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Labour Productivity Model for Structural Elements By Varying Buildability Factors using Multiple Regression Analysis

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ABSTRACT

Construction productivity is one of the most frequently researched topics due to its importance to the viability of the industry. Buildability is defined as the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building. In this project, the major buildability factors hypothesised to influence the labour productivity of the main trades, i.e. formwork, reinforcing steel fixing and concreting, included grid patterns of footings and columns, type of structural framing system, geometry and dimensions of elements, height of floors, the degree of design rationalisation, standardisation and repetition of elements, reinforcing steel quantity and diameters, location and congestion of reinforcement, volume and workability of concrete as well as surface finish. In addition, and due to its importance to the productivity of the construction industry, the effect of the learning curve theory has been also examined in this study. This research project has quantified the relationship between the principal design characteristics of in situ reinforced concrete construction and labour productivity of the various trades involved. It can provide practical guidance to architects and structural designers who seek to optimize their designs. In addition, it can give a feedback on how well the designed building considers the requirements of the basic buildability principles and provides for tangible consequences of their design decisions on the construction labour productivity.

Keywords: *SPSS Software, Microsoft Excel, Multiple Regression Model.*

1. INTRODUCTION

Construction is the world's largest and most challenging industry. On average, it contributes one-half of the gross capital and 3% to 8% of the Gross Domestic Product (GOP) in most countries. Consequently, improvement in the productivity of this industry would translate into national economic prosperity, lower production cost, higher demands for building construction, thus, higher wages and ultimately, higher standards of living. The productivity is defined as a ratio of output to input, construction productivity can be regarded as a measure of outputs which are obtained by a combination of inputs. The labour constitutes a large part of the construction cost, and labour hours are more susceptible to the influence of other factors such as buildability, management, construction method, and weather, than materials or equipment, this research focuses on the single factor productivity, namely, the labour productivity. Several factors affect labour productivity but, buildability is amongst the most important. Buildability, as defined by the Construction Industry Research and Information Association (CIRIA), is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building. Major buildability factors influencing the labour productivity of the main trades in in-situ reinforced concrete buildings, i.e. formwork, reinforcing steel fixing, concreting and finishing, include grid patterns of footings and columns , type of structural framing system , geometry and dimensions of elements, height of floors , the degree of design rationalisation, standardisation and repetition of elements, reinforcing steel quantity and diameters, location and congestion of reinforcement, volume of concrete cast, surface finish and the specified concrete workability. Investigating and quantifying the effects and relative influence of partial buildability factors, i.e. structural, on the labour productivity of buildings, are the focal points of this research.

1.1 Objectives of the Study

- To identify the major buildability factors influencing labour productivity of the main trades involved in in-situ reinforced concrete buildings, namely, formwork, reinforcing steel fixing and concreting
- To quantify the impacts and relative influence of such partial buildability factors on the labour productivity of in situ reinforced concrete trades.
- To predict the overall labour productivity of buildings.
- To compare the actual productivity of the building with the predicted productivity and find the percentage of error in the prediction
- To investigate the applicability of learning curve theory to recurring activities of formwork, reinforcing steel fixing and concreting.
- To provide practical guidance on specific buildability knowledge and feedback on how well the designed building considers the requirements of the basic buildability principles to in situ reinforced concrete designers.

2. LITERATURE REVIEW

Abdulaziz M. Jarkas (2015) explained about the practical quantification approach that notwithstanding technological advancements, construction continues to be a labour intensive industry, and labour productivity remains the industry’s predominant determinant of performance. Numerous factors influence labour productivity, but buildability is among the most significant. Nevertheless, one of the barriers, and perhaps the most important to the implementation of the buildability concept, is the difficulty in measuring its tangible benefits to the construction industry; hence, the dearth of quantitative related research reported in the literature. Using a practical approach, this study has determined the relationship between relevant buildability factors and formwork labour productivity of building floors.

