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Comparing International Construction Performance

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Abstract

The measurement of construction performance is a vexed problem. Despite much research effort, there remains little agreement over what to measure and how to measure it. The problem is made even more complicated by the desire to benchmark national industry performance against that of other countries. As clearly construction cost forms part of the analysis, the mere adjustment of cost data to an 'international currency' has undermined past attempts to draw any meaningful conclusions. This paper proposes a new method for comparing international construction performance, and in so doing integrates cost with time and quality to determine ratios capable of ranking projects, building contractors, cities and even entire industries – not only today, but retrospectively over time.

The aim in this paper, therefore, is to outline the new model and test it using what is understood to be one of the largest samples of construction project data ever assembled across two sample countries: Australia and the United States. The research comprises 337 high-rise projects of 20 storeys or more, completed between 2003 and 2012, throughout the five largest cities in Australia and the United States and representing two-thirds of the known population of such buildings in these locations. The ensuing analysis not only demonstrates the practical application of the model, but provides new insight into the efficiency track-record of the construction industry in Australia and the United States by city over the last decade.

Cost is measured as the number of standard 'citiBLOC' baskets necessary to construct a project, where a standard basket comprises common and globally-applicable construction items priced in each city in local currency, removing the need to apply currency exchange rates that otherwise introduce volatility and erroneous outcomes. Time is measured as the quantity of finished gross floor area completed per month, inclusive of delays related to the construction process on site. Quality/complexity is measured as a function of unit price and implicitly includes factors such as buildability, innovation, building height, extent of fit-out, environmental performance, compliance, standard of finish and supervision levels. Construction efficiency is extracted and defined as the ratio of construction cost per month, and is used to comment on the relative performance of the procurement process in different locations.

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It is concluded that, based on data from the largest five cities in each country, efficiency on site is improving in both countries. The growth in baseline cost/m^2 suggests a possible rise in project complexity over time. While the trend in efficiency improvement is similar, there is evidence that base costs in Australia have outstripped the United States, meaning that 'real' construction efficiency in Australia is relatively less. If Australia held an advantage in the past, then it seems that advantage might be disappearing. Notwithstanding the larger number of projects found in the United States (251) compared to Australia (86), the top 10 US performers in terms of construction efficiency have higher scores that the top project found in Australia, and the reasons underpinning this clearly demand future project-level investigation.

Keywords: *construction efficiency, purchasing power parity, benchmarking, key performance indicators, Australia, United States*

Introduction

The global construction industry is highly competitive, fragmented, cyclical and frequently operates on low margins (Loosemore 2003). Yet construction accounts for a significant portion of economic activity and is a catalyst for many other sectors. The industry is also labour intensive, project-specific and involves team relationships that form and disband on a regular basis. It is not surprising, therefore, that construction performance and reform have dominated research within the industry for over fifty years.

Yang et al. (2010) undertook a critical literature review of performance measurement in construction. Their work provided an excellent platform from which to propose a fresh approach to the problem. They classified performance measurement studies into three categories: project, organizational and stakeholder. The major frameworks were shown to be the European Foundation for Quality Management excellence model, key performance indicators (KPIs), and balanced scorecards. Gap analysis (e.g. trend analysis), integrated performance index (e.g. multiple criteria analysis), statistical methods (e.g. regression analysis) and linear programming (e.g. data envelopment analysis) were shown to be the most frequently applied research methods for performance measurement.

Performance measures are approaches to determine if a process has obtained the desired result. However, the diversity of the construction process makes it difficult to apply just a simple definition. In reality, performance is relative and assessed via comparison to observed best practice. This requires appropriate and current data in an objective (i.e. numeric) format across a wide range of building types, locations, time and regulatory environments that makes the task difficult if not impossible to complete.

The construction industry has long been criticized for apparent underperformance (e.g. Pieper 1989). Reports such as Latham (1994) and Egan (1998) have called for a rethink of the traditional construction process, but over a decade on many might conclude that little has changed. So the debate continues, and the search for appropriate measures lie on the leading edge of research into the performance of contractors, projects and industries, and probably will do so well into the future.

Yang et al. (2010:281) concluded that no single framework or approach fits all situations – all have their advantages and disadvantages – and therefore "*it is an important task to develop a more comprehensive performance measurement framework in construction in the future"*. The aim here is to propose a new model for performance measurement and to test it using what is understood to be one of the largest samples of construction project data ever assembled across two sample countries: Australia and the United States. The analysis of this data not only demonstrates the practical application of the model, but provides new insight into the efficiency of the construction industry in these two countries over the last decade.

Performance and Productivity

Performance and productivity are often used interchangeably in the literature. To some extent the difference lies in the type of study being undertaken and its scope. For example, studies into the merits of a single project or contractor may be best described as performance measures, even though the productivity of employed labour may be incorporated in the analysis. On the other hand, studies into the efficiency of multiple projects or contractors may help to understand industry performance, and these types of studies tend to focus on comparative productivity. In both cases ratios of output over input are typically involved.

Benchmarking is also a common strategy. Liao et al. (2012) stated that the benchmarking of engineering productivity can assist in the identification of inefficiencies and thus can be critical to cost control. Their study developed a standardized approach using 'z-scores' to aggregate engineering productivity measurement from data collected from 112 actual projects, and resulted in a metric incorporating a project level view of engineering productivity. The metric enables benchmarking of heavy industrial project productivity as a basis for comparison of individual project performance. Mohamed (1996) earlier urged organizations to be actively involved in project benchmarking to assess their performance, measure their productivity rates and validate their cost-estimation databases.

Motwani et al. (1995) discussed the importance of measuring productivity over time. Changes in productivity, rather than absolute values, were seen as critical if building contractors were to be competitive and successful in the increasingly global construction market. Furthermore, Yates and Guhathakurta (1993) looked at international labour productivity differences and concluded that labour quality, motivation and management were the main issues. Labour quality, for example, may include union agreements, restrictive work practices, absenteeism, turnover, delays, availability, level of skilled artisans, use of equipment and weather. Mohamed and Korb (2002) found that productivity falls when thermal comfort moves away from the optimum range. Disruption was also shown to be correlated with poor management and led to low productivity (Enshassi et al. 2007).

Various studies have attempted to measure labour productivity at the project or task level through cost and quality management maturity (e.g. Willis and Rankin 2012), concurrent engineering (e.g. Shouke et al. 2010), organizational analysis (e.g. Sahay 2005), process improvement (e.g. Stewart and Spencer 2006) and human resource management (e.g. Hewage and Ruwanpura 2006).

Key Performance Indicators

Performance is not just about efficiency but achieving desired results. To help in this endeavour, a wide variety of KPIs have been identified and used to measure the success of construction projects. These include indicators of client satisfaction, stakeholder engagement, service delivery, investment return, urban renewal, defect minimization, trust, dispute avoidance, innovation, safety and standard. Three of the most commonly cited KPIs are on-time completion (time), within agreed budget (cost) and non-defective workmanship as specified (quality).

Time, cost and quality necessarily interact. It is well understood in the industry and in the literature that trade-offs occur between optimizing performance for any of these KPIs. For example, accelerating completion of a project will usually involve extra cost, reducing cost will tend to lower quality, and increasing quality standards will take more time to deliver.

