A Comparison of Construction Cost and Technology Choice

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Abstract

Building economists have produced construction cost indices to allow for a comparison of building construction costs for a wide range of locations. These are updated regularly to enable building owners, contractors and investors to estimate the cost of an equivalent building on a per square metre basis. This method of computing construction costs, either in local currency, or adjusted using a purchasing power parity approach provides a reasonably accurate description of the cost relativities between countries. This focus on per square metre building costs disregards the differences in construction methods or technologies employed to construct buildings. Thus, they do not provide a complete insight into the reasons for the differences in construction costs observed across countries and localities. The aim of an ongoing research project is therefore to develop a construction cost index to compare the various methods of concrete construction that are available to produce the same build-up floor area. Differences in local practices, availability of local resources (materials, labour and capital), domestic building materials industries, and local regulations all combine to influence the construction cost of a building. An illustrative example of this framework is reflected in labour and plant constants for three concrete structural systems in Australia, UK, Malaysia and the US. The findings indicate that it is now possible to utilise simple ratios of material costs to labour rates to justify the choice of concrete construction technologies. These derived cost indices should be able to provide a rational method for selecting appropriate building technologies to suit the circumstances of the construction sector in different economies. This is important as countries continue to seek new ways of making construction products affordable as well as to stimulate the development of domestic construction industry.

Keywords: construction cost, construction technology, building economics

1. Introduction

Construction technology involves the choice of materials and the 'means and techniques' used in construction. Total building cost will be significantly influenced by the choice of technology and vice versa. For example, local and abundant construction materials can reduce transportation costs and limits price inflation as compared to foreign sourced materials. Also, when a technology is easily adopted by the building industry locally involvement of expensive external skilled manpower or contractors is eliminated. Similarly, local technologies and materials that are durable and inexpensive to maintain reduce the maintenance and life cycle cost of buildings. However, it is also possible that investments in new technologies may reduce the costs of construction in the long run when the technology becomes widely accepted locally. For example, though unknown for many years prefabricated building has become the least expensive and widely used technique in the public housing sector of many developing countries while in other countries in-situ construction remains the cheapest and most widely used (Warszawski, 1999). Policy makers need to continue to evaluate contextual conditions and formulate policies to advance the local industry in the most appropriate directions with regards to construction technologies. A careful choice of technology will have both economical and social impacts. Thus construction technology used must be constantly reviewed and, when necessary, redirected by appropriate policies to encourage more suitable options. Generally, the choice of construction technology may be influenced by many factors but total cost is the most rational criteria for evaluating alternatives. Other factors include design, availability of construction materials, exposure to hazards and risks, speed, climate, indoor comfort and energy efficiency, social cultural acceptance and appropriateness, environmental impact (demolition, recycling etc), availability of local skills and opportunities for participation of livelihoods. It may be argued that these other factors will ultimately translate into cost in one form or the other.

Building economists have produced construction cost indices to allow for a comparison of building construction costs for a wide range of locations, usually at major urban areas in developed and developing countries. These indices are updated regularly to enable building owners, contractors and investors to estimate the cost of an equivalent building on a per square meter basis. This method of computing construction costs, either in local currency (Davis Langdon, 2010), or adjusted using a purchasing power parity approach provides a reasonably accurate description of the cost relativities between countries (McCarthy, 2011). Existing indices often do not link cost with other important local conditions such as dominant technology used locally. In effect, the focus on per square meter building costs ignores the different construction methods or technologies employed to construct buildings. Thus, the use of these indices does not provide a complete insight into the reasons for the differences in construction costs observed across countries and localities. Cost advisors are not able to produce estimates that account for differences in construction practices especially construction technology which can vary significantly between countries. Also, existing international cost indices account for location conditions in a broad manner. At the project level, estimates produced using such an approach can lead to inaccurate estimates and the potential for cost overruns when projects are completed (Stapel, 2002). At the industry level, this estimating approach does not allow for economic evaluation of alternative construction techniques and may limit industry development with regards to construction technologies. While many previous studies (Davis Langdon 2010, Stapel 2002, Walsh

and Sawhney 2004) have made cost comparisons between countries, relatively little or no study has linked total cost comparison to choice of construction technology and industry specific conditions. When locations indices are constructed and used to estimate the total cost of projects, it may be argued that the choice of technology is indirectly accounted for. However, the problem is: existing location indices are often constructed and are specified without any indication of what construction technology is referred to for each location represented by the indices.