Long D and Hung T (2012) explained about the relationship between Floor Number and Labor Productivity in Multistory Structural Work, Construction activities are repetitive from floor to floor in multistory building construction. Labor productivity may neither reach 100 percent of the normal level at the very first floors nor the very top floors. Nevertheless, labor productivity may follow a certain pattern as construction activities progress. The case study methodology and learning curve theory are adopted for this research. Records from the structural works of an apartment building were analyzed to calculate floor number-based labor productivities for the two investigated activities. The unit rate of the formwork activity reduced more than 50 percent in the first five floors. If the first cycle (floor 2) is omitted, the straight-line learning curve model shows a learning rate of 83.5%. The productivity of the formwork activity tended to level off in the remaining thirteen floors. The unit rate of the rebar activity was prone to reduce in the first fifteen floors. If the first two cycles are omitted, the straight-line learning curve model indicates a learning rate of 83.6%. If only the first cycle is omitted, the learning rate of the rebar activity is 87.9%. The productivity of the rebar activity tended to decrease in the last three top floors though data points were not adequate to confirm such pattern.

Abdulaziz M. Jarkas (2012) explained about the factors affecting construction labour productivity in Kuwait about the buildability factors. There are many challenges facing the construction industry in the state of Kuwait but one of the most important is low productivity. The objective of this research, therefore, is to identify and rank the relative importance of factors perceived to affect labour productivity on construction sites in Kuwait. Min Liu, Glenn Ballard and William (2011) explained the work flow variation and labour productivity. Different types of flow variation and how they affect construction project performance have been studied by previous researchers. One aspect that has not been well researched is how work flow variation and labour productivity are related to construction practice. To study that issue, 134 weeks of project production data were collected and analyzed to explore this relationship. Labor productivity was found to be positively correlated with Percent Plan Complete (PPC), a measure of work flow variation.

3. METHODOLOGY

It deals with the objective of a research study, the method of defining the research problem, the type of hypothesis formulated, the type of data collected, the method used for data collecting and analyzing the data etc. The methodology includes a collection of primary and secondary data. Multiple regression analysis is used for this study. Multiple regression analysis using SPSS software will finalize the coefficients of the varying buildability factors in the model.

A research design is a plan that specifies the source and type of information relevant to the research problem primary data is collected through the AutoCAD plans which include all the structural details of the high rise building and the labour productivity data are collected from the quantity and man power details of each project. The secondary data is interpreted from the primary data by equations and analysis is further done with the help of SPSS software. Data required for the project work were collected from different construction sites.

4. PRODUCTIVITY

Productivity is the quotient obtained by dividing output by one of the factors of production. In this way, it is possible to speak of the productivity of capital, investment or raw materials according to whether the output is being considered in relation to capital, investment or raw materials, etc.

5. STATISTICAL METHODS

One of the main objectives of this research is to investigate and quantify the influence of buildability factors on the labour productivity of in situ reinforced concrete trades. First, is to predict the value of a dependent variable if the value of the independent variable is known and second, to measure relationships between a dependent variable and one or more independent variables. In

this research, the dependent variable is the observed labour productivity, and the independent variables are the buildability factors hypothesised to influence the labour productivity.
When there is only one independent variable, the model is determined by simple linear regression. If on the other hand there are two or more independent variables, the model is termed multiple linear regressions. The general form of the regression model is as shown below,

$$Y = \beta o + \beta 1\ X1 + \beta 2\ X2 + \beta 3\ X3 + ... + \beta K\ XK + \varepsilon.$$

Where Y = the dependent variable; βo = intercept; βi are the regression coefficients, where i = 1 ,2, ... , k; and ε = error or residual term.
The prediction equation of the model is expressed as follows:

$$\hat{Y} = bo + b1X1 + b2X2 + b3X3 +..... + bKXK$$

Where $\hat{Y}$ = the predicted value of Y, also referred to as Y hat; bo = the value of $\hat{Y}$ when all the Xi values are zero; and bi = the regression coefficient or the measure of the average rate of change in $\hat{Y}$ per unit change in Xi, holding all other variables in the model constant.

5.1 Formwork Labour Productivity

Based on labour productivity data collected from numerous construction sites, quantified the effects of buildability factors on formwork labour productivity of building floors by developing a multiple categorical regression model, which involved the following buildability determinants: (1) Variability of beam sizes (2) Floor repetition (3) Usable floor area (4) Average slab panel area in the floor (5) Number of joints formed in beams due to beam intersections (6) beam-floor ratio (7) Percentage of curved beams in the floor (8) Percentage of nonrectangular slab.

a. Formwork labour productivity
= Usable floor area (m^2) / lh

b. Formwork Regression Model For Slab

$$P(m^2/lh) = bo + b1VOB+ b2UFA + b3SPFI + b4BFI + b5NBI + b6FCRC + b7FPGeom$$

Where , VOB = Variability of beam sizes ,UFA = Usable floor Area,SPFI = slab panel-floor index, BFI = beam floor index,NBI = Number of beam intersections,FCRC = Floor configuration repetition criteria , FPGeom = floor perimeter geometry.

