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FRAMEWORK FOR MEASURING OVERALL PRODUCTIVITY IN CONSTRUCTION PROJECTS

Ayele, Selam Y. [1] and Fayek, Aminah Robinson [2,3]

[1] MSc Student, Hole School of Construction Engineering, Department of Civil and Environmental Engineering, University of Alberta, 1-051 Markin/CNRL Natural Resources Engineering Facility, Edmonton, Alberta T6G 2W2, Canada

[2] Professor, NSERC Industrial Research Chair in Strategic Construction Modeling and Delivery, Ledcor Professor in Construction Engineering, Hole School of Construction Engineering, Department of Civil and Environmental Engineering, University of Alberta, 7-287 Donadeo innovation Center for Engineering Facility, Edmonton, Alberta T6G 1H9, Canada.

[3] aminah.robinson@ualberta.ca

Abstract: In construction research, the concept of productivity is generally measured as the relationship between outputs and inputs, where total productivity (TP) compares outputs to all identifiable inputs, such as labour, capital, material, and energy. TP is considered to be a meaningful measure for showing effectiveness in utilization of resources as well as overall project success. However, the majority of research related to productivity measurement and analysis are limited to labour productivity, which considers only a single input. The widespread use of labour productivity measures to assess operational efficiency is due in part to the relative availability of data, despite the fact that such measures exhibit substantial limitations in assessing overall project productivity. Determining total productivity on construction projects has its own challenges, which stem from project complexity and data requirements. This study adopts a two-phase approach to introduce a method for measuring total productivity in construction projects. The first phase of the study comprises a comprehensive analysis of productivity measurement methods, which aids in the development of an appropriate measurement metric. The second phase of the study focuses on the development of framework to measure overall productivity in construction projects. The outcome of this paper provides construction project owners and researchers with an approach to evaluate total productivity at the project level.

1 INTRODUCTION

Productivity improvement has been a major concern in the construction industry for many years; a productivity increase in this industry will not only benefit this sector but also the country as a whole. In today's competitive environment, companies should be making the management of productivity a high priority in order to effectively and efficiently convert resources into marketable goods and services (Kao et al. 2013).

Chau and Walker (1988) described two major considerations for productivity analysis and management: (1) the meaning of productivity and (2) the methods by which it is measured. The concept of productivity is broad and is defined differently across disciplines such as economics, operations research, and engineering (Sumanth and Dedeoglu 1988, Yi and Chan 2014). This variation in definitions can create confusion and may limit the transferability of productivity research to different contexts. For the purpose of this paper, productivity can be defined as the ratio of output to inputs.

Existing productivity measures can be categorized into two major groups, single factor productivity and multifactor productivity, depending on the type and amount of inputs taken into consideration in the measurement metrics (Yi and Chan 2014). Previous methods in construction productivity studies have focused on single factor productivity, such as labour productivity, which considers only one factor as input (Kim 2007, Yi and Chan 2014). Measurement of productivity using single factor productivity measures has various drawbacks such as the inability to consider the impact of technological and price changes (Lowe 1987). According to Lowe (1987), the limitation of these measures can be overcome by considering total productivity, which takes into account of all major inputs in the production process

The purpose of this paper is to review various approaches in measuring productivity in construction projects. This research will then be used to propose a framework that will support the quantification of the total inputs or resources used in construction projects at the construction stage, which will give an indication of project performance from an owner's perspective. While there are various performance metrics that can be used to support construction decision making by functioning as an indication of project status, this research focuses specifically on the productivity measurement performance metric.

This paper is structured as follows: Section 2 illustrates productivity measurement techniques at different levels of analysis that are used in construction industry; Section 3 describes the methodology implemented to select a suitable method of measurement for total productivity in construction projects; Section 4 discusses the developed framework, along with the proposed metrics; and the final section presents the conclusion and areas that will be addressed in a future study.

