the vector auto-regression (VAR) model for forecasting the volume of private sector investment in construction works. Explanatory modelling is primarily concerned with the building and testing of theories (Runeson, 2011). In contrast, forecasting-oriented research is focused on using established theories to solve practical problems (Shmueli and Koppius, 2011). In cases where forecast models generate unreliable results, the theory upon which the model was built must ~~needs to~~ be discarded or modified.

Despite the significant effect~~ce~~ that construction output has upon an economy (see Anaman and Osei-Amponsah, 2007; Dang and Low, 2011), studies that focus upon developing models to predict its changes are few. Evidence from literature shows that fluctuations in the volume of construction output are~~is~~ a recurring problem in several countries, including: Singapore (Goh, 1996), Hong Kong (Sing et al., 2015) and the United Kingdom (Tanratanawong and Scott, 2000). As identified in previous studies, the negative consequences of fluctuating construction output volume include: inefficiency in the production process (Ofori et al., 1996); bankruptcy; and retrenchment within the construction industry during periods of low production (Jiang et al., 2013; Ng et al., 2008). Therefore, construction output forecast models provide an understanding of its predictors. This evidence-based information is required for developing strategies to mitigate the impact of construction output fluctuation.

Although Dang and Low (2011) report upon a review of studies exploring the relationship between construction output and the economy, hitherto~~,~~ no comprehensive review on construction output forecasting has been published. This current study therefore builds upon the earlier review (ibid) by~~ut~~ undertak~~es~~ing a systematic review of published studies on construction output modelling *and* forecasting. Note, those explanatory modelling studies within the scope of the research conducted by Dang and Low (2011) are excluded. Specifically, the review provides answers to the following questions: (i) when and where were the construction output modelling studies published?; (ii) ~~where are construction output modelling studies published?; (iii)~~ what ~~are the~~ methods are employed~~used~~ for construction output modelling?; (iii~~v~~) what has been~~is~~ the focus of previous studies on construction output modelling research?; (iv) which variables are the determinants of construction output?; (v~~i~~) what is the relative performance of models used for construction output forecasting? and (vi~~i~~) what are the key findings exposed by the review~~is the focus of previous studies on construction output modelling~~? This study contributes to existing knowledge in the field of construction management by: (i) mapping the existing construction output modelling intellectual territory; and (ii) speculating upon ~~the research~~ opportunities for future research~~questions that can be explored in the future~~ based on the observed gaps in contemporary knowledge. The consolidation and organisation of the literature on construction output modelling will provide valuable insights to various stakeholders (such as policymakers and researchers).

CONSTRUCTION OUTPUT

Construction output is the monetary value of all construction works executed in a country ~~at~~over a defined period (usually quarterly). There are variances in the process of collecting and presenting ~~the~~ data on construction output and its determinants from country to country. For instance, the Census and Statistics Department of Hong Kong views construction output as the *"total gross value of construction works performed by main contractors"* at a defined time

(Census and Statistics Department, 2015). Similarities exist between this definition and that of the UK Office of National Statistics (ONS) ~~of the UK~~ (see Office for National Statistics, 2015), but it is important to note that the ONS deducts value-added tax from the value of construction works. Despite these differences, construction output is a valid measure for quantifying the volume of activities in the construction market at a defined time.

Several metrics are used to quantify the volume of construction output, for example: gross output (Fan et al., 2010); the gross floor area of development commenced (Goh, 1999); and value of construction approvals (Jiang and Liu, 2014). Despite these variances, Ofori (1990) affirms that gross output is an accurate reflection of the volume of activities in the construction industry, because it is the monetary value of developments which clients are willing and able to pay for (i.e. effective demand). Furthermore, Akintoye and Sommerville (1995) find that a lagged relationship exists between ‘demand’ and ‘~~‘~~effective demand’ for construction works, which suggests that demand for construction works eventually translates to ~~‘~~effective demand~~’~~ (i.e. construction output) at a later date. While a variety of metrics exist for measuring the volume of construction output, it is evident that gross output is an objective measure of the volume of activities within the construction sector.

Disaggregation of construction output

The need to unmask the factors responsible for changes in the volume of investment in construction works has led to its disaggregation. Although some authors report upon models for construction output at an aggregate level (cf. Jiang and Liu, 2011), others disaggregate construction output into its constituent parts, for instance~~,~~ based upon the market sectors of manufacturing (Nicholson and Tebbutt, 1979), commercial (Akintoye and Skitmore, 1994) and residential (Goh, 1996). Disaggregation of construction output is targeted at identifying ~~the factors’~~ changes within the factors that affect ~~in~~ the volume of activities in the various segments of the construction market.

Construction output modelling: an overview

Modelling of construction output provides answers to the following questions: (i) what are the underlying factors responsible for fluctuation in the volume of construction output?; (ii) can existing theories found in literature be used to explain the movements in the volume of construction output?; and (iii) can the changes in the volume of construction output be predicted based on existing theories? As stated by Shmueli and Koppius (2011), forecasting is useful for evaluating the practical relevance of theories found in the literature, thus studies focused on modelling contribute to the creation of knowledge.

The first published study on construction output modelling was carried out by Duffy (1975) with further investigations undertaken in subsequent years (cf. Goh, 1996; Jiang and Liu, 2014). Building on the work carried out by Duffy (1975), researchers use several techniques for construction output modelling. As stated in the research rationale~~ section~~, model research is either used for ‘explanation’ or ‘prediction’ and the processes of developing explanatory and predictive~~on~~ models are distinct. Shmueli and Koppius (2011) assert that data partitioning is one of the main differences between explanatory and prediction models. For explanatory models, the model is estimated using the whole dataset. In contrast, studies focused on forecasting partition the collected data ~~is partitioned~~ into two groups ~~in studies focused on forecasting~~ (one group is used for estimating the model~~,~~ and the other group is used for validating the model).

Another distinction between the techniques used for modelling ~~of~~ construction output is the type of relationship presumed between the variables. In the earlier research studies~~y years~~, it was assumed that a linear relationship exists~~s~~ between construction output and its determinants, an~~. This~~ assumption ~~is~~ responsible for the use of regression ~~in previous research~~ on construction output modelling (Duffy, 1975). However, the lagged relationship between variables was often overlooked (Goh, 1996). The earlier methods are therefore called ‘static’ models, whereas in contrast, models that capture contemporaneous and lagged relationships between variables are termed ‘dynamic’ models. For a detailed explanation on the distinction between static and dynamic models refer to Flood and Issa (2009). The need to address the gap in knowledge has led to the application of several techniques for construction output.

RESEARCH METHODOLOGY

This research employed~~s~~ an interpretivist epistemological lens to undertake the literature review. Interpretivism is an established philosophical stance employed within construction management literature and has been successfully employed to, for example,~~:~~ review post occupancy evaluation (Roberts et al., 2019)~~;~~ and automate~~ing~~ construction manufacturing procedures using BIM digital objects (BDOs) (Al-Saeed et al., 2020). Several types of literature review (e.g. critical review, integrative, systematic, etc.) have been previously published. However, the findings drawn from certain types of review studies are difficult to replicate and may be questionable due to the lack of detailed information ~~about~~regarding the research approach (e.g. sampling approach and inclusion criteria). A~~s a proven method, a~~ systematic literature review, as a proven method,~~–~~ was adopted in this study to integrate the existing knowledge and a gain~~for~~ a deeper understanding of the research problem (Tranfield et al., 2003; Golizadeh et al., 2020). Although a generally accepted guideline for reporting systematic reviews does not exist, Booth (2006) recommends providing information using the ~~"~~'STARLITE'~~"~~ mnemonic (i.e. sampling strategy, type of study, approaches, range of years, limits, inclusion and exclusions, terms used, electronic sources).

Many researchers have utilised the systematic review approach in the field of construction management, for example it has been used to highlight the current state of knowledge on drivers of green building (Darko et al., 2017), practice-based learning (Kokkonen and Alin, 2015) and public-private partnership (Ke et al., 2009). Empirical evidence has shown that the systematic review approach integrates existing knowledge about a research problem into a meaningful whole. In the current study, it was used to gain insights into the extant literature on construction output modelling. The systematic review was carried out in two phases,~~ viz:~~ phase 1 being the database search and screening (search results were screened using the selection and inclusion criteria); and phase 2 being the content analysis of the selected papers.

Scope of the Research Outputs Covered in this Study

The sample for this study ~~is~~ comprised of manuscripts published in academic journals only. The reasons for limiting the search to academic journal articles ~~a~~were that: (i) the outcome of studies reported in conference papers were updated and published as journal articles at a later date; and (ii) the outcome of unpublished works were published as journal papers, for instance, the outcome of an Australian PhD study on construction demand forecasting (Jiang, 2013) was published in two journal papers (Jiang and Liu, 2011; Jiang and Liu, 2014).