Meng (2012) found that construction projects often suffer from poor performance in terms of time delays, cost overruns and quality defects, and from an analysis of previous research findings concluded that *"time, cost and quality are the three most important indicators to measure construction project performance"* (p.188). From a survey of 400 construction practitioners in the UK, with a response rate of 30%, his research found that 35.6% of projects studied were delayed, 25.2% were overspent, and 17.7% had significant defects. These problems were more prevalent in traditional procurement relationships compared to partnering (or relationship management) arrangements, and the deterioration of supply chains was a major reason for the occurrence of poor performance.

Rankin et al. (2008) identified a number of performance metrics suitable for KPI-style evaluation. These were divided into time, cost, quality, scope, safety and sustainability. Brown and Adams (2000) undertook 15 case studies derived from UK data, and found that project management as implemented in the UK failed to perform as expected in relation to the three predominant performance evaluation criteria of time, cost and quality. In fact, they showed that project management had little effect on time performance, no effect on cost performance, and a strong yet negative effect on quality performance. Other factors were assumed to be at play.

Time Performance

Time performance usually means the project is completed on or before the agreed handover date. Sometimes contractual documents refer to time being the 'essence of the contract', which exemplifies the criticality of timely completion due to subsequent plans that cannot be delayed.

Time on construction projects can be measured in days, weeks or months. Obviously large projects take more time to construct than small projects, so a reasonable KPI might be square metres of gross floor area completed per month (m^2/month). This is an output measure describing production. A high value for this KPI would mean that the construction process was fast, and vice versa.

Walker (1995) found four factors that significantly affect construction time performance. These comprised and can be summarized as:

1. construction management effectiveness (i.e. competence),
2. the sophistication of the client and the client's representative in terms of creating and maintaining positive project team relationships with the construction management and design team (i.e. teamwork),
3. design team effectiveness in communicating with construction management and client's representative teams (i.e. communication), and
4. a small number of factors describing project scope and complexity (i.e. work definition).

Prediction of construction time has been studied at length. One of the earlier studies was Bromilow (1969), in which a predictive model was developed using the relationship between cost and duration. It was found that the time taken to construct a project is highly correlated only with the project's size, as measured by its final cost. Love et al. (2005) proposed an alternative model to Bromilow and concluded that gross floor area and the number of storeys were also key determinants of time performance in forecasting construction project duration. Lin et al. (2011) reviewed a number of attempts at duration prediction in various countries based on the relationship between variables. Likewise in their own research concerning steel reinforced concrete buildings in Taiwan, regression was the chosen methodology, and cost, floor area and number of storeys were the variables showing the strongest correlations, with no significant multicollinearity detected. Change orders and rainy days were added and slightly improved the predictive reliability of their model.

Cost Performance

Cost performance is normally judged relative to an agreed budget. Sometimes projects may have no budget, which means that cost is not a consideration, but this is rare. Completion close to budget is usually preferable; in some cases being well below budget is seen as an advantage, although often not. Clients tend not to like surprises, so the final project cost should be the result of prudent cost management processes and therefore, by definition, deliver an end result close to the agreed budget.

Construction cost is measured in pure financial terms, usually in local currency, and should focus on the building rather than the land (i.e. should exclude site purchase costs). Since construction often spans many years it is necessary to bring costs to a common date. The conversion to a common date is undertaken using building price indices that reflect inflationary change appropriate to the current level of construction intensity.

Cost conversion is also required to take account of geographic location. This applies to cities or centres in a particular country, or in other countries. The latter will involve different currencies and the problem of exchange rates. One solution is to establish a 'locality index' for major cities that uses the principle of purchasing power parity (PPP). For example, by pricing a representative basket of construction-related items covering labour, material and plant, a standard basket price in each city (in local currency terms) can be computed and act as a locality index. Thereafter, the cost of a project can be divided by the cost of the representative basket to obtain the equivalent number of baskets required to pay for the construction. Although the unit of measure is ‘baskets’, not currency, the answer is an indicator of cost performance that has no locational boundaries. For example, if Project A in Hong Kong was 5 baskets/m^2 and Project B in New Delhi was 4 baskets/m^2, then the construction cost in Hong Kong would be 25% more than that in New Delhi.

In this research, the representative basket for a city is called a *citiBLOC* (BLOC = **b**asket of **l**ocally **o**btained **c**ommodities). The construction cost of a project, therefore, can be measured in citiBLOCs that will take account of location and are converted for time. The unit of cost performance employed in this study is baskets per square metre (citiBLOCs/m^2). This is an input measure describing resources. Costs should ideally exclude site works since it is not proportional to building area. A high value for this KPI would mean that the construction process was expensive (i.e. either high quality or inefficient), and vice versa.

Chau (1993) demonstrated that construction productivity could be measured from an analysis of only cost and price data and the relative value shares of inputs. These data are in general more readily available than the detailed information required by other methods, and therefore his proposed approach was less restrictive. A ratio of output to multiple inputs was used in his model, and all were expressed in monetary terms.

Quality Performance

Quality performance is referenced to the standard of the delivered project and that specified in the contract documents. The expectation is to receive what is specified, no more and no less, and often this is judged in the detail of the finishes and the workmanship applied. There is no convenient unit of measurement for quality, and it therefore involves a collection of issues, some of which are objective (e.g. number of identified defects) and others are subjective (e.g. craftsmanship).

Quality is influenced by a number of related factors, all of which would normally add cost and time to some extent as the level of quality increases. These include buildability, innovation, building height, extent of fit-out, environmental performance, compliance, standard of finish, supervision levels and efficiency.

While quality defies objective measurement, relative comparison is possible. Hotels, for example, are classified according to quality and assigned a star rating, so what to expect from a five-star hotel is well understood. Relative quality performance involves comparing like with like. Standards and expectations differ between residential, commercial and industrial applications, between urban and rural settings, between different countries and cultures, and between project stakeholders.

Hsieh and Forster (2006) found that the structural quality of residential construction in Taiwan falls, and falls measurably, as production reaches higher levels and skilled labour shortages arise. Also in Taiwan, Yang (2009) found that the quality of project deliverables is significantly associated with automation technology usage in the front-end, design, procurement and construction phases. Furthermore, using a case study methodology, Tchidi et al. (2012) found that prefabrication improved project quality and reduced construction waste.

Quality management has grown in prominence over the years. Lesley and Malcolm (1992) believed that quality was probably the best strategy to ensure customer loyalty, defend against foreign competition and secure continuous growth and profits in difficult market conditions. ISO-9000 (Quality Management) is the current international standard for assuring quality, and ISO-certification is a demonstrable way that construction contractors can communicate to customers that they have systems in place to deliver quality outcomes and grow in abilities through continuous process improvement (Ali and Rahmat 2010).

Rosenfeld (2009) investigated the cost of quality via case studies and concluded that the optimal range for investment in quality is between 2% and 4% of a construction company’s revenue per annum. Investing less than 2% in prevention and appraisal with definitely entail higher failure costs, whereas an investment of over 4% most probably will not pay itself back. He also found that quality failures bear substantial hidden costs that cannot be readily measured. Quality failure is the result of not doing things right the first time (Abdelsalam and Gad 2009).