2 PRODUCTIVITY MEASUREMENT

Measurement and management of productivity has plays an important role in the success of any project. The management of productivity processes can be thought of as a four-phase cycle commonly termed as the "productivity cycle". The four phases of the cycle are as follows: (1) productivity measurement, (2) productivity evaluation, (3) productivity planning, and (4) productivity improvement (Sumanth and Dedeoglu 1988). These phases of productivity management involve the quantification, comparison, establishment of targets, and application of techniques that increase productivity at any level of production.

Productivity measurement, which is the initial step in the productivity cycle, lays the foundation for the ongoing management of productivity. In general, productivity measures can be categorized into two classes: (1) single factor productivity (SFP), which compares the output with one specific input factor (e.g., labour or capital); and (2) multifactor productivity (MFP), which relates the output with all resources used (Lowe 1987, Chau and Walker 1988, CII 2013). These productivity measures can be computed at three different levels for production systems that transform inputs (i.e., resources) into outputs. Haung et al. (2009) divides existing system measures in the construction industry into three major categories: task-level, project-level, and industry-level productivity measures. Activity-level productivity measures assess individual construction activities such as concrete placing and steel erection. In contrast, project-level productivity measures consider set of activities required for the construction of a facility. Industry-level productivity measures are based on an overall assessment of productivity in the industrial sector; this approach is considered as a macro-level measurement metric. The main concept underlying construction industry productivity measures is the connection between the output of an activity, project, or industry and the required inputs used to generate that output (Huang et al. 2009).

At the industry level, productivity can be tracked as the amount of output produced per unit of input; these values are a measure of industrial efficiency. Measuring productivity at the industrial-level provides vital information for assessing living standards, the productive capacity of the economy, international productivity, and the impact of economic policies (Huang et al. 2009). According to CII (2013), productivity at the industrial level can be measured using two metrics: total factor productivity and labour productivity. Total factor productivity can be represented by dividing the total output (i.e., the produced goods and services) by the input used in the completion of activities. Equation [1] shows the widely used TFP measure expressed in terms of labour, material, equipment, energy, and capital (CII 2013, Thomas et al. 1990).

$$[1]\ \text{Total Factor Productivity}=\frac{\text{Total Output}}{\text{Labor + Material+Equipment+Energy+Capital}}$$

Labour productivity at the industrial level can be measured as a ratio of total output to the labour hours devoted to deliver that output, as indicated in Equation [2] (CII 2013). When assessing productivity at the industrial level, multifactor productivity is preferred over labour productivity, because the labour productivity measure is limited in its capacity to assess all the required measures, and it is prone to misinterpretation (Huang et al. 2009).

$$[2]\ \text{Labor Productivity}=\frac{\text{Total Output}}{\text{Labor (Direct Workhours)}}$$

In contrast, according to OECD (2001), industry-level productivity measures can be expressed with gross output to input components and with value added that captures the flow of output. The gross output describes the goods and services that are produced by the project, firm, or industry. The output is manufactured with the use of available input resources, which can be labour and capital or both. Value added refers to the difference between the value of output and the value of intermediate input (materials, energy, services, etc). In simpler terms, value added may also be described as the difference between sales and the cost, as it represents the profit generated through the production process (OECD 2001).

Activity-level productivity metrics are the most commonly used productivity measures in the construction industry. Single-factor productivity measurement metrics are widely applied to measure activity level productivity, particularly labour productivity.

Since a construction project requires the execution of numerous activities, measuring productivity at the project level is more complicated than measuring productivity at the activity level (Huang et al. 2009). In measuring productivity at project level, information regarding the required inputs and outputs depends on how the metrics is defined, which involves quantification of the inputs and outputs in the project. Over the years, different studies have been conducted to develop meaningful project-level productivity metrics that provides qualitative estimates of project productivity based on activity data (Ellis and Lee 2006, Thomas et al. 1990, Liao 2012).