Identification of Search Keywords for Database Search

As suggested in Tranfield et al. (2003), a scoping study was carried out to identify suitable search keywords. The initial search was undertaken using the ARCOM (Association of

Researchers in Construction Management) database. Two terms, ~~i.e. "~~'construction output'~~"~~ and '~~"~~construction demand',~~"~~ were utilised for this initial search. These terms were used to satisfy the objective of the current study and because they are used interchangeably within the literature. The need to identify relevant phrases for the extensive database search was the main reason for this initial exploration. A total of 19 (18 journal and 1 conference) articles were uncovered from the ARCOM database search.

Ananiadou et al. (2009) suggest the use of term extraction, which is a text mining technique, to identify relevant keywords for a systematic literature review. In this study, the TerMine software (Frantzi et al. 2000) was used for term extraction. The title, keywords and abstract of the 19 articles~~,~~ from the ARCOM search were~~as~~ used to create a corpus for term extraction. At the end of the term extraction process, '~~"~~construction output'~~"~~, '~~"~~construction demand'~~"~~, '~~"~~model'~~"~~ and '~~"~~forecasting'~~"~~ were identified as suitable keywords for the extensive database search.

Search Process

The systematic process used to search for relevant articles was carried out in three phases (see Figure 1). In phase one, a search was carried out using the SCOPUS and Web of Science [WOS] databases. Several lines of evidence indicate that SCOPUS is a comprehensive database of journals when compared to WOS, CSA Illumina, Microsoft Academic and Google Scholar (Norris and Oppenheim, 2007; Siguenza-Guzman et al., 2015; Hug and Brändle, 2017). As suggested in Baykoucheva (2010), the extensive literature search was carried out on both the SCOPUS and WOS database, ~~. The use of these two databases~~ ensuring~~ed~~ that the search covered a comprehensive range of publication outlets.

In~~At~~ phase two, an additional search was carried out on the database of key journals. Previous systematic literature reviews have shown that the use of a combination of indexed and journal database searches ensures that relevant articles are captured (Ke et al., 2009; Kokkonen and Alin, 2015). Due to the multidisciplinary nature of construction output research, an additional search was conducted on journals related to the ~~covering the~~ following academic disciplines: (i) construction management; and (ii) real estate.

In~~At~~ phase three, textual data (titles, abstracts and keywords) relating to papers identified~~found~~ in the second phase~~stage~~ were entered in the TerMine software. The data was analysed to check ~~if~~for ~~any~~ new keywords ~~will be~~ identified and these~~. The new keywords~~ were used for an additional search on the SCOPUS and WOS databases. This robust search strategy ensured~~s~~ that all the relevant articles were identified at the end of the search process.

Phase One ~~The~~ Search~~ – (phase one)~~

The combination of keywords used for the database search we~~a~~re: (i) ‘~~“~~construction output’~~”~~ AND ‘~~“~~forecast*’~~”~~; (ii) ‘~~“~~construction output’~~”~~ AND ‘~~“~~model*’;~~”~~ (iii) ‘~~“~~construction demand’~~”~~ AND ‘~~“~~forecast*’~~”~~; and (iv) ‘~~“~~construction demand’~~”~~ AND ‘~~“~~model*’.~~”~~ A total of 155 journal articles were identified~~found~~ at the end of the database search (111 articles from SCOPUS and 44 articles from WOS). An initial screening of search results was undertaken to remove duplicates and irrelevant papers (i.e. papers not within the scope of the review). It was observed that there were numerous duplicates in the search results which was~~and this is~~ due to the overlap in the journals indexed in both databases. At the end of the database search and initial screening, 23 relevant journal papers were identified.

~~The Search – (p~~Phase T~~t~~wo Search~~)~~

Construction output research is predominantly published in construction management and real estate journals. In the field of construction management, an additional search was conducted on the databases of the following journals: *Construction Management and Economics*; *Journal of Construction Engineering and Management*; *Journal of Management in Engineering*; *Engineering, Construction and Architectural Management*; *Habitat International*; *Construction Economics and Building*; *International Journal of Construction Management*; *Building and Environment*; and *Building Research and Information*. In the field of real estate, a supplementary search was conducted on the databases of the following journals: *Real Estate Economics*; *Journal of Real Estate Finance and Economics; Journal of Real Estate Research*; *Journal of Property Finance*; *Journal of Property Valuation and Investment* and *Journal of Property Research*.

The choice of these journals was informed by~~ the following~~: (i) the ranking of the journal in the selected field (for details of ranking of construction management and real estate journals, refer to: Wing, 1997; Newell et al., 2002; and Hardin III et al., 2006);~~,~~ and (ii) the number of relevant papers found in the journal at the end of the SCOPUS and WOS search. At the end of the second search (journal database search), 14 relevant articles were identified.

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P~~The Search – (p~~hase T~~t~~hree Search~~)~~

The titles, abstracts~~,~~ and keywords of the 14 articles identified~~, from t~~ in the second phase~~stage~~ of the search~~,~~ were used to create a corpus. This corpus was analysed in the TerMine software and additional keywords ~~were~~ identified for the third phase of the ~~stage of~~ search process, namely:~~. From the corpus,~~ '~~"~~housing investment'~~"~~, '~~"~~construction activity'~~"~~, '~~"~~building supply'~~"~~, '~~"~~construction supply'~~"~~ and '~~"~~property market'~~" were identified~~. These keywords were used to carry out an additional search on the SCOPUS and WOS databases. The search process was repeated several times ~~(the stage was done in three phases)~~ to ensure that a comprehensive list of relevant journal papers was identified. 13 journal papers were found during phase three.

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Screening and Collation of the Search Results

At the completion of the search process, a total of 50 articles were identified (i.e. 23+14+13 = 50 journal articles). An initial screening was used to remove irrelevant articles from the search results. Out of the 155 articles found in ~~the~~ phase one, 133 journal papers were excluded from the search results for the following reasons: (i) duplication [articles were found twice or more in the search results]; (ii) inappropriate focus of article subject matter [e.g. construction cost forecasting); and (iii) replication, where studies were covered in the scope of a previous review on relationships between construction output and economic growth (Dang and Low, 2011). In addition, screening was completed at the end of the second and third phase of the search. The filtering (screening) phase of articles entailed a brief review of the journal paper~~(s)~~ titles and abstracts found in the search results.

Subsequently, the full-text of the 50 articles was assessed for eligibility for inclusion into the study sample. Two unrelated articles were excluded from the outcome of the comprehensive search process. The secondary data (48 journal articles) was collected using the methods previously described and subjected to further analysis. In terms of time, there were no published articles on construction output modelling and forecasting before 1975 and the search reported in this paper was undertaken in 2019. Thus, the scope of the search covered the time period between 1975 and 2019; albeit, no papers published in 2019 meet the inclusion criteria (see

Table 1). This search criteria ensured that a comprehensive list of relevant journal papers was~~ere~~ identified during the search process.

Table 1 presents an overview of previous studies selected for this review. In this study, qualitative content analysis was used to dissect the selected journal papers. As suggested in Decrop (1999) and Edwards and Holt (2010), the use of methodological triangulation improves the reliability of findings derived from qualitative research. Subsequently, a data driven approach was used to analyse the title and abstract of each publication. Text mining was used for the analysis and visualisation of the text (i.e. the corpus created using the title, abstract and keywords). The findings emerging from the use of both methods was triangulated.

'Insert Table 1 here'

'Insert Figure 1 here'

RESULTS

Detailed information relating to journal papers selected for this study ~~are~~is presented in Table 1, ~~that~~which reveals that a large number of studies have ~~have~~ focused on modelling of residential construction output and that most~~. Also,~~ studies ~~found in literature~~ have largely focused on countries in the developed world (e.g. UK, US, Australia and Singapore).

The results of this study are ~~remaining six constituent parts of this section were~~ structured to address the research questions stated in the research rationale subsection, viz: (i)~~.~~ to provide an insight~~s~~ into the number of papers published annually~~in each year~~ for construction output modelling, together with the journal outlets used~~ for construction output modelling~~; (ii) to present the modelling techniques used in previous research; (iii) to illustrate the research themes addressed in previous studies; (iv) to identify the determinants (i.e. predictors used to explain or predict movement in the volume of construction output) of construction output; (v) to determine the relative performance of construction output forecast models; and (vi) to summarise the study's key findings.

Construction Output Modelling Research: Annual Publication Trend and Journal outlet

~~The content of this subsection addresses the first and second research question stated in the opening section of this paper.~~ A comprehensive literature search~~ of literature~~ revealed that there were 48 articles that focused on construction output modelling. ~~were published in various journals.~~ These manuscripts were published in various journals, 24 in total, ~~journals,~~ as presented in Table 2. In terms of numbers of published papers, the top-four outlets for disseminating construction output modelling studies were: *Construction Management and Economics*;~~,~~ *The Journal of Real Estate Finance and Economics*;~~,~~ *Journal of Property Research and Engineering*~~,~~; *and Construction and Architectural Management* ~~represent the top-four outlets for disseminating construction output modelling studies~~.