Stakeholders in multinational projects (e.g., contractors, investors, international organizations, financiers, designers) need to understand the total cost of projects at the feasibility stage and prior to bidding and construction. They require sufficient information that can help them choose different construction technologies when planning projects in different environments. Knowledge of differences in costs between locations accounted for by differences in technology can help stakeholders choose the right technologies/techniques that give highest benefit in terms of value derived from projects. On top of that, the choice and investment in appropriate technology can facilitate and advance the development of the local industry.

The aim of this project is therefore to develop a series of construction cost indices which are linked to the various methods of construction that are available to produce that same square meter of building space. The differences in local practices, availability of local resources (raw materials, land, labour, capital and technology), domestic building materials industries, and local regulations all combine to influence the construction cost of a building. These indices will be derived from a compilation of the costs of building material, construction costs for various building elements, labour costs, capital costs together with the choice of construction method and technology employed. The findings will inform on many current research and policy initiatives: to manage the exploitation of indigenous resources, to develop domestic building materials industries, to improve construction methods, modernise and upgrade the construction sector in different countries. It will make it possible for countries to learn from each other in terms of choice of construction technology and how they impact economics of building, local economy and the growth of the local industry. The findings should also provide a rational method for selecting an appropriate building technology to suit the condition of the construction industry in different countries. This is important as countries continue to seek for ways of making construction products affordable as well as seek to encourage the development of domestic construction industry.

2. Background and Literature Review

Sultan and Kajewski (2006) indicated that in some developing countries, the construction industry is very dependent on the importation of construction components and materials combined with issues of high unemployment leading to high construction costs from imported materials, inflation and an unstable economy. Thus policies put forward by various countries to improve the economic performance of their respective construction industries need to be informed by a precise economic model that illustrates the link between the cost of inputs to the construction industry to the price of its outputs and its follow-on benefits to the national economy.

Recent work by construction economists (Stapel 2002, Walsh and Sawhney 2004, Best et.al 2010, McCarthy 2011) are focused mainly on gathering data on construction costs in major cities around the globe and conducting research to explain observed differences in these indices based on the type of building; whether the building is to be used as a hotel, premium office tower, or an industrial or manufacturing facility. The demand for these indices are driven mainly by investors from developed countries looking to invest in major growth areas, or by manufacturers seeking to relocate their operations to less expensive locations. On the other hand, local construction activities are organised by managers sourcing building materials locally, employing local or migrant labour, and selecting a method of construction that reflects the ability of the local industry aim to achieve a lowest cost solution.

This project therefore seeks to bring these two areas of research – construction cost economics and construction technology, to mutually inform on the technology choices available to the designers and builders, based on a succinct understanding of the fundamental cost factors in each location. If industrialists spend a hundred dollars to manufacture a product within its borders, the capital that is used to pay for materials, labour and other costs moves through the economy as each recipient spends it thereby generating further economic activities. Due to this multiplier effect, a hundred dollars worth of primary production can add several hundred dollars to the Gross National Product of that country. This is the reason an industrialised product-exporting/commodity-importing country is wealthy and an undeveloped product-importing/commodity-exporting country is poor. Although this economic theory is well known, it has not been considered seriously in many economic development models for the construction industry. Many developing countries seek to import expensive construction technologies or use high-tech products in their local construction sectors to improve productivity or quality of their products. Ganesan (2000) suggested that construction methods that provide greater employment be adopted in Sri Lanka to cater for the under-employment of the labour force.

Moavenzadeh (1978) found that designs by expatriate professionals are often poorly suited to locally available labour, materials, equipment and construction methods. Developing nations thus tend to rely rather heavily on aid from developed countries in the professional sector of the industry. In the developed countries, increase in the cost of labour relative to other inputs have led contractors to search for labour substitutes, perhaps through the use of more productive equipment or a more capital-intensive method of construction which reduces on-site labour requirements. It is very likely that the techniques currently being developed in the industrialised countries may not be especially suitable for use in developing countries due to their incompatibility with local conditions. Some older techniques relying less on capital-intensive methods and more on labour, particularly unskilled and semi-skilled labour, might be more appropriate.

3. Methodology

This project explores the use of basic construction material, labour and capital cost indices to develop a framework for evaluating the structure of the construction industry. A systematic approach based on the structure of construction inputs and outputs is proposed and applied to evaluate the industry-wide impact of changes in inputs on the performance of the industry. The framework is used to map the

technology choices to various combinations of input cost indices in a number of developed and developing countries. The approach is to examine a number of countries with the availability of indigenous raw materials, high and low labour costs, and to show the price developments of production factors used in their respective construction industries.