Thomas et al. (1990) suggests a project-specific productivity measure that considers labour, material, and equipment as input resources. Ellis and Lee (2006) also developed a project-level productivity measurement procedure that uses activity data from transportation projects, by adopting equivalent work units (EWU) to calculate the total output of a transportation project. EWU expresses the amount of work that can be completed within an eight-hour work period. An EWU-based approach for determining overall output requires that each activity in a project be weighted in order to develop a composite unit; however, this data can be difficult to analyze for complex projects involving many different activities. Moreover, when applying EWU to normalize and aggregate output, this method does not consider the variance of the installed quantities for each work item or activity, which results in an imprecise project-level productivity value. Yun et al. (2015) and Liao et al. (2012) used construction discipline productivity data to develop high-level project productivity metric. In measuring project-level productivity, actual work hours were used as an input for selected construction disciplines.

Previous studies mainly focus on the productivity of specific activities such as concreting (Liao 2012, Ellis and Lee 2006). Ellis and Lee (2006) argue that the success of a project is influenced by the productivity of all task elements in the project; therefore, incorporating only a few work elements or activities is inadequate for assessing overall project productivity. To remedy these limitations, this paper will propose a measurement method that can address the effects of all input resources in evaluating productivity at the project level.

3 OVERALL PRODUCTIVITY MEASUREMENT METRIC

Determining overall productivity on construction projects has its own challenges, which stem from project complexity and data requirements. This study will adopt a two-phase approach to introduce a method for measuring overall project productivity. The first phase of the study comprises a comprehensive analysis of productivity measurement methods, mainly at the project level, which will aid in the development of an appropriate measurement metric that can be used to measure overall productivity in construction projects. The second phase of the study focuses on the development of framework that will be used as a structure for measuring total productivity in construction projects at the construction stage.

Total productivity is the ratio of outputs to all inputs used in the production process (Chau and Walker 1988). Using all inputs in measuring total productivity provides good insight into the performance of the whole project. Even though a considerable amount of research has focused on productivity measurement, less attention has been given to total productivity measurement at the project level, due mainly to the complexity in determining project inputs and outputs (Thomas et al. 1990). Thomas et al. (1990) further states that implementation of Total Productivity (TP) in construction projects or sites can result in imprecise measurement values, due to challenges in getting proper estimates for the inputs. Furthermore, measurement of the outputs in construction projects is challenging. Given the heterogeneity of different activities, expressing the value of the whole project with a single output measure can be quite difficult.

Little progress has been made towards identifying project-level productivity metrics that measure other inputs besides labour. Table 1 gives a summary of existing construction project-level productivity measures in the literature; these approaches are based on different measurement methods (i.e., single factor or multifactor productivity).

Table 1: Summary of productivity measurement literature

Measurement Method	Productivity measurement approach	Author
Labour Productivity	• Measures productivity of building projects by measuring the total manpower in man-days as the input and the completed gross floor area as the output.	Lim (1996)
	• Producing project-level productivity data by considering all the task elements as a ratio of total worker hours and total equivalent work unit (EWU).	Ellis and Lee (2006)
	• Quantity-based approach that measures construction productivity as actual work hours per installed quantity.	Yun et al. (2015)
	• Cost-based approach that assesses cost for construction activities per work hour.	Yun et al. (2015)
	• Uses engineering productivity as a ratio of direct engineering work-hours to construction quantities.	Liao et al. (2012)
Partial factor Productivity (Labour and Equipment)	• Uses a ratio of units of physical output to inputs, the latter of which is a monetary value representing labour and equipment.	Thomas et al. (1990), CII (2013)
	• Uses a ratio of units of physical output to inputs, which is a monetary value representing labour together with fixed capital.	Goodrum and Hass (2002)
Multi-factor Productivity	• Similar to TFP, integrates labour, material, and equipment as an input.	Thomas et al. (1990)
	• Multifactor productivity with labour, circulating capital, and fixed capital as an input.	Goodrum and Hass (2002)