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The need to understand factors (i.e. determinants) responsible for fluctuations in the volume of construction output necessitated the study. Despite the importance of construction output modelling, little attention has been paid to this area of research (see Figure 2) ~~(see Figure 2)~~. It is visible that there has been an inconsistent trend in the number of construction output modelling studies published between 1975 and 2019. Scant research in this area could be attributed to the non-availability of data in some countries, as observed in previous research (K'Akumu, 2007; Yitmen et al., 2012). Unavailability of data on construction output and its determinants makes it impossible to estimate construction output models. ~~As shown in Figure 2, there is an inconsistent trend in the number of construction output modelling studies that were published between 1975 and 2019.~~

'Insert Table 2 here'

'Insert Figure 2 here'

Modelling Techniques

~~The third research question sought to identify the methods used for modelling of construction output.~~ Several modelling techniques are used to explain and/or predict the changes in the volume of construction output. These techniques ~~used for modelling of construction output can~~can be classified based on: (i) ~~the~~ number of variables included in the model [multivariate and univariate], (ii) consideration of the temporal characteristics of data [time series and non-time series] and (iii) academic discipline [statistical and artificial intelligence]. In some cases, it is difficult to ascribe a modelling technique to one particular category; this~~. This pitfall~~ can be attributed to the overlap in the label assigned to each modelling approach. For example, the Box-Jenkins model is a statistical, univariate (i.e. captures the relationship between the current and previous values of construction output) and time-series based approach. In contrast, a vector error correction model is a multivariate technique that captures the relationship between construction output and its determinants. In addition, a vector error correction model is a statistical and time-series based approach.

'Insert Table 3 here'

A classification summary of t~~Table 4 shows that the~~he descriptive statistics that relate~~ing~~ to modelling techniques used in previous research and the purpose of the study are displayed in Table 4. As stated previously, 48 construction output modelling studies were published in various journals. Of~~In~~ these studies, 13 models were estimated to explain the relationship between construction output and other input variables, whilst ~~. Also,~~ 35 models were used to generate forecasts of construction output. In some studies, models are estimated for explanation and forecasting purposes. For example, Fan et al. (2011) estimated a model that explains 40% of the variations in the volume of construction output. Subsequently, the estimated model was used to generate forecasts of construction output. In terms of the number of variables included in the developed model, multivariate models we~~a~~re the predominant technique used for modelling of construction output, with 50 instances of utilisation as compared to 19 for univariate models. Jiang and Liu (2011) developed two multivariate models, VEC and VEC-D, for forecasting of Australia's construction output. The popularity of multivariate models may be due to the need to identify underlying reasons for the changes in the volume of construction output. The output of multivariate models helps to identify the determinants (predictors) of construction output.

Based on time consideration, 31 non-time series and 38 time series techniques were used for construction output modelling. Between 1975 and 1983, it was observed that no consideration was given to a temporal relationship among variables during the process of developing construction output models (Duffy, 1975; Nicholson and Tebbutt, 1979; Thomas and Stekler, 1979; Thomas and Stekler, 1983). In recent years (2012-2019), there has been a shift towards the use of time series techniques in construction output modelling research. Statistical techniques (vis-à-vis artificial intelligence techniques) were~~have been~~ found to be the predominant method used in construction modelling research. The prevalence of this approach can be linked to its ability to explain the strength of the relationship between construction output and its determinants. For instance, Chiang et al. (2015) found that a bi-causal relationship exists between g~~G~~ross d~~D~~omestic p~~P~~roduct and construction output.

'Insert Table 4 here'

Construction Output Modelling: Research Themes and Topics

Various topics have been investigated in construction output modelling research. As stated in Ofori (1990), the determinants of construction output tend to vary across ~~the~~ different segments of the construction market. The need to understand the determinants of construction output in each market segment has led to a disaggregation of construction output into its constituent parts. Authors, such as Hillebrandt (1985) and Ofori (1990), have thematically classified construction output into (for example) housing, industrial, commercial and maintenance. For this~~In th~~ study~~is paper~~, construction output was~~is~~ classified based on the content of the published studies selected for the review.

Figure 3~~2~~ shows that construction output can be disaggregated into the ~~and~~ classifications~~ed into various main and subgroups, namely:~~: industry/regional (total, regional); project financier (private, public); and market sector (residential, commercial, manufacturing, maintenance, others, structures and facilities). Some previous~~past~~ research endeavours focused on the modelling of two or more types of construction output. For example, Akintoye and Skitmore (1994) developed forecast models for residential, commercial and industrial construction output. This disaggregation is vital for gaining insights into the determinants of each segment.

'Insert Figure ~~2~~3 here'

Determinants of construction output

~~Table 4 reveals that multivariate techniques are frequently used for construction output modelling.~~ Multivariate models provide insights into the underlying determinants responsible for changes in the volume of construction output and Table 4 reveals their frequent use for construction output modelling. The identification of 'best' determinants is essential for the application of multivariate techniques to construction output modelling. Historically, several multivariate techniques have been used for construction output modelling and as a~~so~~ consequence~~tly~~,~~.~~ a large number of determinants (i.e. input variables) of construction output have been identified (see Table 5).~~.~~

~~Table 5 summarises the determinants (i.e. input variables) used for construction output modelling in previous studies.~~ Since construction output tends to fluctuate over time, there is a need to understand the underlying reasons for these cycles. Mitigating the adverse effect of fluctuating construction output is impossible without identifying the determinants that cause changes in its volume. A whole range of determinants (e.g. interest rate and unemployment rate) could influence the volume of construction output as shown in Table 5. However, a closer examination of these previous studies indicates that the determinants ~~of construction output~~ vary when different classes of construction output are compared. As suggested in Jiang and Liu (2015), the determinants of construction output were therefore allocated~~grouped~~ into five groups, namely: price; income and production; demography and labour force; customer~~'~~s' expectations; and other factors. Based on the classification of construction output presented in~~(~~ Figure 2~~)~~, the determinants were~~content of t~~ also~~his subsection is~~ presented according to the ~~under~~ three classications of~~headings, namely:~~ 'pro~~"pro~~ject financier~~"~~', ~~"~~'market sector'~~"~~ and ~~"~~'industry/regional'.~~"~~ A summary table of the 48 modelling studies mapped against the classifications is presented in Table 6.

'Insert Table 5 here'

Project financier

Based on the ~~criteria of~~ 'project financier' classification, construction output can be disaggregated into 'public' and 'private' (Figure 3). Two of the studies that employed multivariate models were~~have been~~ developed for 'private' construction output (Ng et al., 2011; Sing et al., 2015). In terms of frequency, the state of the economy, which is a proxy of GDP/GNP/NI, ~~i~~was the most common determinant of private construction output (Table 5). In contrast, little is known about the determinants of 'public' construction output because no multivariate model(s) have been estimated for it. However, it must be noted that there were univariate models ~~were~~ estimated for public construction output ($Public_{t+1}$) forecasting in Lam and Oshodi (2016a). These univariate models used information contained in its current ($Public_t$) and past values ($Public_{t-1}$).

Market Sector

In terms of market sector, construction output can be disaggregated into the following components: residential, commercial, manufacturing~~industry~~, maintenance, structures and facilities and ‘others’ (Figure 3). From Tables 1 and 6, it can be seen that 30 studies reported the development of models for ‘residential’ construction output (e.g. Akintoye and Skitmore, 1994; Goh, 1996). In contrast, the modelling of ‘structure and facilities’ and ‘maintenance’ construction output received the least attention in published studies. In terms of frequency, interest rate (12 studies), construction price index (nine studies) and population (nine studies) were the most common determinants of residential construction output.

In relative terms, the number of multivariate models ~~were~~ developed for ‘commercial’ (nine studies) and ‘manufacturing’ construction output (ten studies) are similar. The most common determinants of ‘commercial’ construction output are "interest rate", "property value", "state of the economy" and "retail sales". In contrast, "state of the economy", "interest rate", "unemployment rate", "property value", "total production", "national savings" and "manufacturing output" are the prevalent determinants of manufacturing construction output. This finding suggests that the determinants of construction output in different segments of the market are unique.

Industry/regional

The data presented in Table 6 shows that 11 models were used for modelling of construction output at the ‘industry’ (overall) level, whilst i~~. I~~n contrast, only one study was carried out ~~on modelling of construction output~~ at ‘regional’ level (Jiang and Liu, 2014). "Interest rate", "unemployment rate" and "state of the economy" are the most cited determinants of overall construction output. Usually, large volumes of financial resources are expended during the process of procuring construction projects. Hence, clients and project sponsors may need to source loans from banks and other financial institution for the execution of their projects. As a result, changes in interest rates and the state of the economy (GDP) are positively related to construction output. This assertion i~~wa~~s validated in Fan et al. (2011) whose work reveales~~d~~ that GDP and interest rates play a role in determining the volume of construction output.