3.1 Compilation of Basic Prices

Construction cost data from Australia, United Kingdom, Malaysia and the United States were obtained from their respective cost information or cost data services (Rawlinsons 2010, BCIS 2012, RSMeans 2012), or directly from a builder when no published data was available. In this pilot study, the investigation was limited to three concrete construction methods (conventional cast-in-place reinforced concrete, precast concrete, and pre-stressed concrete) and includes 4 countries (Australia, UK, Malaysia and US) to validate the research approach before proceeding to a more comprehensive examination of a wider range of structural systems and international coverage. Selecting a mix of developed and developing countries will allow a comparative analysis of the differences among and between the two groups of countries in terms of technology choice and its relationship with regards to construction costs. Due to difficulties in obtaining representative data from developing economies, the comparison is currently limited to one developing country.

3.2 Case studies of concrete systems

Three case studies were identified to represent the conventional cast-in-place reinforced concrete, precast concrete and prestressed concrete systems, respectively, in Melbourne, Australia. The cast-in-place system was utilised in a double storey (and a single basement) 2,405 square metre retail and office development at Balwyn. Only the ground and first floor concrete structures were considered for this building. The precast concrete case study was a double storey residential apartment at St.Kilda, previously reported by Yong (2010) providing a built-up area of 1,154 square metres. The pre-stressed concrete project was a single post-tensioned concrete slab in the upper level of 1,122 square metres for an office/industrial building at Noble Park.

Two separate analyses were conducted. The first analysis was to determine contractor's or builder's costs for one cast-in-place reinforced concrete building based on cost data in Australia, UK, Malaysia and US. This will allow a comparison of the various material costs, labour and plant constants, and the final structural system costs. The significance of the derived ratios described in section 3.1 will be discussed. The second analysis consists of a comparison of the three different systems in Australia and two systems in Malaysia.

4. Basic Prices and Derived Ratios

A selection of basic prices for these four countries is shown in Table 1 below in the respective local currencies. If these basic prices are compared based on currency exchange rates, it can be observed

that labour rates and concrete costs are dependent on domestic factors whereas internationally traded commodities such as steel reinforcements and structural sections are linked to global prices. Labour rates in developed economies tend to be significantly higher than those in developing countries. Malaysia has routinely engaged a large number of construction workers from Indonesia and Bangladesh to support the local construction industry as the local labour force was reluctant to work in the industry (Abubakar, 2002). When these basic prices are presented as a ratio(e.g. one cubic metre of concrete/one day skilled worker wages), it is apparent that one cubic metre of concrete is worth 2.11 days wages in a low wage developing country as compared to 0.32 days wages in a high labour cost country such as Australia. The comparatively lower labour cost in Malaysia should motivate builders to adopt more labour intensive processes and to economise on concrete materials in their construction. The higher wage costs in a developed economy will evidently motivate builders to reduce their dependence on labour by adopting standard concrete element sizes even though these may result in a greater quantity of concrete.

Table 1: Basic prices and derived ratios

	Australia *AUD*	*Malaysia* *MYR*	*UK* *GBP*	*US* *USD*
Basic Prices				
Skilled Worker (per day)	*500*	*95*	*120*	*342*
Concrete (cu.m)	*158.55*	*200.85*	*94.95*	*134.40*
Steel Reinforcement (tonne)	*1,510*	*2,520*	*890*	*980*
Structural Steel (tonne)	*1,800*	*3,000*	*1,015*	*860*
Derived Ratios				
Concrete/Skilled Worker	*0.32*	*2.11*	*0.79*	*0.39*
Steel Reinf/Skilled Worker	*3.02*	*26.52*	*7.40*	*2.86*
Structural Steel/Skilled Worker	*3.60*	*31.57*	*8.44*	*2.51*
Skilled Worker/Concrete	*3.15*	*0.47*	*1.27*	*2.55*
Steel Reinf/concrete	*9.52*	*12.55*	*9.37*	*7.29*
Structural Steel/concrete	*11.35*	*14.94*	*10.69*	*6.40*
Skilled Worker/Steel Reinf	*0.33*	*0.04*	*0.14*	*0.35*
Concrete/Steel Reinf	*0.11*	*0.08*	*0.11*	*0.14*
Structural Steel/Steel Reinf	*1.19*	*1.19*	*1.14*	*0.88*

Note: AUD 1.00 = MYR 3.221, GBP 0.678, USD 1.073 in March 2012.