Despite different attempts to measure total productivity in construction projects, there appears to be no consensus on a specific method of measurement. Productivity measurement at any level of production requires a detailed understanding of how productivity data are measured and analyzed, and it must also take into consideration any data collection and measurement restrictions. Therefore, based on these gaps identified in the literature, this study proposes Equation [3] as a measurement metric for overall productivity in construction projects. Tangible output in the metrics shows the value of the finished product, which is measured in terms of physical units. Chau and Walker (1988) classify inputs into two major categories: tangible and intangible inputs. Tangible inputs include labour, material, capital, energy, and other expenses that are used in the production process. In contrast, intangible inputs include factors affecting the productivity value such as material quality, management practices, and contract type. In this research, tangible inputs will be considered in dollar value, where the components of each will be discussed in detail in the subsequent section. When comparing project productivity overtime, the effects of inflation on projects that span long periods of time can be accounted for by using cost indices developed by Statistics Canada. Cost indices are tools that can be used to measure price changes taking place in an economy. The most commonly used price indices in the construction industry are the new housing price index, apartment building construction price index, non-residential building construction price index, input cost indices, construction union wage rate index, industrial products price index, and raw materials price index (Harrison 2007).

[3] Total Productivity =Total Tangible Output (Unit) /Total Tangible Inputs ($)

When productivity is viewed as a ratio of inputs and output, the productivity of individual inputs used in a project can also be calculated as follows:

[4] Labour Productivity =Total Tangible Output (Unit) /Labour Inputs ($)

[5] Capital Productivity =Total Tangible Output (Unit) /Capital Inputs ($)

[6] Material Productivity =Total Tangible Output (Unit) /Material Inputs ($)

[7] Energy Productivity =Total Tangible Output (Unit) /Energy Inputs ($)

4 DEVELOPMENT OF MEASUREMENT FRAMEWORK AT CONSTRUCTION STAGE

Harrison (2007) categorized construction into three main sub-industries in the context of productivity studies: building construction, engineering construction and repair construction. Building construction includes residential and non-residential projects. In contrast, engineering construction comprises different sectors such as oil and gas, electric power, transportation, communication and other engineering construction projects. This paper introduces a total construction productivity model (shown in Figure 1) that can be adopted to determine how much output can be produced for every input consumed on a construction project, where inputs included in the metrics are expressed in terms of dollar value and output is expressed as a quality-based measurement. The model shows a list of inputs with examples that are used to measure the total productivity of a project at the construction stage. The details of each component will be discussed in the next section of this study.

In this part of the paper, a framework will be developed that includes a list of the required information about total tangible outputs and total tangible inputs. The total productivity measurement framework provides a structured view on the components required for measuring overall productivity of a project at the construction stage. The framework also provides a description of the components of each cost element, which includes information for calculating cost data for each input.

As a general guideline, at this stage, the sets of input and output categories are formulated for construction projects. Every construction project has unique characteristics, while also sharing physical, administrative, and operational features with other projects. Starting from initiation to the final execution and closure of the project, these physical, administrative, and operational features have an impact on the intangible aspects of a project such as decision making and management (Manu et al. 2010). In studying the total productivity of a project, this research only accounts for the effect of tangible inputs on total project output.