'Insert Table 6 here'

The relative performance of construction output forecast models

As explained by Shmueli and Koppius (2011), the processes for ~~of~~ validating explanatory and prediction models are distinct. For explanatory models, strength of fitness is the primary metric used to evaluate the developed model, whereas the accuracy of the out-of-sample forecast is the measure for validating predictive models. For instance, Jiang and Liu (2011) collected data covering the period from 1996Q3 to 2010Q2. The data series covering 1996Q3 to 2009Q2 was used for model estimation and subsequently, the developed model was used to generate the out-of-sample forecast for the last four data points from 2009Q3 to 2010Q2. In the out-of-sample period, the forecast values were compared with the actual values of construction output.

Error variance (i.e. the difference between the actual and forecasted value of construction investment) is used to quantify the uncertainty of an~~the~~ estimated model. In the field of construction economics, forecast errors are computed using percentage error (PE), mean squared error (MSE), mean percentage error (MPE), mean absolute percentage error (MAPE), Theil's inequality coefficient (*U*), root mean squared error (RMSE) and index sum (IS).

'Insert Table 7 here'

Summary of results

Seven interesting findings emanated from this research. First, a total of 48 studies were published between 1975 and 2019, although it should be ~~. It is imperative to~~ noted that no study was published on this topic in 2019 itself. Second, previous construction modelling studies have predominantly focused on countries located in the Northern hemisphere, for example ~~. Previous construction output modelling studies~~ (Table 1) ~~have focused on t~~the UK (Duffy, 1975; Tanratanawong and Scott, 2000), USA (Thomas and Stekler, 1979; Fullerton et al., 2001), Australia (Jiang and Liu, 2011), Singapore (Goh, 1996) and Hong Kong (Fan et al., 2011) among others. Third, from the data in Table 4, multivariate and statistical techniques were identified as~~are~~ the dominant tools used in construction modelling research.

Fourth, interest rate, state of the economy (GDP/GNP/NI), unemployment rate, population, construction price index, national savings and rent were found to be popular determinants of construction output (Table 5). The use of a subjective variable, such as the occurrence of global financial crisis, was~~has been~~ limited to two studies (Jiang and Liu, 2011;

Jiang et al., 2013). Fifth, little is known about the determinants of certain classes of construction output. This finding is due to the development of a limited number of models for those classes of construction output. For example, Tanratanawong and Scott (2000) is the only study to apply multivariate techniques to maintenance construction output (cf. Table 5~~3~~). Thus, little is known about the determinants of maintenance and public construction output. Sixth, it is apparent from Table 7 that statistical models provide reliable forecasts of construction output. However, a comparison shows that the artificial intelligence models outperform statistical models in terms of predictive performance.

Finally, a data driven approach, i.e. text mining, was used to verify the findings emanating from the review of the selected journal papers. The title, abstract and keywords of the selected papers were used to construct a corpus. Due to the absence of abstracts, two publications (i.e., Duffy, 1975; Nicholson and Tebbutt, 1975) were not added to the corpus. The corpus was analysed using the R programming software (R Core Team, 2015) to generate the most frequent terms found within it~~in the corpus~~. In terms of frequency of occurrence, the top 20 words are presented in Figure 4. The five most frequent words in the corpus are model, construction, forecast, construction output and housing. There are similarities between the findings obtained from the content analysis and data-driven text analysis. For example, the data presented in Table 4 shows that most construction output modelling studies focused on forecasting. This convergence indicates that the study is credible and robust.

'Insert Figure 4 here'

DISCUSSION OF FINDINGS

Models are used to unmask the underlying factors responsible for fluctuations in the volume of construction output. This study has undertaken a systematic review of the published studies on construction output modelling and a~~A~~ summary of the main findings has been~~were~~ presented. The following discussion highlights further several key results that were raised by the r~~ in the previous subsection. In this section, the r~~esults of this study.~~ raise several key issues which are discussed in subsequent paragraphs.~~

One interesting finding is that socio-economic variables [such as GDP, interest rate and unemployment rate, among others] are the predominant determinants of construction output.

This study supports the evidence presented in previous research (Turin, 1978; Anaman and Osei-Amponsah, 2007), which showed that construction output and economic growth are positively related. As stated earlier, finding the right balance between construction output and the capacity of the construction sector is quintessentially important for developing strategies to mitigate the impact caused by changes in volume. For example, a contracting firm could decide to seek overseas opportunities based on an envisaged drop in the volume of construction output.

It was found that few studies focused on construction output modelling. There are several possible explanations for this result. The unavailability of data could be one limiting factor.~~of the reasons limiting the interest in construction output modelling.~~ Studies have shown that the quantity and quality of construction statistics is inadequate in certain countries (K'Akumu, 2007). To address this, there is a need to identify alternative metrics for quantifying the volume of construction activities. For instance, Gruneberg and Folwell (2013) demonstrate that the construction component of gross fixed capital formation (GFCF) could be used as a substitute for construction output. Based on the information available from World Bank, data on GFCF is relatively available in most countries (World Bank, 2019). The adoption of GFCF would make it easier to develop models for construction output in several countries.

Terms associated with forecasting are popular in construction modelling publications (see Figure 3). This finding suggests that construction output modelling is at the third stage of knowledge creation. In most of the previous published studies, authors fail to explicitly state the theory which informed the choice of variables in model development~~used to develop models~~. Runeson and de Valence (2015) assert that the main weakness of most studies in the field of construction economics stems from the failure to utilise existing theories. However, it must be mentioned ~~here~~ that most of the variables included in construction modelling studies are informed by findings from previous research. Comparison between the findings of construction modelling studies is useful for validity and refuting of existing theories.

Statistical techniques are the most commonly used tool employed~~approach~~ for construction output modelling,~~—~~ quite possibly because of the imperative need to understand the relationship between~~ co~~ con~~n~~struction output and its determinants. However,~~Some~~ issues were observed in some previous construction output modelling studies which used statistical techniques. First, non-stationary variables were included in some ~~of the~~ statistical models. T~~; t~~his may be partly responsible for the high value of R-square reported in these~~some previous~~ studies, f~~. F~~or example~~,~~ the R-square value of one of the models estimated in Tang et al. (1990) is 0.96. The observed relationship could be attributed to spurious regressions (Brooks, 2014). Second, some statistical models provide little or no information about the relationship between construction output and its determinants. Despite being atheoretical, univariate models are proven to be useful for modelling and forecasting construction output (Goh and Teo, 2000; Fan et al., 2010). Hence, researchers need to find the right balance between theory and model fit when estimating construction output models. This claim stems from the fact that some atheoretical models are useful in practice.

Lastly, it was revealed that ~~the~~ non-linear techniques (such as ANN and SVM) tend to generate a more reliable forecast of construction output when compared with linear models. This result is consistent with those reported in earlier studies (Weron, 2014). Flexibility and lack of explanatory information are two main weaknesses of non-linear models. The effect of each determinant on construction output is unknown; this is the main reason for naming this class of techniques as 'black box' models. In practice, the management of fluctuation in the volume of construction output is not entirely dependent on the accuracy of forecast models. However, the theory, policy and practice implications of this research are potentially far reaching. From a theoretical perspective, the range of models reviewed illustrates academia's inimitable attempts to further refine, fine-tune and improve the accuracy of models produced. This partly acknowledges the fact that forecasting models are often limited to short term forecasts (typically three to five years) and subject to perturbations in macro-economic conditions. From a political perspective, models can be used as a simulation laboratory (so called economic levers) for evaluating the impact of competing policies on the predicted variable (Ogunlana et al., 2003). From a supply chain perspective, ~~For example,~~ government may, for example, relax immigration laws to attract foreign workers due to a projected increase in the volume of construction activities. Alternatively, government interventions to lower taxation or inflation rates can trigger business growth and home purchasing which in turn stimulates: the aggregates sector to produce more raw materials; the manufacturing sector to build more construction products; and ~~Also,~~ construction equipment manufacturers to build more machinery to cater for booming demand. Of course the converse is true, but the construction and civil engineering sector is inextricably linked to national wealth which underscores the importance of accurate prediction models. In practice, an accurate forecast is essential to industry who must fine-tune investments in key resources so as to expand operations when markets are buoyant (and capitalise on market growth), and contract operations when in a recession, to preserve the business in readiness to capitalise upon future expansion. ~~could use information provided by construction output forecasts to develop strategies for product sales.~~ These practical implications of forecasting market elasticity indicate~~s~~ that the reliability of construction output forecasting is vital for various stakeholders and ~~a~~the national economy.