The difference for steel reinforcement is significantly greater where one tonne of steel reinforcement is equivalent to more than 26 days wages in Malaysia as compared to only 2.86 days in the US. The high relative cost of steel reinforcement in a developing economy will certainly ensure that steel reinforcements are used optimally whereas prefabricated steel systems such as the labour saving BAMTEC steel reinforcing carpets are increasingly being utilised in Australia. The ratio of steel reinforcement to concrete does not seem to differ as significantly as other ratios ranging from 7.29 in the US to 12.55 in Malaysia. A higher ratio should lead to a greater utilisation of deeper concrete sections with reduced steel reinforcement densities to achieve the same load carrying capacities. The next comparison of structural steel to concrete indicates that structural steel is relative cheap in the US

as compared to Australia, UK or Malaysia. This is borne out by the anecdotal evidence of a greater number of structural steel buildings in the US as compared to these countries where there is a stronger tradition of concrete construction.

5. Cost of Concrete Systems

A summary of the rates and quantities for the cast-in-place reinforced concrete system is attached in Table 2. The rates were divided into basic material rates, and labour and plant constants to determine the approximate proportion of expenditure in each segment. As this study was focused on the main structural system, items such as the basement, roof, walls and other components of the building were not considered. When priced with local Melbourne rates, the materials consist of 50% of the total structural costs with labour and plant at 45% and 5%, respectively. This is comparable with both the UK and US prices where the split for material, labour and plant remain at approximately 43%-46%-11% and 45%-54%-1%, respectively. Plant and equipment cost ranges from 1% to 11% depending on the type of concrete conveyance system employed. Significant differences can be observed when the same project is priced based on rates obtained from a builder in Malaysia. The lower labour rates result in a lower proportion for labour at 22% with a corresponding material proportion at 72%.

A closer examination of the labour components indicates that the labour constant for installing steel reinforcements in the suspended slabs are extremely low at 0.01 for Australia and the US compared to 0.03 – 0.04 for the UK and Malaysia. Labour constants for placing concrete are again lower for Australia and the US compared to the UK and Malaysia. The analysis also indicates that labour intensive activities such as the installation and dismantling of formwork comprise a large proportion of the labour costs. In fact, the labour component of formwork exceeds the material costs due to multiple uses (up to 5) of the same formwork in the building. It is also pertinent to note that formwork consists of 47% to 65% of the total costs of cast-in-place concrete works in developed countries as opposed to 23% in Malaysia.

Based on this observation, it is not surprising that numerous innovative systems of precast concrete elements or lost formwork systems have been developed to reduce the utilisation of timber forms in reinforced concrete works in developed countries. Although labour is cheaper for a low wage country, formwork installation and dismantling costs are 65% of total labour and remains the largest component of the total labour requirements. However, it constitutes only 22% of the total concrete works whereas the materials make up a more significant 71%. Considering that labour only constitutes 22% of the total cost of concrete works, there is little incentive to employ more productive methods of construction.