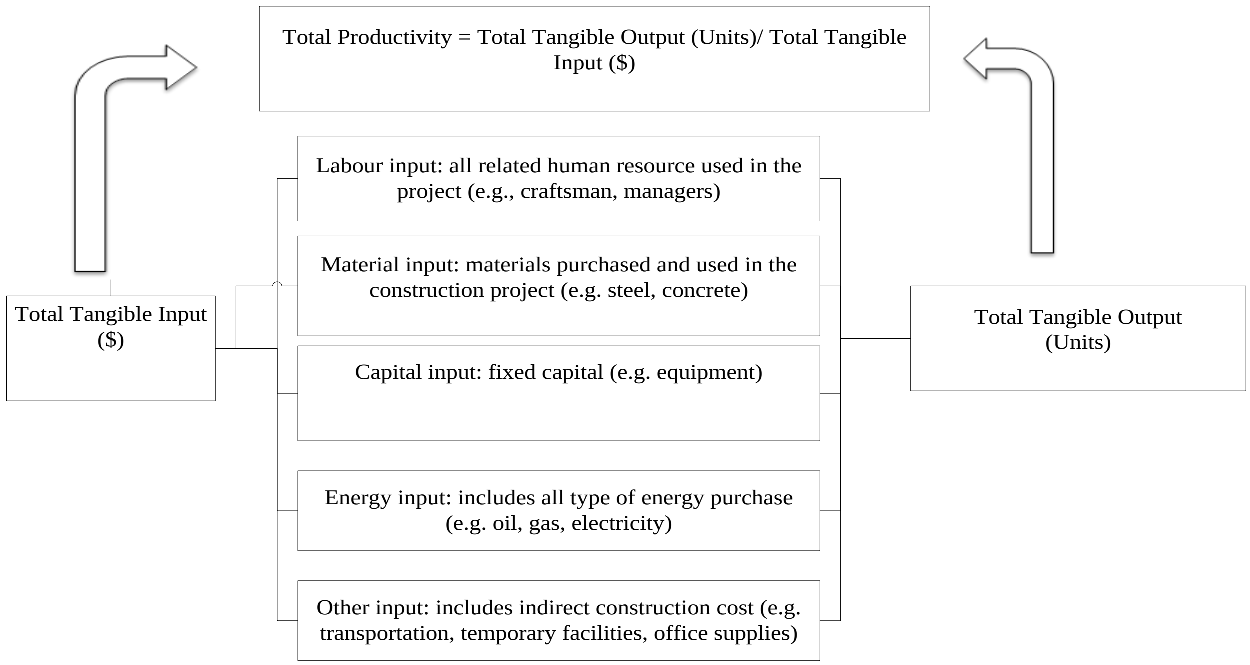

Figure 1: Total construction productivity model

4.1 Input

4.1.1 Labour Input

The construction industry is one of the most labour-intensive industries in the world, which makes labour a vital component of construction projects. Labour inputs on construction projects often represent as much as 35% of the total project cost (Proverbs et al. 1999). Labour costs typically includes the cost of human resource inputs used in the project. More specifically, labour costs consist of direct labour costs, which can easily be traced to activities executed by workers, as well as indirect labour costs, which include wages for support staff that are not directly associated with the undertaken activity (Humphreys 2004). Proverbs et al. (1998) state that estimating construction labour cost is one of the most challenging aspects of making a total project cost estimate. Construction labour cost comprises the basic rate of hours worked, overtime pay, social security taxes, vacation pay, holiday, and sick leave. In determining the cost of labour for a project, several factors should be taken into consideration such as scope of work, quality definition requirements, project size, project complexity, project execution plan, design technology, specification, local culture and local labour laws, site conditions, location consideration, availability of local craft resources, currency exchange fluctuations, and union or open/merit shop considerations (Westney 1997). The proposed framework uses the list of direct and indirect labour categories for measuring productivity in the construction stage of a project, which was proposed by Kim (2007); this list is shown below in Table 2.

Table 2: Direct and indirect labour (Kim 2007)

Direct Labour	Indirect Labour
Direct craft labour	Project manager/Construction manager
Foreman	Project engineer
Site planner	Project controls (Cost/schedule/estimating)
Site engineer	Constructability consultant
Superintendent	Owner project staff
	Design consultants (Architect, Engineer, etc.)