c. Formwork Regression Model for Coloumns

P(m2/1h) = b0+b1VOC+b2SA+b3CGeom Where, SA = Shutter area of the coloumns, CGeom = coloumn geometry, VOC = variability of coloumn sizes
Formwork model for Beams

P(m2/1h) = b0+b1VOB+b2TSA+ b3TNJ Where TSA = total shutter area of beams, TNJ = Total number of beam intersections

5.2 RCC Labour Productivity

a. Concreting labour productivity (m^3/lh)
= Volume of concrete placed (m^3)/labour input (lh)

b. Reinforced cement concrete Regression Model

$$P(m^3/mh) = bo + b1V + b2H + b3SCR + b4HWRK + b5LWRK$$

where P = concreting labour productivity;
V = volume of placed concrete;
H = height of the concreted element above ground level;
SCR = steel congestion ratio;
HWRK and LWRK = the categorical or “dummy” variables representing high and low concrete work- ability, respectively.

5.3 Reinforced Steel Labour Productivity

Labour productivity (kg/ lh) = Reinforcement quantity fixed (kg) / Labour input (lh)

a. Reinforced Steel Regression Model for Slabs

$$P(kg/lh) = bo + b1\ AVA + b2\ CBDia + b3\ TQ$$

Average panel area (m^2), AVA
Characteristic bar diameter (mm), CBDia
Total quantity of reinforcement fixed (kg), TQ

b. Reinforced Steel Regression Model for Columns

$$P(kg/mh) = bo + b1VOC + b2CBDia + b3TQ + b4\ CGeom.$$

VOC = variability of column sizes
CBDia = characteristic beam diameter
TQ = quantity of steel

CGeom= Dummy variable indicating column geometry which has the following two values: 0 if the column is rectangular in shape, and 1 if circular

c. Reinforced Steel Regression Model for Beams

$$P(kg/mh) = bo + b1CBDia + b2SDia + b3TQ + b4W + b5D$$

CBDia =m characteristic bar diameter
SDia = stirrups diameter
TQ = quantity of steel
W = width of beam
D = depth of the beam

6. SPSS SOFTWARE

SPSS is a comprehensive and flexible statistical analysis and data management solution. SPSS can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and conduct complex statistical analyses. SPSS is a Windows-based program that can be used to perform data entry and analysis and to create tables and graphs. SPSS is capable of handling large amounts of data and can perform all of the analyses covered in the text and much more.

For this paper, regression analyses followed by the creation of optimized cost significant models were done with the help of SPSS Software 16.0 version.

7. MICROSOFT EXCEL

Microsoft Excel is a spreadsheet application developed by Microsoft. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications. It has been a very widely applied spreadsheet for these platforms, especially since version 5 in 1993, and it has replaced Lotus 1-2-3 as the industry standard for spreadsheets. Excel forms part of Microsoft Office. There are usually several different ways to perform the same function in Excel and several functions can be performed.

- Model creation is the final step in this analysis
- Linear regression models have been created by using SPSS software.
- After creating the model, we are able to predict the labour productivity by putting the appropriate parameters affecting the labour productivity.
- Validation of the model is done by comparing the regression model with another data of a building. Then the percentage of error formed in the model is formed out.
- Due to this simplicity, the straight-line learning curve model is most commonly used for construction activities. An investigation into the applicability of learning curve theory using the unit straight-line model was conducted on formwork, reinforcing steel fixing and pumped concrete trades.

8. ANALYSIS OF FORMWORK LABOUR PRODUCTIVITY

The impact and relative influence of buildability factors on formwork labour productivity of the various observed activities were quantified using linear regression analysis. Activities observed included slabs, columns, and beams. Results of regression analyses of the various observed activities are following;

a. Formwork Labour Productivity of Slab

The relationship between formwork labour productivity of slab and the independent variables is quantified by the following multiple regression models:

$$P\ (m^2/lh) = bo + b1VOB + b2UFA + b3SPFI + b4BFI + b5NBI + b6FCRC + b7FPGeom$$