Paths for future research

T~~In the previous section, t~~he published studies on construction output modelling were hitherto consolidated. This compression of information provides details on the trends and gaps in ~~the~~ current knowledge within this area. Based on the gaps identified, the directions for future construction output modelling studies are speculated. The four main topics which emerged, ~~in the preceding sections,~~ either explicitly or implicitly, are ~~:~~as follows:

1) Selection of ‘best’ input variables (determinants) for the estimation of construction output models has become increasing important (cf. Jud and Winkler, 2003). Although the current study indicates that a large set of macroeconomic variables (e.g. interest rates and population) affects the volume of construction output, there is a need to identify the best ‘set’ of determinants. This information would ease the process of calibrating construction output models and ~~this~~ is vital for identifying the optimal set of variables.
2) The determinants of construction output were found to vary from sector to sector (see Table 3). Ofori (1990) asserts that the determinants of construction output in the different segments of the construction market are unique, whilst Bon (1992) contends that the dynamic nature of the construction sector is also influential. This suggests that the determinants of construction output vary at different stages of development, and across countries, which demonstrates the need to understand the underlying causes of fluctuations in construction output volume in various segments of the construction ma~~a~~rket. Although multivariate models have been estimated for construction output in the different segments of the construction market, little is known about the changes in certain market sectors (Table 3). For example, there have been limited studies on modelling of public, private and maintenance construction output. These areas should be explored in future studies.

3) Hitherto~~enceforth~~, the inclusion of dummy variables in models used for forecasting construction output has been limited to four previous research studies (viz: Thomas and Stekler, 1979; Thomas and Stekler, 1983; Jiang et al., 2013; Jiang and Liu, 2011). The addition of a dummy variable, representing the global financial crisis, improved the reliability of construction output forecasts in ~~a~~ previous research (Jiang and Liu, 2011). Alaka et al. (2016) suggest that the inclusion of subjective data into models would result in reliable predictions and in this case, would improve the understanding of the effects of these factors on construction output. For instance, the government of Hong Kong introduced the mandatory building inspection scheme (MBIS) and mandatory window inspection scheme (MWIS) in 2012 (Tan et al., 2012). The policy is targeted at stimulating growth in the volume of maintenance works. The effect of this policy (including other similar interventions) on the volume of maintenance construction output needs to be investigated. However, the inclusion of these non-traditional determinants of construction output into models must be adequately justified.
4) The application of contemporary techniques to construction output modelling research needs to be explored. For example, interrupted time series models could~~an~~ be used to evaluate the impact of policies (e.g. MWIS and MBIS (ibid)) on changes in the volume of construction output. Research in the field of artificial intelligence has shown ~~that~~ the potential of using text mining for prediction (Nassirtoussi et al., 2014). However, the use of these techniques has not been explored in construction output modelling research. In future investigations, it might be possible to use text mining to predict public construction output.
5) Evaluation of the quality of the construction output model is important. The purpose of the study is the main criteria for deciding on the approach used to evaluate the developed model. Shmueli and Koppius (2011) proffer that the coefficient of determination and errors (variances between actual and forecast values) are the metrics for evaluating explanatory and forecast models, respectively. MAPE and *U* coefficient are popular metrics used for evaluating construction output forecast~~s~~ing models (Fan et al., 2011; Jiang and Liu, 2014). However, the limitations of these measures have resulted in the development of new metrics for evaluating forecast accuracies (Hyndman and Koehler,

2006), such as the mean absolute scaled error. The use of these new metrics could improve the process of validating construction output models.

CONCLUSION

Modelling offers a useful approach for unveiling the determinants that account for the changes in the volume of construction output. The main goals of this current study were~~as~~ to systematically review the literature on construction output modelling and~~but~~ ~~also~~ raise the importance of accurate modelling, ~~s~~not only for industry practitioners but also the wider national economy. The study has found that macro-economic variables are significant predictors of the volume of construction output but finer nuances between the way that data is reported in various countries means that a singular 'one-shoe-fits-all' global model is unlikely to be achieved. Residential construction output modelling has been the main focus of numerous previous research studies, while significantly less attention has been paid to modelling of maintenance and public construction output. Also, the inadequacies of certain techniques used for construction output modelling were highlighted. In this regard, construction output modellers can benefit from the advances that are being made in the field of statistics and computer science.

The findings of this study have theoretical and practical implications. In several countries across the globe, governments are implementing strategies to stimulate construction activities. The impact of these interventions (such as MBIS in Hong Kong and Help to B~~b~~uy scheme in the UK) are currently unknown. This~~e outcome of this~~ study provides a comprehensive list of determinants that can be used in~~for~~ future~~the~~ construction output model ~~-~~development ~~of construction output models~~ for evaluating the impact of these intervention programs, and also~~.~~ ~~The outcome of this study~~ provides insight into the trends and gaps in the current knowledge on construction output modelling. This information could serve as justification for future studies within this area. Reduced volatility in the volume of construction output is important due to its causal relationship with employment, equipment sales and economic development (Chiang et al., 2015; Holt and Edwards, 2012). An understanding of the determinants of construction output could help stakeholders anticipate changes in its volume and develop appropriate strategies for responding to such events.

Several limitations to the current study must be acknowledged. First, the study's sample was limited to papers published in academic journals. Second, the search was limited to academic papers published in English. Thus, relevant papers published in other languages (such as Chinese and Spanish) were excluded from the study. Notwithstanding these limitations, the objectives of the present study were achieved. Five research gaps were identified, namely: (i) the need for an objective approach for identifying the 'best' variables for modelling of construction output; (ii) a lack of studies that focused on maintenance and public construction output modelling; (iii) lack of consideration for inclusion of subjective factors in construction output models; (iv) the need for a greater use of contemporary techniques in construction output modelling; and (v) the need to use robust metrics for evaluating the predictive accuracy of construction output models. Further studies must be conducted to address these identified gaps.

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Figure 1 Research f~~F~~ramework