	Accountant
	Procurement staff
	Field warehouse staff
	Safety engineer
	Subcontract specialists
	Field clerical staff
	Janitorial staff
	Security

4.1.2 Material Input

Materials include raw materials and purchased parts that are assembled as a component of the final build facility or project (Oberlender 2014). The cost of materials includes material price, sales tax, and shipping cost. Among the different cost components in a project, material cost is considered to be the most predictable. The amount of material used in a project can easily be quantified, and the current price can be collected from different data sources. For categorizing the cost of materials, COAA (2011) used the following bulk material groups: civil/structural, pipe, instrumentation, electrical, and miscellaneous. For building elements and site work, ASTM (2009) established standard categories of classification that assist in structuring elements that are common for building projects. In the UNIFORMAT II classification of building elements, components are categorized into several major groups ranging from level 1 to level 3: substructure, shell, interior, service, equipment & furnishing, special construction & demolition, and building site work (ASTM 2009). In this research, the cost of materials associated with the construction of a facility are grouped into different categories, based on the major components that are mainly used in the construction stage. These categories and relevant examples are shown below in Table 3.

Table 3: List of material input categories

Material Category	Examples
Civil structural components	Materials included in substructure and superstructure work such as excavation, concrete, reinforcing steel, structural steel, etc.
Interior and exterior part excluding structural parts	Includes interior partitions, finishes, furnishing
Piping	Underground and above ground system, pipe, fittings, valves, pipe supports,
Mechanical components	Equipment and mechanical parts of the built facility
Electrical components	Conduit, cables, fixtures, transformers, etc.
Fittings and fixtures	
Fire protection	
Heating, ventilation and air conditioning (HVAC)	
Miscellaneous	Painting, supporting fixtures , etc.

4.1.3 Capital Input

Humphreys (2004) defines total capital as a combination of fixed capital and working capital. Fixed capital includes land, equipment, utilities, design and engineering. In contrast, working capital comprises funds available for contribution throughout the project such as cash on hand, accounts, and notes receivables that are going to be used in the project. For construction projects, working capital is commonly used to purchase inputs, such as energy, material, and labour; therefore, in order to prevent double counting, working capital will be excluded in the measurement of total capital cost. Since the main focus of this study is to determine the input costs that are incurred at the construction stage, besides equipment costs, other fixed capital costs are not considered. Table 4 shows the list of cost components that are treated as fixed capital in construction projects.

Table 4: Construction phase capital cost

Direct Equipment Cost	Indirect Equipment Cost
Rental/ownership cost	Repairs and maintenance
Gasoline or fuel cost	Mechanics labour and burden
Oil	Depreciation
Lubricant	Insurance
Filter	

4.1.4 Energy Input

Energy is one of the inputs used in the construction industry, and it comes in the form of coal, petroleum products, electricity, natural gas, and liquefied petroleum gas (Das et al. 2014). Nyboer and Bennett (2015) used data from producers to study energy use and greenhouse emission from the Canadian construction industry. The report based its study on seven categories: natural gas, liquid gas, gasoline, kerosene, diesel, light fuel oil, and heavy fuel oil. The study further notes that from the listed categories of energy sources in construction sites, energy is usually provided by diesel fuel, gasoline, and natural gas, in addition to electricity (Nyboer and Bennett 2015). Therefore, energy costs for construction projects can be obtained by adding up all resource costs during the relevant period. For the purpose of this study, diesel fuel, gasoline, natural gas, and electricity are considered as energy inputs for calculating the amount of energy consumption on construction projects.

4.1.5 Other Input

Other input costs include costs that are charged in the project and that cannot be categorized as labour, capital, material, and energy costs. This cost category includes items such as transportation, temporary facilities, office supplies, taxes, etc.

For cost elements in the construction phase, other input cost categories can incorporate indirect costs that are incurred. The indirect cost categorization framework (IDCC) developed by Becker et al. (2012) together with Westney (1997) will be used by excluding indirect labour costs and construction equipment consumables. The list of other input cost categories includes costs related to temporary construction, temporary facility costs, and indirect construction costs, as indicated in Table 5.