The overall regression model and coefficients statistics are shown below

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.873[a]	.763	.735	.37593786

a. Predictors: (Constant), VAR00008, VAR00004, VAR00007, VAR00006, VAR00005, VAR00003, VAR00002

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.683	7	3.955	27.982	.000[a]
	Residual	8.621	61	.141		
	Total	36.304	68			

a. Predictors: (Constant), VAR00008, VAR00004, VAR00007, VAR00006, VAR00005, VAR00003, VAR00002

b. Dependent Variable: VAR00001

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.867	.480		-1.805	.076
	VAR00002	-.079	.016	-.885	-4.837	.000
	VAR00003	.001	.000	.433	2.588	.012
	VAR00004	5.893	2.741	.388	2.150	.036
	VAR00005	39.524	3.735	1.392	10.584	.000
	VAR00006	-.005	.003	-.222	-1.910	.061
	VAR00007	.455	.137	.221	3.312	.002
	VAR00008	-.006	.003	-.169	-2.463	.017

a. Dependent Variable: VAR00001

Multiple regression models for predicting formwork labour productivity of slabs is

$$P(m^2/lh) = -0.867 - 0.079VOB + 0.001UFA + 5.893SPFI + 39.$$

b. Formwork Labour Productivity of Column

The relationship between formwork labour productivity of column and the independent variables is quantified by the following multiple regression models:

$$P(m^2/lh) = bo + b1VOC + b2SA + b3CGeom$$

The overall regression model and coefficients statistics are shown below

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.867[a]	.752	.740	.25787589

a. Predictors: (Constant), VAR00004, VAR00003, VAR00002

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.096	3	4.365	65.645	.000[a]
	Residual	4.322	65	.066		
	Total	17.419	68			

a. Predictors: (Constant), VAR00004, VAR00003, VAR00002

b. Dependent Variable: VAR00001

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.155	.100		-1.555	.125
	VAR00002	.021	.002	1.326	11.883	.000
	VAR00003	-.005	.001	-.439	-5.262	.000
	VAR00004	.629	.137	.422	4.598	.000

a. Dependent Variable: VAR00001

Multiple regression model for predicting formwork labour productivity of column is

$$P(m^2/lh) = -0.155 + 0.021VOC – 0.005SA + 0.629CGeom.$$

c. Formwork Labour Productivity of Beam

The relationship between formwork labour productivity of beam and the independent variables is quantified by the following multiple regression model:

$$P(m^2/lh) = bo + b1VOB + b2TSA + b3TNJ$$

The overall regression model and coefficients statistics are shown below

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.867[a]	.751	.739	.48761720

a. Predictors: (Constant), VAR00004, VAR00002, VAR00003

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	46.600	3	15.533	65.329	.000[a]
	Residual	15.455	65	.238		
	Total	62.055	68			

a. Predictors: (Constant), VAR00004, VAR00002, VAR00003

b. Dependent Variable: VAR00001

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.295	.269		-4.822	.000
	VAR00002	.090	.012	.499	7.598	.000
	VAR00003	.014	.001	.841	12.411	.000
	VAR00004	-.006	.002	-.191	-2.720	.008

a. Dependent Variable: VAR00001

Multiple regression model for predicting formwork labour productivity of beam is

$$P(m^2/lh) = -1.295 + 0.090VOB + 0.014TSA - 0.006TNJ$$

9. VALIDATION OF THE REGRESSION MODEL

All the factors affecting labour productivity in formwork, steel and concreting are collected.Parameters like VOB, UFA, SPFI, BFI, NBI ,FCRC, VOC, SA, CGeom, TSA, FPGeom, V, H, SCR, LWRK , HWRK, AVA, CBDia, VOC, SDia, W, D, and TQ are calculated and tabulated.

a. Formwork productivity of slab

Table-1: formwork productivity of slab

F	beams	slabs	number of days	number of labours	labour hours	P	VOB	UFA	SPFI	BFI	NBI	FC RC	FP Geom
1	32	81	4	13	520	1.37	6	710	0.11	0.05	32	0	9
2	29	78	4	12	480	1.15	4	550	0.14	0.05	28	1	9
3	29	78	4	11	440	1.25	4	550	0.14	0.05	28	1	9
4	29	78	3	12	360	1.53	4	550	0.14	0.05	28	1	9
5	29	78	3	10	300	1.83	4	550	0.14	0.05	28	1	9
6	29	78	2	8	160	3.44	4	550	0.14	0.05	28	1	9
7	29	78	2	8	160	3.44	4	550	0.14	0.05	28	1	9
8	29	78	2	9	180	3.06	4	550	0.14	0.05	28	1	9
	29.38	78.38	3.00	10.38	325.00	2.13	4.25	570.00	0.14	0.05	28.50	0.88	9.00