An Integrated Time-Cost-Quality Performance Index

Langston and Best (2001) developed a performance index (PI) based on a ratio of output (production capacity) to input (resource consumption). Production capacity was measured as constructed floor area completed per month, computed as the gross floor area (m^2) divided by the time between commencement and handover (months). Resource consumption was measured as construction cost per square metre, computed as the number of representative baskets (e.g. citiBLOCs converted to a base year) divided by the gross floor area (m^2). They suggested that for projects of similar quality, the resultant index produced an indicator of construction efficiency, where the higher the index the more effective was the process of the project’s construction. Equation 1 describes the PI:

$$\begin{aligned}\text{Performance index (PI)} &= \frac{\text{production capacity}}{\text{resource consumption}} \qquad (1)\\ &= \frac{m^2/\text{month}}{\text{cost}/m^2}\\ &= \frac{a^2}{ct}\end{aligned}$$

where: a = *gross floor area in square metres*
c = *completed project cost (e.g. number of citiBLOC baskets)*
t = *time for completion in months*

While high PI scores identify projects with strong production capacity per unit of input (i.e. construction efficiency), low PI scores conversely identify projects with strong resource consumption per unit of output (i.e. construction quality). Both can be considered advantageous. The best projects are arguably the ones that display efficiency and quality, and hence are more likely to have scores around the mean.

The PI is a rare attempt to integrate both time and cost into a single performance indicator. But while it can separate projects according to their strengths, it does not clearly identify best practice. Adjustment of data to 'normalize' for either efficiency or quality/complexity is problematic. A different approach is needed.

Multiplying production capacity and resource consumption together computes a weighted measure of performance that does not disadvantage projects that are expensive on the basis of their quality and/or complexity. This alternative approach is shown by Equation 2:

$$\begin{aligned}\text{Construction efficiency (CE)} &= \text{production capacity} \times \text{resource consumption} \\ &= \text{m}^2/\text{month} \times \text{cost}/\text{m}^2 \\ &= \frac{c}{t}\end{aligned} \tag{2}$$

where: c = *completed project cost (e.g. number of citiBLOC baskets)*
t = *time for completion in months*

Given quality and/or complexity would be expected to affect time and cost in the same direction (i.e. higher levels of difficulty takes longer to build and cost more), a ratio of cost over time would see quality/complexity (and project scale for that matter) cancelled out between the numerator and the denominator. Project cost is treated, in this case, as an output measure despite being determined from the amount of money spent to construct the building (an input measure for PI). The time to construct is now the input measure in delivering the project. This approach is similar to that used by Chau (1993).

CE is a valuable indicator for judging the efficiency of a contractor, the efficiency of construction in a particular location, or the efficiency of the construction industry overall. As costs are expressed in citiBLOC terms, this analysis can be performed between projects constructed in any location, nationally or internationally. However, CE is affected by working hours/month and delays due to inclement weather, so comparing it to the mean efficiency of other projects of similar context and expressing the outcome as a ratio would be necessary to enable proper interpretation.

Chiang et al. (2012) investigated construction efficiency (they used the term productive efficiency) for contractors based in mainland China and Hong Kong. Their study reviewed single factor productivity, defined as relating to individual contractors and focused on average labour productivity (i.e. output per hour worked), and total factor productivity, defined as relating to the entire industry but hampered by the complexity of measurement methods and the lack of available data. They found that generally both mainland China and Hong Kong contractors improved their efficiency over the period 2004-2010, with Hong Kong firms doing better due to their managerial rather than technical competence.

CE can be separated from overall performance to determine construction complexity (CC), defined as a mix of a project's quality standard and its buildability. Equation 3 shows CC is related closely to project cost per square metre (cost/m^2) and therefore the amount of resources consumed in the construction process underpins the calculation:

$$\text{Construction complexity (CC)} = \frac{CE}{PI} = \frac{c}{t} \cdot \frac{ct}{a^2} = \frac{c^2}{a^2} \qquad (3)$$

where: c = *completed project cost (e.g. number of citiBLOC baskets)*
a = *gross floor area in square metres*

Understanding project performance and determining best practice, from a stakeholder's perspective, can then be determined by a study of the factors affecting CC. These were stated earlier as including, but not limited to, buildability, innovation, building height, extent of fit-out, environmental performance, compliance, standard of finish, supervision levels – but not efficiency as this is now assessed independently. As with CE, expressing the outcome as a ratio relative to the mean of a number of projects would aid interpretation.

Low (2001) compiled data from various sources to measure the relationship between buildability, structural quality and productivity in the Singaporean construction industry. Buildability was measured using the Building Design Appraisal System (BDAS) produced by Singapore's Building and Construction Authority (BCA), quality was measured by the Construction Quality Assessment System (CONQUAS) also produced by the BCA, and productivity was measured as floor area completed per man-day for a range of case studies reported in the literature. The latter, however, did not seem to take account of different skill levels and would have been difficult to collect without detailed records of working patterns and rosters. Nevertheless, he found a weak correlation between buildability and quality but a stronger correlation between buildability and productivity. This sounds intuitively correct. Yet the robustness of data particularly related to average labour productivity remains an area of concern (Chang 1991; Chan and Kaka 2007; Doloi 2007; Allan et al. 2010).

Best practice may lie where projects have balanced scores for both CE and CC. Multiplying CE and CC scores together (i.e. c^3/a^2t) can be useful to highlight such projects. However, high cost/m^2 can be a sign of high standard or poor execution. The technique of data envelopment analysis may be a more appropriate method to assess the impact of multiple performance measures and to determine the best practice 'frontier' (e.g. Chiang et al. 2012; Horta et al. 2012).

Method

Crawford and Vogl (2006) called for further research into construction performance to focus on creating new or improving existing datasets. Advancements in this area are hampered by data quality and availability. Information is often commercial-in-confidence and powerful to those who have access, so data sharing is limited. There is no existing database where all the relevant information can be found to undertake a robust analysis of construction performance. Nevertheless, the information exists in fragmented forms and requires considerable time to collect it into a single place and fill the numerous gaps. As stated by Wegelius-Lehtonen (2001:115) and undoubtedly many before him, *"if you want to improve something – measure it"*.

A case study method is employed here to demonstrate the application of performance measurement to construction and to make international comparisons. Buildings completed in the last 10 years (2003-2012) of 20 storeys or more in height are selected as the population for the study. These projects are sourced from the Skyscraper website[2]. All such projects in the five largest cities in both Australia and the United States are identified and assembled into a database. Information about these projects can be found in the public domain via the Internet, since tall buildings get publicity, but where key information is not discoverable it can be followed up through contact with the project architect or building contractor where possible. The database fields are shown in Table 1:

Table 1: Performance index database fields

Field	Comments
Building ID	Skyscraper database identifier
Project Name	
Detailed Address	
City	
Country	
Building Type	commercial, residential, hospital, hotel, mixed, other
Date Completed	year (2003-2012)
Storeys Above Ground	number of upper floors (minimum 20)
Storeys Below Ground	number of basement floors
Building Height	roof height above ground (metres)
Area	gross floor area (square metres)
Construction Cost	A$ or US$ (excluding design, land and site costs*)
Fitout	fully furnished or shell
Construction Time	commencement to handover (months)
Architect Name	
Contractor Name	
Special Factors	unusual features noted

**external works is not very significant for high-rise buildings and is not deducted from cost in this study*

A similar approach was undertaken by Kaming et al. (1998) using 31 high-rise projects of various types in Indonesia, and by Langston and Best (2001) using 76 high-rise projects across twelve countries. Data was based on case studies with participant interviews or questionnaires. Area, construction duration and cost were collected in both cases, although the Indonesian study did not involve the complexity of multiple currencies.

The cost of the representative citiBLOC basket is priced locally for each city (mid-year 2012). The citiBLOC basket contains ten common construction items plus an indicator of market conditions, as listed in Table 2. Items are about equal value and divided into material (50%), labour (40%) and plant (10%) reflecting typical composition. A citiBLOC can act as a building price index to convert historical costs to present day terms (actual price deflators[3] and market conditions are applied in this study as historical citiBLOCs are not available). Online data from Cordell (Australia) and RS Means (United States) are used to price the citiBLOC items consistently.