Table 5: Construction phase capital cost

Temporary Construction	Temporary Facility	Indirect Construction Cost
Temporary road and parking	Temporary office and service	Travel/relocation/subsistence and field per diems
Temporary enclosure	Temporary field facilities	Safety and first aid
Utilities to trades	Scaffolding	Construction consumables (Defined by project team)
Mobilization and demobilization cost	Communications and computers	Insurance/taxes, statutory payroll burdens and benefits
	Temporary housing and camps	Subcontractor facilities
		Environmental mitigation cost
		Personnel training cost
		Material testing cost
		Financing costs
		Escalation
		Contingency

4.2 Output

The development of a framework to measure productivity will aid in alleviating the problem of data deficiencies by providing guidance for the data requirements needed for productivity calculations. In order to get a reliable productivity measurement, both input and output values should be properly measured. At any level of measurement, output can be expressed either as a physical quantity or financial value. For homogenous production output, physical units can be used for measuring the output of a production process such as meter cube of concrete. The heterogeneous nature of construction projects makes quantification of output difficult. In areas where output is not uniform, it is mainly measured as a dollar value. Selection of a measurement metric depends on the objective of the measurement and the availability of data.

The method suggested in this study is to measure output in terms of functional units. The functional unit, or the physical unit of measurement, depends on the type of construction. For example, highway projects can be measured by lane mile, and bridge projects can be measured using surface area. These measurements can be done after the completion of major milestones in a project, such as finishing one story in a building project or one mile in a road project.

5 CONCLUSIONS AND FUTURE RESEARCH

This paper has presented a measurement approach for evaluating the overall productivity of a construction project, while also considering the effects of all the inputs used in the production process. The measurement approach proposed herein classifies the inputs into five main categories to facilitate the evaluation of total consumed inputs. The study also developed a framework containing a basic description and list of elements that enable proper structuring of measurement components. This framework facilitates the systematic collection of inputs and outputs data and subsequently allows proper evaluation of overall productivity in construction projects. Development of project-level productivity measures allows owners to analyze the project performance by showing the overall efficiency in the use of all key input resources at the construction stage. As part of the future development of this study, the applicability and completeness of the input categories and output measures will be validated through discussion with industry experts. Since the proposed metrics are most relevant to the owner group, the research will also continue to study the influential input resources for owners in phases leading to construction (i.e., during initiation, design and engineering, and procurement) and will assess their impact in capital effectiveness.

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References

ASTM E1557-09. 2015. *Standard Classification for Building Elements and Related Sitework—UNIFORMAT II*. ASTM International, West Conshohocken, PA, USA.

Becker, T. C., Edward J. J., Mohamed El., and Jing, D. 2012. Industry Practices for Estimating, Controlling, and Managing Key Indirect Construction Costs at the Project Level. *Construction Research Congress 2012*, West Lafayette, IN, USA. doi:10.1061/9780784412329.248.

Chau, K. W., and Walker, A. 1988. The measurement of total factor productivity of the Hong Kong construction industry. *Construction Management and Economics*, **6**(3): 209-224. doi:10.1080/01446198800000019

Construction Industry Institute (CII). 2013. *The Construction Productivity Handbook*. (Implementation Resource 252-2d). Edited by Jacqueline Thomas. University of Texas at Austin, Austin, TX, USA.

Das, K. D., Erumban, A. A., and Aggarwal S. 2014. *Measuring Productivity at the Industry Level.* The India KLEMS data base. University of Delhi & University of Groningen.

Ellis, R. D., and Lee, S.H. 2006. Measuring Project Level Productivity on Transportation Projects. *J. Constr. Eng. Manage.*, **132**(3): 314-320.