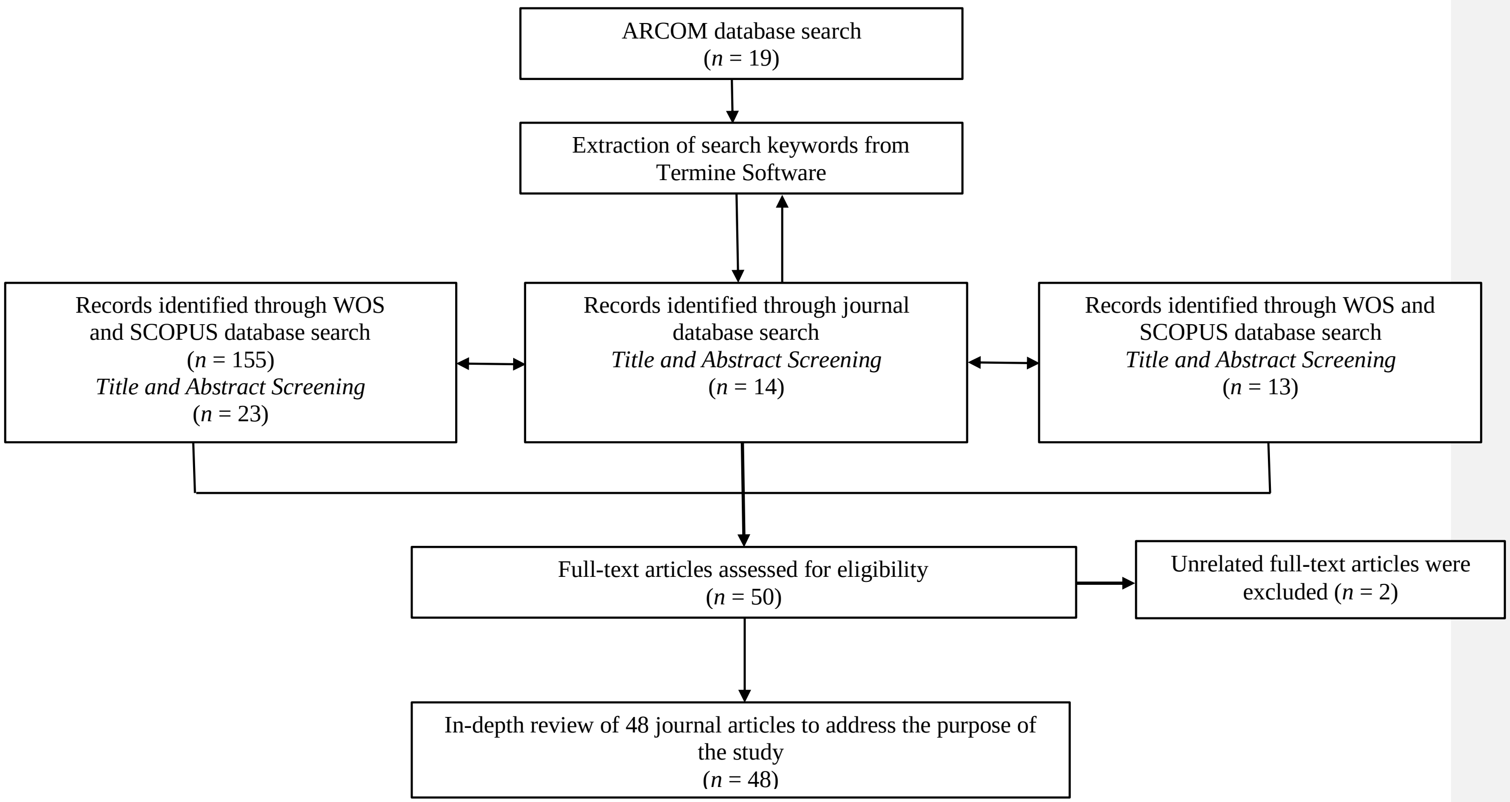

Figure 2: Number of relevant articles published per year

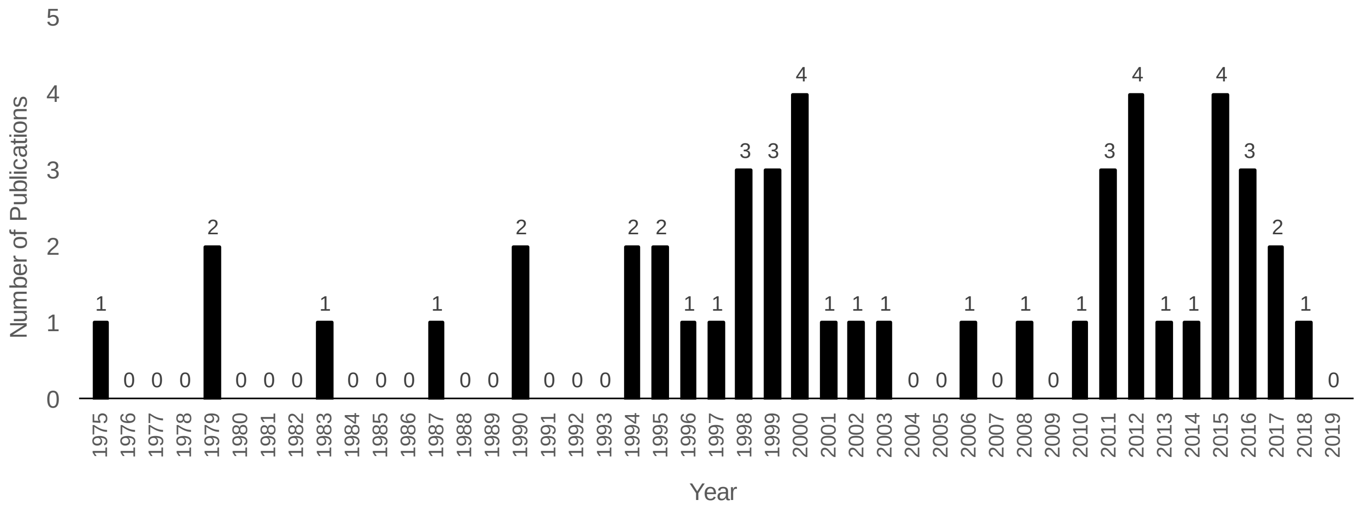

Figure 3 - An overview of c~~C~~onstruction o~~O~~u~~u~~tput c~~C~~lassification

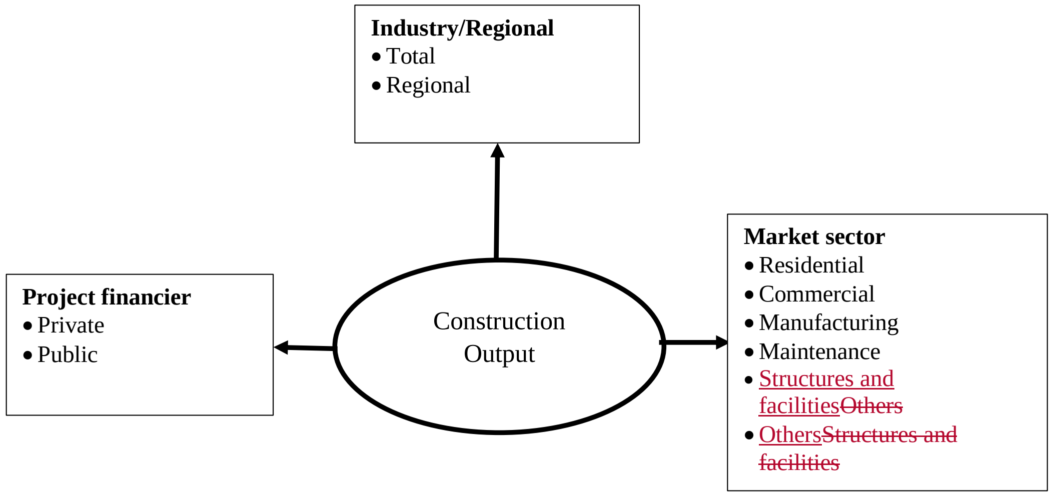

Figure 4 - Term analysis of construction output modelling publications

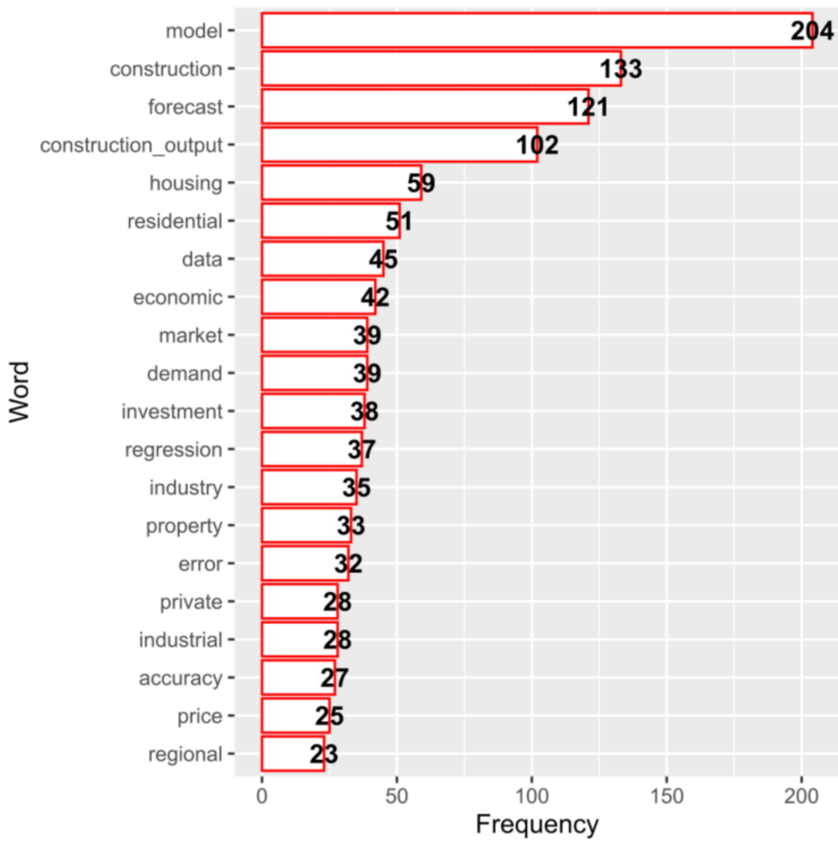

Table 1 - An overview of c~~C~~onstruction o~~O~~utput m~~M~~odelling s~~S~~tudies

No.	Author(s)	Country	Output variable(s)	Publication outlet
1	Duffy (1975)	U~~nited~~ K~~ingdom (UK)~~	Residential	*Applied Economics*
2	Nicholson and Tebbutt (1979)	UK	Manufacturing	*Journal of Industrial Economics*
3	Thomas and Stekler (1979)	U~~nited States (U~~SA~~)~~	Residential	*Economics Letters*
4	Thomas and Stekler (1983)	USA	Residential	*Regional Science and Urban Economics*
5	Sklarz et al. (1987)	USA	Residential	*Real Estate Economics*
6	Tang et al. (1990)	Thailand	Residential, manufacturing and others	*Construction Management and Economics*
7	Chang and Linneman (1990)	Japan, Korea, Taiwan and USA	Residential	*Growth and Change*
8	Akintoye and Skitmore (1994)	UK	Residential, commercial and manufacturing	*Construction Management and Economics*
9	Giussani and Tsolacos (1994)	UK	Manufacturing	*Journal of Property Research*
10	Benjamin et al. (1995)	USA	Commercial	~~*The*~~ *Journal of Real Estate Finance and Economics*
11	Tsolacos (1995)	UK	Manufacturing	*Journal of Property Research*
12	Goh (1996)	Singapore	Residential	*Construction Management and Economics*
13	Ball and Grilli (1997)	UK	Commercial	*Journal of Property Research*
14	Goh (1998)	Singapore	Residential	*Engineering, Construction and Architectural Management*
15	Notman et al. (1998)	UK	Overall	*Construction Management and Economics*
16	Tsolacos (1998)	UK	Commercial	*Journal of Property Research*
17	Fergus (1999)	USA	Residential	~~*The*~~ *Journal of Real Estate Finance and Economics*
18	Goh (1999)	Singapore	Residential, commercial and manufacturing	*Construction Management and Economics*
19	Somerville (1999)	USA	Residential	~~*The*~~ *Journal of Real Estate Finance and Economics*
20	Goh (2000)	Singapore	Residential	*Construction Management and Economics*
21	Goh and Teo (2000)	Singapore	Residential	*Construction Management and Economics*
22	Tanratanawong and Scott (2000)	UK	Residential, maintenance and others	*Journal of Financial Management of Property and Construction*
23	Thompson and Tsolacos (2000)	UK	Industrial	*Journal of Real Estate Research*
24	Fullerton et al. (2001)	USA	Residential	*International Journal of Forecasting*
25	Ball and Tsolacos (2002)	UK	Commercial and manufacturing	*Journal of Property Research*
26	Jud and Winkler (2003)	USA	Residential	~~*The*~~ *Journal of Real Estate Finance and Economics*
27	Berg and Berger (2006)	Sweden	Residential	~~*The*~~ *Journal of Real Estate Finance and*