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[2] see *http://skyscraperpage.com*

[3] see *http://www.rba.gov.au/calculator/annualDecimal.html* and *http://www.usinflationcalculator.com/* for Australia and the United States respectively

Table 2: Representative construction items for citiBLOC (Sydney)

Item	**Standard Description**	**Unit**	**Quantity (weighting)**	**Local Currency (ex-tax)**
Material *(supply only including CBD delivery)*				
A	32 MPa ready-mixed concrete (1 m^3 = 35.31 cu. feet)	m^3	45	11,144
B	Steel in 250 x 25.7kg/m 'I' beam (17.3 lb/foot)	t	6.8	9,350
C	10mm clear tempered glass (1 m^2 = 10.76 sq. feet)	m^2	44	10,472
D	13mm thick gypsum plasterboard (½" thick)	m^2	1,300	10,140
E	100 x 50mm sawn softwood stud (1 m = 3.28 feet)	m	2,750	9,873
Labour *(charge-out rate including on-costs)*				
F	Electrician	hr	150	9,900
G	Carpenter	hr	185	10,915
H	Painter	hr	200	10,400
I	Unskilled labour	hr	275	10,863
Plant *(third party hire rate including operator and fuel)*				
J	50 t mobile crane	day	5	10,200
			average price per item (i.e. 1 citiBLOC):	**10,326**

SYDNEY, AUSTRALIA (2012)

Current Market Conditions: ☑ very competitive (low profit) ☐ normal ☐ overheated (high profit)

Figure 1 shows an example of the citiBLOC index (avoiding and embracing current market conditions) over the study period. The former is a cost index that essentially follows the rate of inflation or deflation, while the latter is a price index that additionally considers the competitiveness of the construction marketplace, and therefore takes account of wider economic factors impacting contractor profit margins (as evidenced in bids to win work). The citiBLOC cost index therefore requires some adjustment (maybe ± 10%) to reflect market prices. It is incorrect to compare citiBLOCs across countries or regions as they are expressed in different currencies.

Figure 1: Variation in mean citiBLOC costs and prices for Australia (2003-2012)

Case Study: Australia

A total of 150 projects were identified in the five largest cities in Australia, comprising 28 in Sydney, 40 in Melbourne, 63 in Brisbane including the nearby Gold Coast (GC), 18 in Perth and 1 in Adelaide. Complete information was discovered for 86 projects, representing 57% of the known population. To achieve this conversion rate, considerable effort was made to contact project stakeholders and obtain missing data. In this process, 29% of the dataset was confirmed and validated, including the single project in Adelaide.

Table 3 summarizes mean performance measures for selected Australian projects. Cities are listed in descending order of size. Each measure is expressed in relation to the national mean for better comprehension, highlighting under or over achievement, and provides a contextual frame to assess impacts such as the relative advantage of different contractors operating in various markets, local custom and climatic conditions. Note that real construction cost per square metre (expressed in 2012 prices) can be determined by multiplying the cost/m^2 column by the citiBLOC index column.

Table 3: Mean performance measures (selected Australian projects)

City	**Projects**	**citiBLOC Index**	**Mean**					**Efficiency Percent**
			m^2/month	**cost/m^2**	**PI**	**CE**	**CC**	
Sydney	15	10,326	1,541	0.46	4,403	694	0.27	+4.11%
Melbourne	26	9,754	2,034	0.30	7,926	587	0.10	-11.94%
Brisbane/GC	38	10,294	1,587	0.47	4,879	699	0.28	+4.86%
Perth	6	9,837	1,752	0.51	3,993	860	0.28	+29.01%
Adelaide	1	9,788	1,240	0.40	3,116	493	0.16	-26.04%
Australia	**Mean**	**10,120**	**1,631**	**0.43**	**4,863**	**667**	**0.22**	**0.00%**
	CoV	*2.83%*	*17.88%*	*19.08%*	*37.64%*	*20.63%*	*38.16%*	

The coefficient of variation (CoV) for the citiBLOC index is extremely low, indicating that prices around Australia are quite consistent. Low CoVs (i.e. less than 30%) are also evident for most performance measures. However, a higher dispersion around the mean occurs for PI and CC. In the case of PI and CC, this may be explained by the broad range of factors that are included in these ratios and which are not necessarily correlated with each other.

Perth displays the highest construction efficiency (29.01% above the national average). Sydney has the highest cost base while all cities other than Melbourne and Adelaide have robust construction complexity scores. Melbourne has the fastest production capacity and the highest performance index, and appears to be the cheapest location to build in, but is 11.94% below the national average in terms of construction efficiency and has the lowest construction complexity score. It may be appropriate to discount the outcomes for Perth and particularly Adelaide on the basis of the small number of projects included in their calculation. When focusing on construction efficiency solely along the eastern seaboard of Australia, therefore, it is evident that Sydney and Brisbane/GC are comfortably outperforming Melbourne. Nevertheless, Melbourne is clearly cost competitive.

Figure 2 shows the distribution of project types, with approximately half designated as residential use. Most projects have fit-out included in their construction cost. Mean citiBLOC cost/m^2 is shown in brackets.

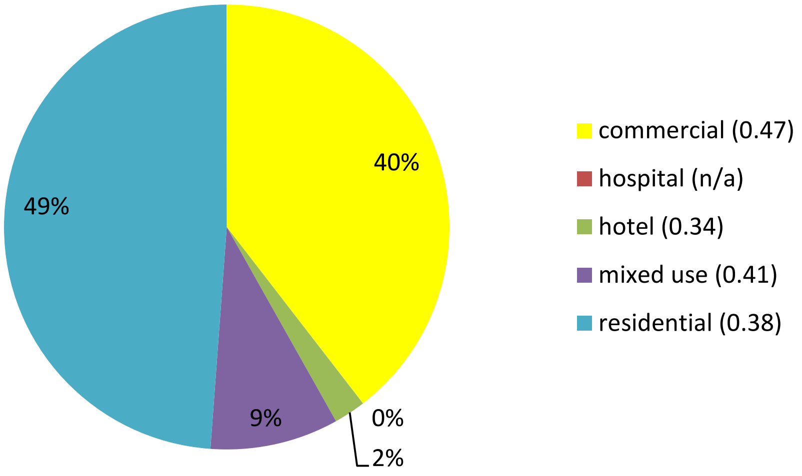

Figure 2: Project types (selected Australian projects)

Figure 3 displays values for construction efficiency compared with cost/m^2 over time, based on all 86 Australian projects according to their year of completion. A rise in cost/m^2 is evident, but a greater rise in efficiency means that 'real' construction efficiency has relatively grown between 2003 and 2012. The cost/m^2 reflects increase in building quality and/or building complexity, which is logical given rising living standards, although an alternative explanation perhaps is an inappropriate cost adjustment algorithm.