Goodrum, P. M., and Haas, C. T. 2002. Partial Factor Productivity and Equipment Technology Change at Activity Level in U.S. Construction Industry. *J. Constr. Eng. Manage.,* **128**(6): 463-472.
Harrison, P. 2007. Can Measurement Error Explain the Weakness of Productivity Growth in the Canadian Construction Industry. Centre for the Study of Living Standards for the Construction Sector Council, *Research Report No. 2007-01*, Ottawa, ON, Canada.
Huang L. A., Chapman E. R., and Butry T. D. 2009. Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations. *NIST Special Publication 1101*. U.S Department of Commerce National Institute of Standards and Technology (NIST), Office of Applied Economics Building and Fire Research Laboratory, Gaithersburg, MD, USA.
Humphreys, K. K. 2004. *Project and Cost Engineers' Handbook*, 4th Ed., Marcel Dekker, New York INC, New York, NY, USA. <http://dx.doi.org/10.1201/9780849390388>
Kao, C., Huang, K. L., Huang, Y. M., Liu, W. J., Huang, S. K., and Wu, C. A. 2013. Productivity of Taiwan's 1000 Largest Companies. *Journal of Industrial and Production Engineering*, **30**(1): 44-53.
Kim, I. 2007. Development and Implementation of an Engineering Productivity Measurement System (EPMS) for Benchmarking. PhD dissertation, University of Texas at Austin, Austin, TX, USA.
Liao, P. C., Thomas, S. R., O'brien, W. J., Dai, J., Mulva, S. P., and Kim, I. 2012. Benchmarking Project Level Engineering Productivity. *Journal of Civil Engineering and Management*, **18**(2): 235-244.
Lim, E. C. 1996. The Analysis of Productivity In Building Construction. Ph.D. thesis, Loughborough University of Technology, Leicestershire, UK.
Lowe, J. G. 1987. The Measurement of Productivity in the Construction Industry. *Construction Management And Economics*, **5**(2): 101-113.
Manu P., Ankrah N., Proverbs D., and Suresh S. 2010. An Approach for Determining the Extent of Contribution of Construction Project Features to Accident Causation. *Safety Science*, **48**(6): 687-692.
Nyboer J., and Bennett M. 2015. Energy Use and Related Data: Canadian Construction Industry 1990 to 2015. *Report for Canadian Construction Association*, Canadian Industrial Energy Enduse Data and Analysis Centre, Simon Fraser University, Burnaby, BC, Canada.
OECD. 2001. "Overview of Productivity Measures. Measuring Productivity" .Organisation for Economic Co-operation and Development Manual, 2001st ed. Vol. 2. Paris: OECD PUBLICATIONS. doi:10.1787/9789264194519-en.
Oberlender, G. D. 2014. *Project Management for Engineering and Construction*. Mcgraw-Hill Education, New York, NY, USA.
Proverbs, D., Holt, G., and Olomolaiye, P. 1998. A Method for Estimating Labour Requirements and Costs for International Construction Projects at Inception. *Building and Environment*, **34**(1): 43-48.
Proverbs, D., Holt, G., and Olomolaiye, P. 1999. The Management of Labour on High Rise Construction Projects: An International Investigation. *International Journal of Project Management*, **17**(3): 195-204.
Sumanth, D. J., and Dedeoglu, M. 1988. Application of Expert Systems to productivity measurement in companies/organizations. *Computers & Industrial Engineering*, **14**(3): 241-249.
Thomas, H. R., Maloney, W. F., Horner, R. M. W., Smith, G. R., Handa, V. K., and Sanders, S. R. 1990. Modeling Construction Labor Productivity. *J. Constr. Eng. Manage.,* **116**(4): 705-726.
Vogl, B., and Abdel-Wahab, M. 2015. Measuring the Construction Industry's Productivity Performance: Critique of International Productivity Comparisons at Industry Level. *J. Constr. Eng. Manage.,* **141**(4): 04014085.
Westney, E., R. 1997. *The Engineer's Cost Handbook*, Marcel Dekker, INC. New York, NY, USA. < http://dx.doi.org/10.1201/9780203910016 >
Yi, W., and Chan, A. P. C. 2014. Critical Review of Labor Productivity Research in Construction Journals. *J. Manage. Eng.*, **30**(2): 214-225.
Yun, S., Mulva P. S., and Kim, Y. D. 2015. Measuring High-Level Project Productivity for Alberta Projects. *11th Construction Specialty Conference*, Vancouver, BC, Canada.