				Economics
28	Ng et al. (2008b)	Hong Kong	Residential	*Building and Environment*
29	Fan et al. (2010)	Hong Kong	Residential, commercial, manufacturing and overall	*Construction Management and Economics*
30	Fan et al. (2011)	Hong Kong	Overall	*Habitat International*
31	Jiang and Liu (2011)	Australia	Overall	*Construction Management and Economics*
32	Ng et al. (2011)	Hong Kong	Private	*Construction Management and Economics*
33	Goh (2012)	Singapore	Residential, commercial and manufacturing	*International Journal of Construction Education and Research*
34	Karamujic (2012)	Australia	Residential	*Construction Economics and Building*
35	Kagochi and Kiambigi (2012)	Kenya	Residential	*African Development Review*
36	Zheng et al. (2012)	Hong Kong	Residential and commercial	*Construction Management and Economics*
37	Jiang et al. (2013)	Australia	Residential, Non-residential and overall	*Construction Economics and Building*
38	Jiang and Liu (2014)	Australia	Regional	*Construction Management and Economics*
39	Chiang et al. (2015)	Hong Kong	Building, structures and facilities, and overall	*Habitat International*
40	Jiang and Liu (2015)	Australia	Overall	*International Journal of Strategic Property Management*
41	Sing et al. (2015)	Hong Kong	Private	*Journal of Construction Engineering and Management*
42	Tan et al. (2015)	Hong Kong	Residential, structures and facilities, maintenance, and overall	*International Journal of Construction Management*
43	Alagidede (2016)	Global	Overall	*Applied Economics Letters*
44	Lam and Oshodi (2016a)	Hong Kong	Others, private, public and overall	*Engineering, Construction and Architectural Management*
45	Lam and Oshodi (2016b)	Hong Kong	Residential, maintenance and overall	*Journal of Management in Engineering*
46	Elíasson (2017)	Iceland	Residential	*Housing Studies*
47	Ma at al. (2017)	Australia	Residential	*International Journal of Strategic Property Management*
48	Ma at al. (2018)	Australia	Residential	*Engineering, Construction and Architectural Management*

Table 2 - Number of relevant manuscripts published in each journal

Journal	**Number**	**Percentage**
Construction Management and Economics	12	25.00
~~The~~ Journal of Real Estate Finance and Economics	5	10.42
Journal of Property Research	5	10.42
Engineering, Construction and Architectural Management	3	6.25
International Journal of Strategic Property Management	2	4.17
Habitat International	2	4.17
Construction Economics and Building	2	4.17
Regional Science and Urban Economics	1	2.08
Real Estate Economics	1	2.08
Journal of Real Estate Research	1	2.08
Journal of Management in Engineering	1	2.08
Journal of Industrial Economics	1	2.08
Journal of Financial Management of Property and Construction	1	2.08
Journal of Construction Engineering and Management	1	2.08
International Journal of Forecasting	1	2.08
International Journal of Construction Management	1	2.08
International Journal of Construction Education and Research	1	2.08
Housing Studies	1	2.08
Growth and Change	1	2.08
Economics Letters	1	2.08
Building and Environment	1	2.08
Applied Economics Letters	1	2.08
Applied Economics	1	2.08
African Development Review	1	2.08

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Table 3 - Summary of m~~M~~odelling t~~T~~echniques u~~U~~sed in p~~P~~revious r~~R~~esearch

No.	Study	Modelling technique	Focus	Classification of technique		
				Variables	Time	Discipline
1	Duffy (1975)	Regression	Forecasting	Multivariate	Non-time series	Statistical
2	Nicholson and Tebbutt (1979)	Regression	Forecasting	Multivariate	Non-time series	Statistical
3	Thomas and Stekler (1979)	LSDV	Explanation	Multivariate	Non-time series	Statistical
4	Thomas and Stekler (1983)	LSDV	Forecasting	Multivariate	Non-time series	Statistical
5	Sklarz et al. (1987)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Autoregressive		Univariate	Non-time series	Statistical
6	Tang et al. (1990)	Regression	Forecasting	Multivariate	Non-time series	Statistical
7	Chang and Linneman (1990)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Trend		Univariate	Non-time series	Statistical
8	Akintoye and Skitmore (1994)	Regression	Forecasting	Multivariate	Non-time series	Statistical
9	Giussani and Tsolacos (1994)	Almon lag polynomial	Explanation	Multivariate	Time series	Statistical
10	Benjamin et al. (1995)	Regression	Explanation	Multivariate	Non-time series	Statistical
11	Tsolacos (1995)	Regression	Forecasting	Multivariate	Time series	Statistical
12	Goh (1996)	Regression	Forecasting	Multivariate	Non-time series	Statistical
		NN		Multivariate	Non-time series	Artificial intelligence
13	Ball and Grilli (1997)	VAR	Explanation	Multivariate	Time series	Statistical
14	Goh (1998)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Regression		Multivariate	Non-time series	Statistical
		NN		Multivariate	Non-time series	Artificial intelligence
15	Notman et al. (1998)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
16	Tsolacos (1998)	Regression	Forecasting	Multivariate	Time series	Statistical
17	Fergus (1999)	Regression	Explanation	Multivariate	Non-time series	Statistical
18	Goh (1999)	Regression	Forecasting	Multivariate	Non-time series	Statistical
		Log-Regression		Multivariate	Non-time series	Statistical
		ANLR		Multivariate	Non-time series	Statistical
19	Somerville (1999)	Regression	Explanation	Multivariate	Non-time series	Statistical
20	Goh (2000)	NN	Forecasting	Multivariate	Non-time series	Artificial intelligence
		GA-NN		Multivariate	Non-time series	Artificial intelligence
21	Goh and Teo (2000)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
22	Tanratanawong and Scott (2000)	NN	Forecasting	Multivariate	Non-time series	Artificial intelligence
23	Thompson and Tsolacos (2000)	Regression	Explanation	Multivariate	Non-time series	Statistical
24	Fullerton et al. (2001)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Random walk		Univariate	Non-time series	Statistical
25	Ball and Tsolacos (2002)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Regression		Multivariate	Time series	Statistical
26	Jud and Winkler (2003)	Regression	Explanation	Multivariate	Time series	Statistical
27	Berg and Berger (2006)	ECM	Explanation	Multivariate	Time series	Statistical

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28	Ng et al. (2008b)	Regression	Forecasting	Multivariate	Non-time series	Statistical
		GA-Regression		Multivariate	Non-time series	Artificial intelligence
29	Fan et al. (2010)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		Regression		Multivariate	Time series	Statistical
30	Fan et al. (2011)	Regression	Forecasting	Multivariate	Time series	Statistical
		VEC		Multivariate	Time series	Statistical
31	Jiang and Liu (2011)	VEC	Forecasting	Multivariate	Time series	Statistical
		VEC-D		Multivariate	Time series	Statistical
32	Ng et al. (2011)	Regression	Forecasting	Multivariate	Time series	Statistical
		VEC		Multivariate	Time series	Statistical
33	Goh (2012)	Log-Regression	Forecasting	Multivariate	Non-time series	Statistical
34	Karamujic (2012)	Structural	Forecasting	Univariate	Time series	Statistical
35	Kagochi and Kiambigi (2012)	ARDL	Explanation	Multivariate	Time series	Statistical
36	Zheng et al. (2012)	ARDL	Forecasting	Multivariate	Time series	Statistical
		ECM		Multivariate	Time series	Statistical
37	Jiang and Liu (2013)	VEC	Explanation	Multivariate	Time series	Statistical
38	Jiang and Liu (2014)	Regression	Forecasting	Multivariate	Time series	Statistical
		P-OLS		Multivariate	Time series	Statistical
		P-VEC		Multivariate	Time series	Statistical
39	Chiang et al. (2015)	Regression	Explanation	Multivariate	Time series	Statistical
40	Jiang and Liu (2015)	VEC	Explanation	Multivariate	Time series	Statistical
41	Sing et al. (2015)	VAR	Forecasting	Multivariate	Time series	Statistical
42	Tan et al. (2015)	Grey box	Forecasting	Univariate	Non-time series	Statistical
43	Alagidede (2016)	Structural	Forecasting	Univariate	Time series	Statistical
44	Lam and Oshodi (2016a)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		NN		Univariate	Non-time series	Artificial intelligence
45	Lam and Oshodi (2016b)	Box-Jenkins	Forecasting	Univariate	Time series	Statistical
		NN		Univariate	Non-time series	Artificial intelligence
		SVM		Univariate	Non-time series	Artificial intelligence
46	Elíasson (2017)	Regression	Forecasting	Multivariate	Non-time series	Statistical
47	Ma et al. (2017)	P-VEC	Forecasting	Multivariate	Time series	Statistical
48	Ma et al. (2018)	P-VEC	Forecasting	Multivariate	Time series	Statistical