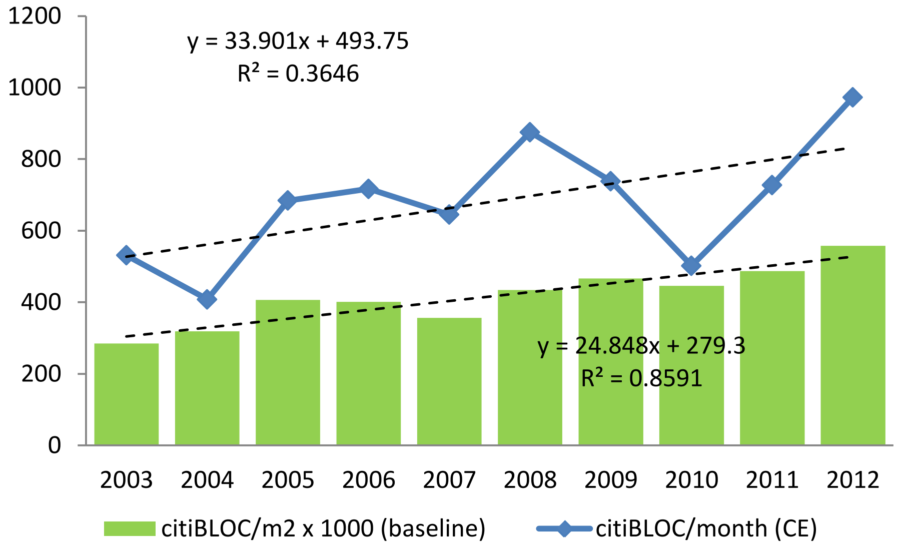

Figure 3: Construction efficiency over time (selected Australian projects)

Chiang et al. (2012) found that construction efficiency increased in both mainland China and Hong Kong over the period 2004-2010, despite the backdrop of a general lack of consensus that the productivity of the construction industry (globally) was improving. The results of this research support the findings of Chiang et al. (2012) by providing some evidence that construction efficiency has improved in Australia over the same period. Using linear regression to determine the trend, the growth in CE over the past decade is +6.87% per annum (i.e. 33.901 / 493.75 x 100). Allowing for the knowledge that base costs have grown in real terms by +5.03% per annum (i.e. 24.848 / 493.75 x 100), real construction efficiency is computed at +1.84% per annum.

Case Study: United States

A total of 354 projects were identified in the five largest cities in the United States, comprising 194 in New York, 11 in Los Angeles, 113 in Chicago, 25 in Houston and 11 in Philadelphia. Complete information was discovered for 251 projects, representing 71% of the known population. None of the projects have been independently validated. Table 4 summarizes mean performance measures for selected American projects. Cities are again listed in descending order of size.

Table 4: Mean performance measures (selected American projects)

City	Projects	citiBLOC Index	Mean m^2/month	Mean cost/m^2	Mean PI	Mean CE	Mean CC	Efficiency Percent
New York	140	10,693	1,287	0.57	2,963	680	0.40	-9.60%
Los Angeles	8	8,559	2,090	0.44	6,229	826	0.24	+9.81%
Chicago	71	9,026	2,300	0.30	9,275	672	0.11	-10.66%
Houston	21	7,005	2,549	0.41	8,137	1,002	0.20	+33.21%
Philadelphia	11	9,638	1,771	0.34	6,434	581	0.16	-22.76%
United States	**Mean**	**8,984**	**1,999**	**0.41**	**6,608**	**752**	**0.22**	**0.00%**
	CoV	*15.19%*	*24.51%*	*25.31%*	*36.22%*	*21.93%*	*49.79%*	

The first point to note is that the citiBLOC basket contains a good deal of variability (i.e. the price of the standard construction basket in New York is over 50% more than in Houston), underlining the importance of a city-based locality index rather than a national average. Each calculated mean has a low CoV and hence low dispersion around the mean, except for PI and CC. The large number of projects located in New York and Chicago add confidence to their results since any individual project can exert little influence on the overall mean. It is interesting, therefore, that Chicago has a performance index over three times that of New York despite displaying equivalent levels of efficiency.

Houston demonstrates that its projects are more efficient (i.e. 33.21% above the national average). Houston has both a low cost base and a high output capacity that leads to the second highest performance index of the group. The strength of its performance appears more a function of construction efficiency than construction complexity, although the latter is respectable.

New York attracts a premium on cost and has the slowest output rate in the study, handing it the lowest performance index by a considerable margin. Overall, it appears that complexity is high while efficiency is relatively low (9.60% below the national average). Chicago, on the other hand, has low cost projects, despite not being a cheap place to build, and both efficiency and complexity are low. Philadelphia demonstrates the lowest construction efficiency at 22.76% below the national average.

Figure 4 shows the distribution of project types, with a dominant 68% in this case designated as primarily residential use. Mean citiBLOC cost/m^2 is shown in brackets.

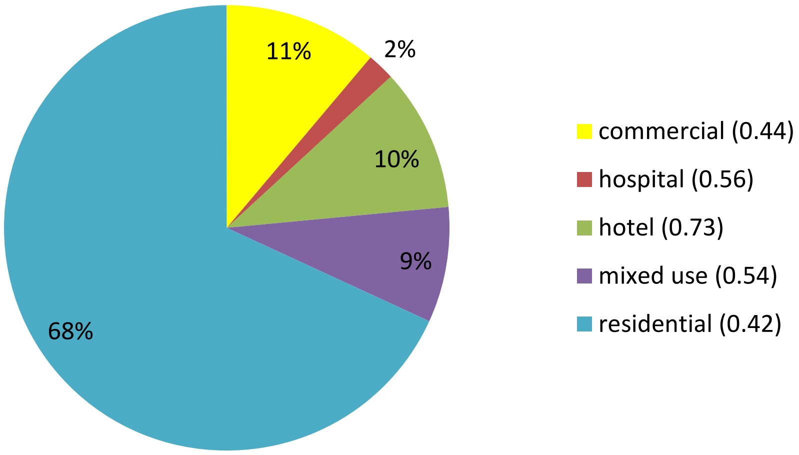

Figure 4: Project types (selected American projects)

The rate of increase over the past decade is +6.14% per annum (i.e. 33.236 / 541.23 x 100). Allowing for the growth in base costs of +3.20% per annum (i.e. 17.344 / 541.23 x 100), real construction efficiency is computed at +2.94% per annum. This is illustrated in Figure 5 using the dataset of 251 projects assembled according to their year of completion. The key findings of Chiang et al. (2012) are once again reflected in the United States.

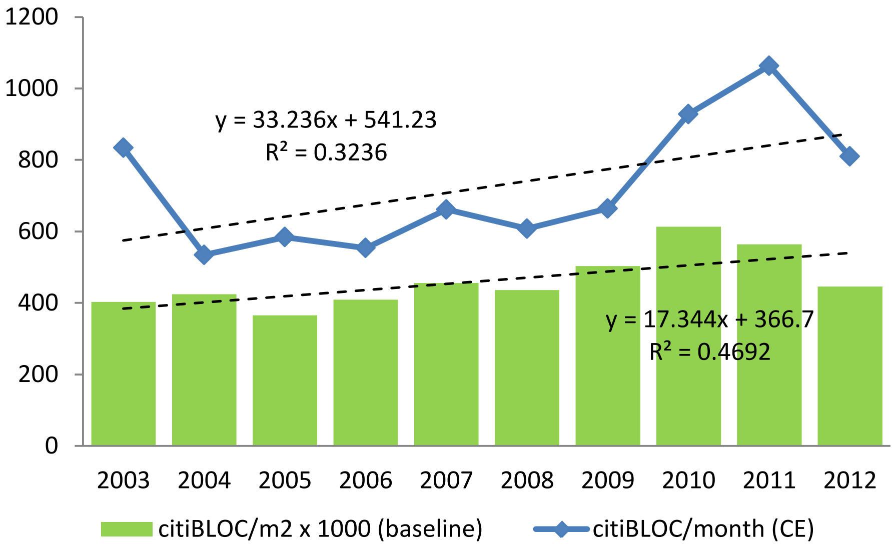

Figure 5: Construction efficiency over time (selected American projects)

Discussion

This data forms the basis for a useful comparison between Australian and American construction performance. Project cost data can be readily combined across cities and countries through the adoption of citiBLOC as an international locality index. In this research, 337 projects are included in the analysis (67% or two-thirds of the projects that meet the set criterion of high-rise buildings completed between 2003 and 2012).