Actual average formwork productivity P = 2.13 m^2/lh

Multiple regression model for predicting formwork labour productivity of slabs is,

$P(m^2/lh) = -0.867 - 0.079VOB + 0.001UFA + 5.893SPFI + 39.524BFI - 0.005NBI + 0.455FCRC - 0.006\ FPGeom$

Substituting the average values of the factors in the equation,

$P(m^2/lh) = -0.867 - (0.079*4.25) + (0.001*570) + (5.893*0.14) + (39.524*0.05) - (0.005*28.5) + (0.455*0.88) - (0.006*9)$

Predicted productivity = 2.37 m^2/lh

Actual productivity = 2.13 m^2/lh

Percentage of error in prediction is about 10 %.

b. Formwork productivity of column

Table -2: Formwork productivity of column

floor	number of days	number of labours	total labour hours	P	VOC	SA	CGeom
1	3	8	264	0.14	31	38	0
2	3	8	264	0.16	31	41	0
3	3	8	264	0.16	31	41	0
4	3	6	198	0.21	31	41	0
5	2	5	110	0.37	31	41	0
6	3	5	165	0.25	31	41	0
7	2	5	110	0.37	31	41	0
8	3	4	132	0.31	31	41	0
	2.75	6.13	188.38	0.25	31.00	40.63	0.00

Actual average formwork productivity P = 0.25 m^2/lh
Multiple regression model for predicting formwork labour productivity of column is,
$P(m^2/lh) = -0.155 + 0.021VOC – 0.005SA + 0.629CGeom$
Substituting the average values of the factors in the equation,
$P(m^2/lh) = -0.155 + 0.021*31 – 0.005*40.63 + 0.629*0$
Predicted productivity = 0.29 m^2/lh
Actual productivity = 0.25 m^2/lh
Percentage of error = 13%

c. Formwork productivity of beam

Table-3: Formwork productivity of beam

floor	number of days	number of labours	total labour hours	P	VOB	TSA	TNJ
1	3	10	330	0.68	6	225	32
2	3	10	330	0.68	4	225	28
3	2	8	176	1.28	4	225	28
4	2	10	220	1.02	4	225	28
5	1	8	88	2.56	4	225	28
6	1	6	66	3.41	4	225	28
7	1	6	66	3.41	4	225	28
8	1	6	66	3.41	4	225	28
	1.75	8.00	167.75	2.06	4.25	225.00	28.50

Actual average formwork productivity P = 2.06 m^2/lh
Multiple regression model for predicting formwork labour productivity of beam is,
$P(m^2/lh) = -1.295 + 0.090VOB + 0.014TSA – 0.006TNJ$
Substituting the average values of the factors in the equation,
$P(m^2/lh) = -1.295 + 0.090*4.25 + 0.014*225 – 0.006*28.5$
Predicted productivity = 2.07 m^2/lh
Actual productivity = 2.06 m^2/lh

Percentage of error = .5%

Table - 4: Actual and Predicted Productivity

Productivity	Actual Productivity	Predicted Productivity	Percentage Of Error
Formwork Productivity Of Slab	2.13	2.37	10%
Formwork Productivity Of Column	0.25	0.29	13%
Formwork Productivity Of Beam	2.06	2.07	0.5%

The above table shows the values of actual productivity and the productivity predicted from the regression model created. In the same way all productivity of the building is calculated and tabulated.

10. CONCLUSION

In today's economic climate, the construction industry is suffering from increasing costs stemming from poor buildability and low productivity. Because of the importance of in situ reinforced concrete material to the construction industry, this research focused on exploring and quantifying the influence of buildability factors on the labour productivity of one of its major trades. Construction is labour intensive, it can be argued that labour-power is the only productive resource, thus construction productivity is primarily dependent on human effort and performance. The buildability variables explored are quantified, coupled with the method applied to establish the relationship between the various factors investigated and labour productivity, further add to the contribution of this study to the body of buildability knowledge. This can ultimately assist in developing a design support system, which can provide designers with the specific buildability knowledge required to make timely design decisions.

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