Note: ANLR = autoregressive nonlinear regression; ARDL = autoregressive distributed lag; ECM = error correction model; GA = genetic algorithm; LSDV = least squares dummy variables; NN = neural network; P-OLS = panel ordinary least square; P-VEC = panel vector error correction; SVM = support vector machine; VAR = vector autoregression; VEC = vector error correction; and VEC-D = vector error correction with dummy.

Table 4 - Descriptive statistics: Classification of modelling techniques

Criteria	Classification	Number
Focus	Explanation	13
	Forecasting	35
Variables	Univariate	19
	Multivariate	50
Time	Non-time series	31
	Time series	38
Discipline	Statistical	60
	Artificial intelligence	9

Table 5 - Determinants of c~~C~~onstruction o~~O~~utput

S/N	Determinant(s)	Residential	Commercial	Manufacturing	Maintenance	S&F*	Others	Private	Overall
	Price								
1	Real price index/relative price index	[6, 22]			[22]				
2	Construction price index/building tender price index	[8, 14, 18, 19, 20, 33, 37, 47, 48]	[13]	[23]			[37]		[31, 37, 38, 40]
3	Property price index	[12, 26, 27, 28, 47]						[41]	
4	Consumer price index	[12, 28]							
5	Commercial land price		[18, 33]						
6	Rents/property value/property price	[26, 27, 36, 48]	[13, 16, 36]	[9, 11, 23]					[40]
7	Industrial share prices index			[11]					
8	Export/import price index			[18, 33]					[40]
	Income and production								
9	State of the economy (GDP/GNP/NI)	[6, 8, 12]	[8, 13, 25]	[8, 11, 18, 25, 33]		[39]	[37, 39]	[32, 41]	[30, 38, 39, 40]
10	Disposable income/national income	[3, 4, 22, 37]			[22]		[22]		[37, 40]
11	Weekly earnings								[40]
12	Total production/industrial production index			[6, 9, 33]	[22]				[40]
13	Productivity		[18, 33]	[18, 33]					
14	Manufacturing profitability		[8]	[8, 11]					
15	National savings/ corporate savings	[14, 18, 20, 33]	[18, 33]	[6, 18, 33]					[31]
16	GDP per capita/ GDP (A) at factor cost	[7, 12, 22]			[22]				
17	Gross fixed capital formation	[12, 14, 18, 20, 22, 33]					[22]		
18	Manufacturing output			[2, 11, 18]	[22]		[22]		
19	Government revenue						[6]		
20	Capital expenditure intention			[33]					
21	Trade balance			[33]					
22	Value of export/ imports	[37]		[18, 33]			[22, 37]		[31, 37, 40]
	Demography and labour force								
23	Population	[3, 4, 6, 7, 14, 18, 20, 33, 37]		[18, 33]			[37]		[31, 37, 38]
24	Labour cost	[12]		[18, 33]					[40]
25	Rate of new immigration	[3, 4]							
	Consumer's expectations								
26	Interest rate	[3, 4, 6, 7, 8, 12, 14,	[8, 10, 25]	[11, 18, 25, 33]			[27]	[41]	[30, 31, 37,

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		18, 20, 28, 33, 37]						38, 40]
27	Unemployment rate	[12, 14, 18, 20, 28, 33, 37]	[8]	[11, 18, 33]		[37]	[32]	[31, 37, 38, 40]
28	Consumer expenditure	[22]	[16]			[22]		
29	Final consumption expenditure	[22]			[22]			
30	Retail sales		[10, 18, 33]					
31	Inflation rate	[7]						
32	Household expenditure	[37]				[37]		[31, 37, 40]
33	Exchange rate			[18, 33]				
34	Leading indicators/bank loans			[18]				[40]
	Other factors							
35	Vacancy rate/ Vacancy rate (industrial)			[9, 11]			[41]	
36	Capital value indices		[25]	[25]				
37	Number of planning approvals		[18, 33]					
38	Depreciation			[11]				
39	Government expenditure	[28]						[40]
40	Total investment/investment intensity	[28, 46]		[18, 33]			[32]	
41	Money supply	[12]		[33]				
42	Money supply (savings and others)	[12]						
43	Volume of pension fund withdrawals	[12]						
44	Additions in housing stock/ housing stock	[3, 4, 14, 18, 20, 33, 46]						
45	Private housing starts/ Private sector: Housing completion	[1, 22]			[22]	[22]		
46	Output index: construction					[22]		
47	Government final consumption	[22]						
48	Gross value added at basic prices	[22]						
49	Household final consumption	[22]						
50	Tax rate		[10]					
51	Precipitation	[17]						
52	Temperature	[17]						
53	Remittance	[35]						

Note: S&F = Structures and facilities; Overall = Overall and regional; [ ] = the numbers in the brackets refers to the numbers associated with each study (see Table 1)

Table 6 – Summary of classification of construction output modelling studies

No.	Classification									
	Residential	**Commercial**	**Manufacturing**	**Maintenance**	**Others**	**S&F**	**Private**	**Public**	**Regional**	**Overall**
1	x									
2			x							
3	x									
4	x									
5	x									
6	x		x		x					
7	x									
8	x	x	x							
9			x							
10		x								
11			x							
12	x									
13		x								
14	x									
15										x
16		x								
17	x									
18	x	x	x							
19	x									
20	x									
21	x									
22	x			x~~X~~	x					
23			x							
24	x									
25		x	x							
26	x									
27	x									
28	x									
29	x	x	x							x
30										x
31										x
32							x			
33	x	x	x							
34	x									
35	x									
36	x	x								
37	x				x					x
38									x	
39					x	x				x

40										x
41							x			
42	x			x~~X~~		x				x
43										x
44					x		x	x		x
45	x			x~~X~~						x
46	x									
47	x									
48	x									
Total	**30**	**9**	**10**	**3**	**5**	**2**	**3**	**1**	**1**	**11**

Note: the numbers in the first column refers to those studies presented in Table 1

Table 7 - Comparison of f~~F~~orecast a~~A~~ccuracy

Study	**Forecasting techniques**	**Error metric(s)**	**Most accurate technique**
Sklarz et al. (1987)	Box-Jenkins Auto-regressive	MSE MAPE	Auto-regressive
Chang and Linneman (1990)	Box-Jenkins Trend	MAPE	Box-Jenkins
Goh (1996)	Regression NN	PE MPE MAPE	NN
Goh (1998)	Box-Jenkins Regression NN	PE MPE MAPE	NN
Goh (1999)	Regression Log-Regression ANLR	PE MPE MAPE	Log-Regression
Goh (2000)	NN GA-NN	PE MPE MAPE	GA-NN
Fullerton et al. (2001)	Box-Jenkins Random walk Structural	Modified *U* coefficient	Structural
Ball and Tsolacos (2002)	Box-Jenkins Regression	MAPE RMSE	Box-Jenkins
Ng et al. (2008b)	Regression GA-Regression	IS	GA-Regression
Fan et al. (2010)	Box-Jenkins Regression	MAPE	Box-Jenkins
Fan et al. (2011)	Regression VEC	MAPE *U*	VEC
Jiang and Liu (2011)	VEC VEC-D	MAPE *U*	VEC-D
Ng et al. (2011)	Regression VEC	MAPE *U*	VEC
Jiang and Liu (2014)	Regression P-OLS P-VEC	MAPE *U*	P-VEC
Lam and Oshodi (2016a)	Box-Jenkins NN	MAPE *U*	NN
Lam and Oshodi (2016b)	Box-Jenkins NN SVM	MAPE *U*	SVM

Note: ANLR = autoregressive nonlinear regression; GA = genetic algorithm; NN = neural network; VEC = vector error correction; VEC-D = vector error correction with dummy; P-OLS = panel ordinary least square; P-VEC = panel vector error correction; SVM = support vector machine; MSE = mean squared error; MPE = mean percentage error; MAPE = mean absolute percentage error; U = Theil's inequality coefficient; IS = index sum