The citiBLOC data is effectively a construction-based PPP index. The standard basket is priced in local currency (i.e. AUD or USD) each year for each location. It enables costs to be compared between locations, including across national borders, without reference to a currency exchange rate. The notion of a city-based international locality index was applied in Langston and Best (2001; 2005) where they used the price of a Big Mac hamburger, sourced from *The Economist's Big Mac Index*, as a PPP index to adjust construction cost data. Interestingly, today the average price of a Big Mac in Australia is AUD \$4.80 and in the United States is USD \$4.20, while the mean citiBLOC index in Australia is AUD \$10,000 and in United States is USD \$8,984 – the ratio is nearly identical. But the Big Mac method did not work well in a number of developing countries where McDonald's hamburgers were more of a western luxury item. The citiBLOC basket is more likely to be representative of global construction prices and is reasonably easy to calculate once per year.

Currency exchange rates rise and fall over time for a range of reasons, many of which have nothing at all to do with purchasing power. It is likely that the relative price of a citiBLOC in Australia and the United States has not changed much this century. The currency exchange rate, however, did change dramatically from 1 AUD = 0.5 USD in 2001 to 1 AUD = 1.08 USD in 2012, so conclusions about performance in the past based on exchange rates are quite misleading if quoted today. This is part of the problem when reviewing earlier research.

BCA (2012) compared the performance of large infrastructure projects in Australia and the United States and concluded that the former was uncompetitive. Included in their report were data on cost/m^2 for airports, schools, shopping malls and hospitals in both countries obtained from a well-known published cost guide. Apart from the obvious problems of using currency exchange rates and arguably not comparing 'like with like', as pointed out by Best (2012), they selected the US Gulf states as the comparative context to Australia. It can be seen from Table 6.4 earlier that Houston (Texas) has a much lower citiBLOC index than other US cities. If construction data had instead been used from New York, for instance, then their conclusions would have been quite different. Using an appropriate 'exchange rate' for international cost comparisons is critical. National averages in countries like United States are useful but location-specific indices are more accurate for benchmarking. Yet assessing comparative performance is still not straightforward.

Take the example of Melbourne and New York. Melbourne is Australia's cheapest location to build with a citiBLOC index of 9,754 and New York is United States' most expensive location to build with a citiBLOC index of 10,693. Melbourne builds fast (2,034 m^2/month) and New York builds slow (1,287 m^2/month). Projects in Melbourne have a lower unit cost and construction complexity index (0.30 citiBLOCs/m^2 and 0.10) than New York (0.57 citiBLOCs/m^2 and 0.40). There is not a massive difference in construction efficiency (587 v 680 respectively), and both are below the national average. So which city demonstrates the higher performance?

PI might be considered to be the best ratio to use. But it favours locations where speed of construction is high and cost and complexity are low. Melbourne projects show such attributes (PI = 7,926). New York projects have the opposite attributes (PI = 2,963). CE gives a more balanced comparison. Despite variations in the complexity index, the ratio of cost over time is less sensitive. Based on the projects studied, New York is slightly ahead of Melbourne when assessing overall industry efficiency, and on a par with both Sydney and Brisbane/GC.

CE provides a mechanism to compare the performance of both Australian and American construction industries based on microeconomic (i.e. project-level) data. It is concluded that, based on data from the largest five cities in each country, efficiency on site is improving in both countries. The growth in baseline cost/m^2 suggests a possible rise in project complexity over time. While the trend in efficiency improvement is similar, there is evidence that base costs in Australia have outstripped the United States, meaning that 'real' construction efficiency in Australia is relatively less. If Australia held an advantage in the past, then it seems that advantage might be disappearing. The United States is outperforming Australia in terms of construction efficiency by 1.10% per annum.

Differences in quality, such as fit-out or shell, are effectively eliminated assuming cost and time vary in proportion to each other. This is probably an over-simplification, particularly as different building types are being mixed together. Nevertheless, high-rise construction is common to all projects in this study, and is arguably a more dominant attribute than functional purpose. Figure 6 shows the correlation between cost and building height across the entire dataset. The higher the building, as you would expect, the higher is the cost to construct it, but the moderate value of R^2 only explains 33% of the relationship between the variables.

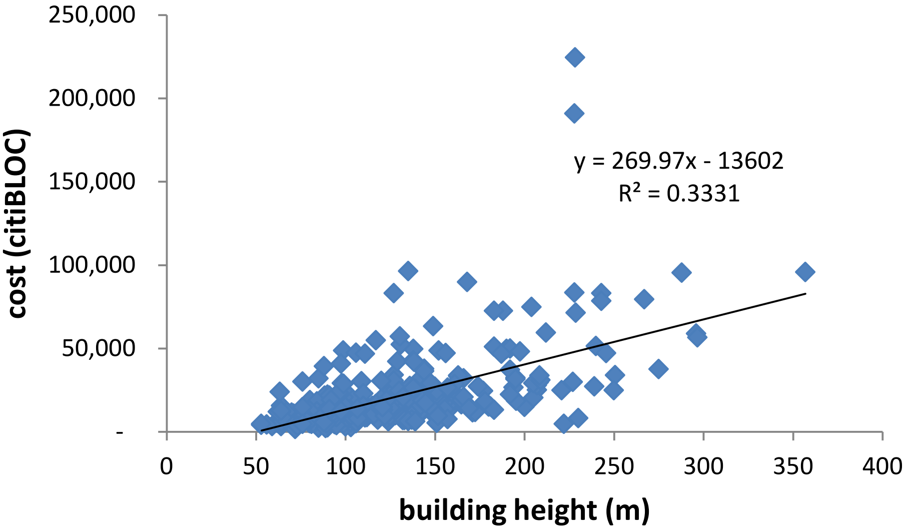

Figure 6: Comparison of building height and cost (all projects)

From the assembled database, the relationship between key variables like cost, time and quality can be explored in detail. The large number of projects reduce the influence of outliers, such as the two projects in Figure 6, however outliers are of great interest as they may represent examples of best (or worst) practice.

Figure 7 shows the relationship between area and cost. A robust value for R^2 suggests that gross floor area is a better predictor of construction cost than building height, explaining over 50% of the relationship between the variables.

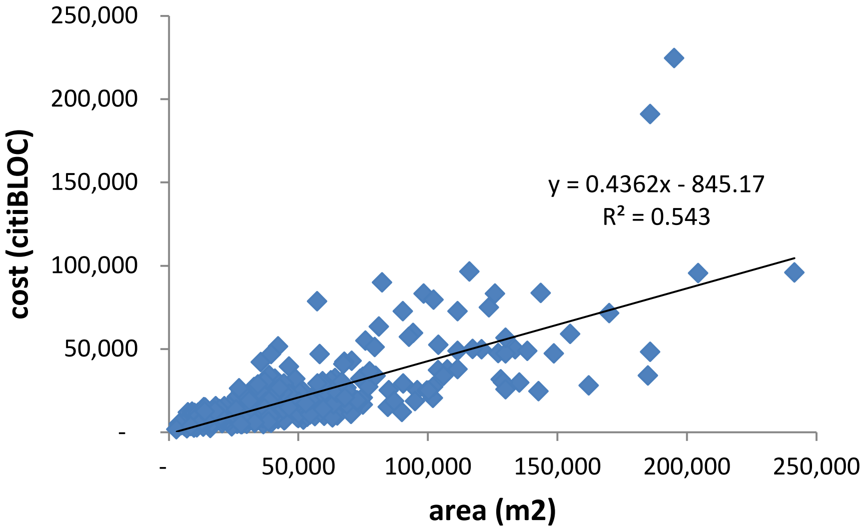

Figure 7: Comparison of area and cost (all projects)

Figure 8 compares floor area with time to construct, while Figure 9 compares cost with time to construct. In both cases a similar result is found to Figure 6.6. Furthermore, time and building height (not shown) also share a modest R^2 of about 33%. It is concluded that while area is a reasonable predictor of cost, neither cost, area nor building height act individually as a reliable predictor of time to construct for this building type. Previous research by Bromilow (1969) and Love et al. (2005) may not apply reliably or consistently for modern high-rise construction.

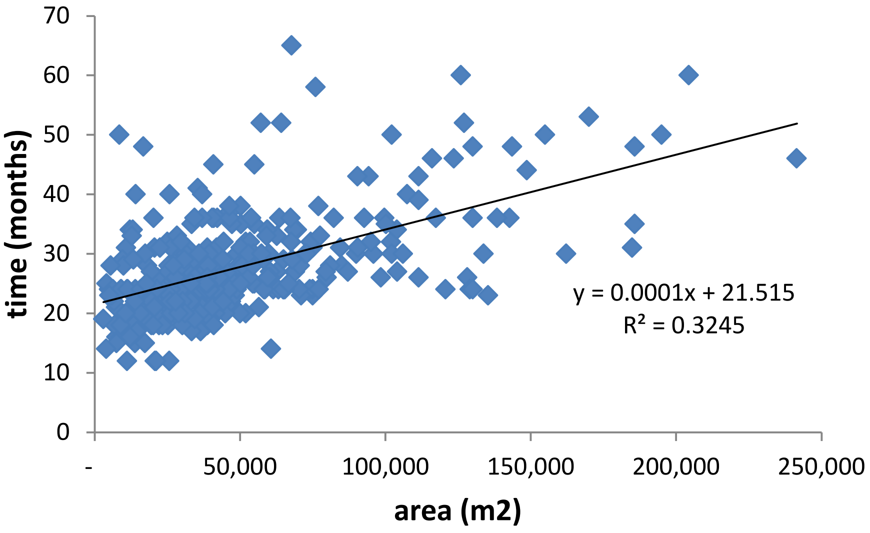

Figure 8: Comparison of area and time (all projects)

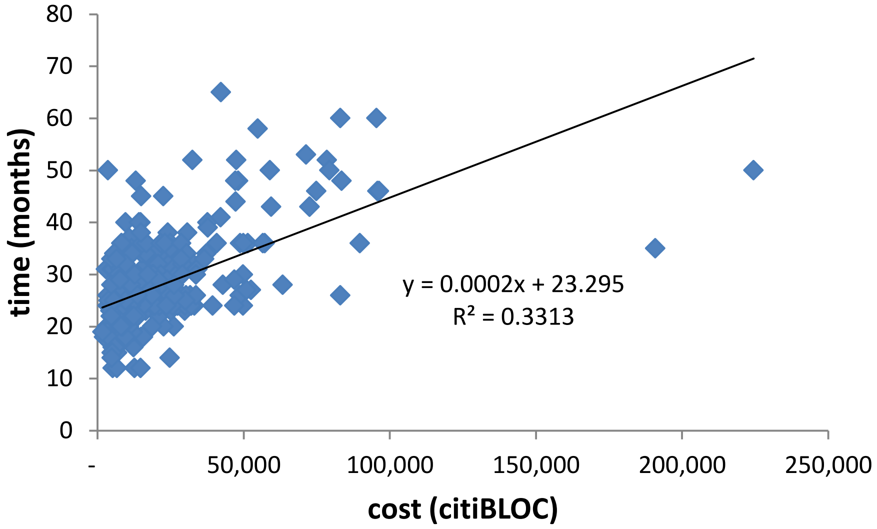

Figure 9: Comparison of cost and time (all projects)

Figure 10 investigates whether complexity is a dominant predictor for time. Clearly CC on its own offers no tangible explanation for the relationship to time. It would appear, therefore, that complexity is being reflected instead by cost in the context of high-rise building construction. Cost and complexity, on the other hand, have intrinsic multicollinearity problems since CC is defined as the ratio of cost^2 over area^2.

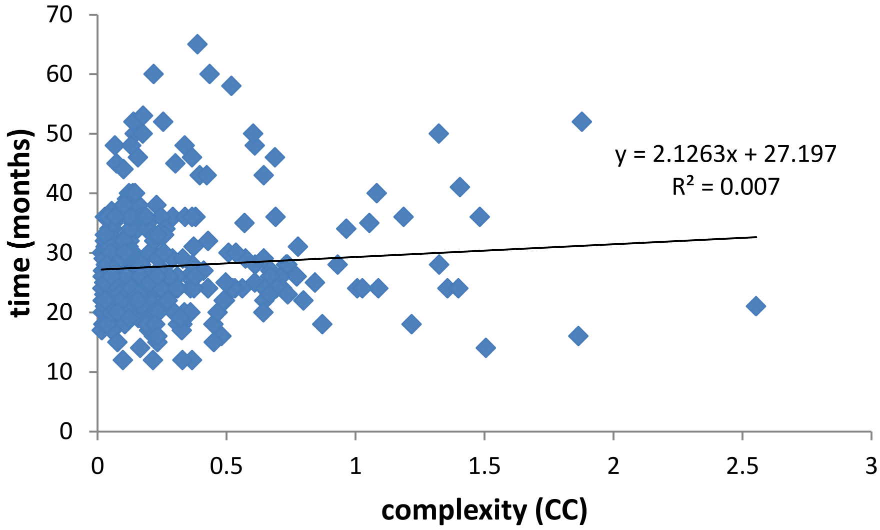

Figure 10: Comparison of complexity and time (all projects)

Comparing m^2/month output between Australia and the United States, however, should consider the different industrial landscapes. Notionally American construction workers have a 40-hour week while Australian construction workers have a 38-hour week with 1 day in 20 being decreed a 'paid' rostered day off. Therefore, taking the 40-hour week as a base, adjusted Australian PI and CE scores could be as much as 5% higher than currently shown. This has no effect on their rate of change over time.

Notwithstanding the above, the top 10 projects in Australia and the United States based on construction efficiency are provided in Table 5. Projects that have a PI less than the national mean, however, are excluded from the list (i.e. projects may be unusually complex). The efficiency percent column is therefore computed with respect to mean CE in each country from those projects remaining in the list.

Table 5: Top 10 projects in each country (based on construction efficiency)

City	Project Type	Height (m)	Project Performance					Efficiency Percent
			m^2/month	cost/m^2	PI	CE	CC	
Melbourne	commercial	163	3,125	0.44	7,071	1,381	0.20	136.88%
Sydney	commercial	166	3,083	0.43	7,131	1,333	0.19	128.64%
Melbourne	residential	296	3,100	0.38	8,151	1,179	0.14	102.23%
Brisbane/GC	hotel	194	2,544	0.39	6,558	987	0.15	69.30%
Brisbane/GC	residential	275	2,688	0.35	7,685	940	0.12	61.23%
Brisbane/GC	residential	207	3,036	0.30	10,266	898	0.09	54.03%
Sydney	residential	151	2,556	0.35	7,291	896	0.12	53.69%
Melbourne	residential	128	3,200	0.26	12,232	837	0.07	43.57%
Perth	commercial	127	2,026	0.40	5,074	809	0.16	38.77%
Brisbane/GC	residential	138	2,200	0.33	6,640	729	0.11	25.04%
Australia (583^)		**Mean**	**2,756**	**0.36**	**7,810**	**999**	**0.14**	**71.34%**
		CoV	*15.15%*	*19.23%*	*26.11%*	*22.37%*	*30.69%*	
Chicago	hotel	357	5,251	0.40	13,251	2,081	0.16	160.06%
Chicago	commercial	138	5,032	0.41	12,220	2,072	0.17	159.00%
Houston	commercial	131	3,857	0.50	7,657	1,943	0.25	142.85%
Houston	hotel	99	4,288	0.44	9,826	1,871	0.19	133.86%
New York	commercial	99	4,333	0.41	10,648	1,764	0.17	120.40%
Chicago	commercial	190	4,459	0.37	11,998	1,657	0.14	107.15%
New York	commercial	288	3,406	0.47	7,299	1,590	0.22	98.70%
Philadelphia	commercial	297	3,613	0.44	8,304	1,572	0.19	96.46%
Houston	commercial	192	3,260	0.42	7,676	1,385	0.18	73.06%
Houston	hospital	152	3,846	0.35	10,914	1,355	0.12	69.35%
United States (800^)		**Mean**	**4,135**	**0.42**	**9,979**	**1,729**	**0.18**	**116.09%**
		CoV	*16.02%*	*10.53%*	*21.61%*	*15.14%*	*21.08%*	

^ mean CE for eligible projects

In regard to the Australian projects, the 'shortlist' has 60% residential buildings, with a majority of projects in Brisbane/GC. Clearly Melbourne can deliver efficient projects. While the mean values across the top 10 are generally higher than the national mean, notably cost/m^2 and CC are lower. The low CoVs suggest that the data variability is not very significant. The efficiency percent column indicates that, on average, these projects are 71.34% more efficient than others in the sample.

In regard to the American projects, Houston has the highest number of projects, and overall the most efficient appear to be commercial buildings (70%), with no residential or mixed-use projects appearing in the shortlist at all. The mean values across the top 10 are all higher than the national mean, except for CC that is slightly lower. The very low CoVs suggest that the data is homogenous. The efficiency percent column indicates that, on average, these projects are 116.09% more efficient than others in the sample, and generally higher than the efficiency of the top Australian project. It is worthy to note that the mean CE for eligible projects is about 37% higher for American projects (i.e. 800) than Australian projects (i.e. 583), or less if the working hour per week adjustment is included. So regardless of the rate of change in CE per annum, this fact adds weight to the suggestion that construction efficiency is comparatively lower in Australia, and is not just a function of the shorter working week.

One large and well-known contractor is responsible for building 22 out of the 86 projects in the Australian sample. The data for all of these projects was independently validated. Four of their projects are among the top 10 Australian projects for construction efficiency, and 8 sit above the national average. The mean and CoV (shown in brackets) across this sample for m^2/month, cost/m^2, PI, CE and CC are 1,944 (32.09%), 0.29 (41.34%), 7,459 (43.54%), 592 (63.46%) and 0.10 (84.70%) respectively. The CoV is larger than the values in the full dataset in all cases, which is surprising. More than half of the projects are located in Melbourne. Maybe as a consequence of this fact their average speed of construction was above the national average and their construction efficiency was below. Their most efficient project can be found in Perth, although it wasn't counted in the top 10 shortlist as its PI was just less than the national average. This analysis demonstrates that contractors can be compared in the same way as projects, cities and nations.

The reasons why the projects in Table 5 are more efficient are yet to be determined. It may be that poor performance is caused by factors beyond the control of the contractor yet unfairly levelled at their doorstep. Detailed case studies are planned to both validate the base data and to explore the characteristics of the procurement process in each top 10 project with the view to identifying those characteristics that drive success. As a result of this next stage of the research, data errors may be discovered and the shortlist may require amendment. The identity of these projects therefore remains confidential until all data are verified.

Conclusion

The main conclusion to be drawn from this research is that the efficiency of the Australian and US construction industries has increased at a similar rate over the past decade, although baseline costs have risen faster in Australia. Real construction efficiency, therefore, may be rising at about 1% per annum faster in the United States, and evidence exists to suggest that its top projects outperform anything found in Australia. But the key question that remains unanswered is why? Understanding the factors that drive efficiency in each country will hopefully shed light on what improvements are possible. These factors may be technical, political or contextual. A detailed examination of the top 10 projects in each country is the next step in this research agenda.

This research advances the notion that construction efficiency at a project level can be aggregated to determine construction efficiency of a contractor, a city or a nation. CE is computed as cost over time and intuitively assumes that complexity (quality and buildability) largely cancels out as both cost and time increase as complexity rises. Some evidence of this effect can be seen in the comparison between New York and Melbourne. However, the data for CC shows no correlation with time to construct. Why this should be so for high-rise construction remains a matter requiring further investigation.

A limitation of this study is that much of the key data concerning project cost, floor area and time to construct is yet to be validated. The enormity of the task means that only a small sample of projects in each country can be scrutinised. The projects listed in Table 5 will be explored in depth. Cost data will be refined to ensure that design fees, site works, demolition and fit-out costs are excluded, and that the construction cost is reflective of the final reconciliation for the project after all variations. Area data will be consistently measured from a standard definition including proper allowance for unenclosed covered floor area like balconies. Time to construct will be calculated from commencement on site to handover, with deductions for closed sites due to bankruptcy as happened during the recent global financial crisis, but still including time lost due to industrial disputation, accident investigation and bad weather. Decisions to work longer hours per week via overtime payments may increase production output (m^2/month) but will also increase resource input (cost/m^2), so PI is not likely to change significantly. However, excessive use of overtime will improve CE scores and may be one reason for differences in perceived efficiency between projects.

It might be tempting for some to conclude that construction efficiency in Australia is actually higher than the United States on the basis of performance in a particular year, such as 2012. The volatility of the time series, to some extent dictated by the number of projects completed in a given year, suggests that a long-term perspective should be taken and hence why it is appropriate to employ linear regression to compute the trend in real construction efficiency over a ten-year period.

The relationships between cost, time and building height indicate each is correlated to the other, explaining about one-third of the relationship in each case. Floor area is by far the most robust predictor of cost and time, while complexity and time have no observed correlation. The CoV of citiBLOC cost/m^2 values between each building type, computed at about 50% in both countries, is offset by the 337 data points that provide a more robust correlation test.

Finally, this research demonstrates the application of citiBLOC as a construction-relevant PPP index. At a national level, with Australia set at a base of 1, the United States is 0.8984. But more importantly, citiBLOC provides different indices for different cities, enabling locational variations in construction materials, labour and plant to be properly considered. The method for computing international locality indices represents a major advance in future construction performance studies, and is relatively easy and practical to compile on an annual basis.

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