Table 2 Cost of cast-in-place reinforced concrete buildings

No	Description	Unit	Quantity	All-in		Material		Labour				Plant			
				Rate	Amount	Rate	Amount	Constant	Hour	Rate	Amount	Constant	Hour	Rate	Amount
RC Bldg	**AU Rates from Rawlinsons (2010)**														
100	**Slab**														
101	steel reinforcement (Y12,16)	kg	26,775	2.42	64,660.71	1.65	44,210.72	0.009	240.97	62.50	15,060.72	6.81E-04	18.24	170.00	3,100.03
102	concrete	cu.m	307.53	269.47	82,869.44	158.55	48,759.11	1.25	384.41	62.50	24,025.89	0.123	37.83	170.00	6,430.48
103	formwork (class 2)	sq.m	1,662.33	174.00	289,245.77	79.26	131,752.93	1.45	2,410.38	62.50	150,648.84	0.049	81.45	170.00	13,847.23
200	**Beam**														
201	steel reinforcement (Y20,24,28)	kg	11,305	2.42	27,301.21	1.51	17,038.87	0.011	124.35	62.50	7,772.08	6.81E-04	7.70	170.00	1,308.90
202	concrete	cu.m	208.69	269.47	56,234.89	158.55	33,087.32	1.25	260.86	62.50	16,303.67	0.123	25.67	170.00	4,363.65
203	formwork	sq.m	697.36	176.00	122,735.55	75.40	52,581.03	1.53	1,066.96	62.50	66,685.16	0.050	34.87	170.00	5,927.57
300	**Column**														
301	steel reinforcement (Y24,R10)	kg	7,971	2.42	19,250.47	1.51	12,014.29	0.011	87.68	62.50	5,480.21	6.81E-04	5.43	170.00	922.93
302	concrete	cu.m	39.89	310.96	12,404.38	158.55	6,324.56	1.80	71.80	62.50	4,487.63	0.134	5.35	170.00	908.69
303	formwork	sq.m	309.96	220.00	68,191.20	79.85	24,750.31	2.07	641.62	62.50	40,101.08	0.062	19.22	170.00	3,266.98
	Structure (cost per sq.m, %, total)		**308.90**	**100%**	**742,893.62**	**154.06** / **50%**	**370,519.13**		**137.45**	**44%**	**330,565.27**		**16.66**	**5%**	**40,076.45**
RC Bldg	**UK Rates from BCIS (2012)**														
100	**Slab (185mm thk)**														
101	steel reinforcement (Y12,16)	kg	26,775	1.43	38,287.71	0.89	23,829.41	0.04	1,070.98	15.04	16,107.61	-	-	-	-
102	concrete	cu.m	307.53	128.04	39,376.32	94.95	29,200.11	2.20	676.57	15.04	10,175.60	-	0	-	-
103	formwork	sq.m	1,662.33	33.25	55,269.88	6.13	10,189.76	1.44	2,393.76	14.25	34,111.05	3.00	4,987.00	2.20	10,971.39
200	**Beam (800-2400 wide)**														
201	steel reinforcement (Y20,24,28)	kg	11,305	1.22	13,791.91	0.85	9,609.12	0.03	339.15	15.04	5,100.75	0	-	2.20	-
202	concrete	cu.m	208.69	147.60	30,802.20	94.95	19,814.83	3.50	730.40	15.04	10,985.28	0.00	-	-	-
203	formwork	sq.m	697.36	87.83	61,248.95	11.73	8,177.67	3.0768	2,145.64	16.15	34,652.10	12.00	8,368.33	2.20	18,410.33
300	**Column**														
301	steel reinforcement (Y24,R10)	kg	7,971	1.17	9,326.31	0.84	6,695.82	0.02	159.42	15.04	2,397.74	0	-	2.20	-
302	concrete	cu.m	39.89	170.16	6,787.68	94.95	3,787.56	5.00	199.45	15.04	2,999.73	0	-	-	-
303	formwork	sq.m	309.96	32.30	10,011.15	5.45	1,689.28	0.975	302.21	14.25	4,306.51	2.5	774.90	4.44	3,440.56
	Structure (cost per sq.m, %, total)		**110.15**	**100%**	**264,902.12**	**46.98** / **43%**	**112,993.56**		**50.24**	**46%**	**120,836.37**		**13.65**	**11%**	**32,822.28**

Table 2 Cost of cast-in-place reinforced concrete buildings (continued)

No	Description	Unit	Quantity	All-in Rate	All-in Amount	Material Rate	Material Amount	Labour Constant	Labour Hour	Labour Rate	Labour Amount	Plant Constant	Plant Hour	Plant Rate	Plant Amount
RC Bldg	**MY Rates**														
100	**Slab (185mm thk)**														
101	steel reinforcement (Y12,16)	kg	26,775	2.90	77,764.21	2.52	67,472.05	0.03	803.24	11.88	9,542.48	7.00E-05	1.87	400.00	749.69
102	concrete	cu.m	307.53	246.04	75,664.26	200.85	61,767.69	2.05	630.44	9.75	6,146.78	0.063	19.37	400.00	7,749.79
103	formwork	sq.m	1,662.33	26.07	43,337.00	9.07	15,077.35	1.50	2,493.50	10.00	24,934.98	0.01	8.31	400.00	3,324.66
200	**Beam (800-2400 wide)**														
201	steel reinforcement (Y20,24,28)	kg	11,305	2.90	32,833.80	2.52	28,488.22	0.03	339.15	11.88	4,029.05	7.00E-05	0.79	400.00	316.54
202	concrete	cu.m	208.69	246.04	51,344.83	200.85	41,914.78	2.05	427.81	9.75	4,171.13	0.06	13.15	400.00	5,258.91
203	formwork	sq.m	697.36	39.77	27,730.56	10.31	7,189.79	1.70	1,185.51	16.15	19,146.05	0.01	3.49	400.00	1,394.72
300	**Column**														
301	steel reinforcement (Y24,R10)	kg	7,971	2.90	23,151.58	2.52	20,087.45	0.03	239.14	11.88	2,840.94	7.00E-05	0.56	400.00	223.19
302	concrete	cu.m	39.89	246.04	9,814.44	200.85	8,011.91	2.05	81.77	9.75	797.30	0.06	2.51	400.00	1,005.23
303	formwork	sq.m	309.96	34.14	10,582.03	11.14	3,452.95	1.90	588.92	10.00	5,889.24	0.01	3.10	400.00	1,239.84
	Structure (cost per sq.m, %, total)		146.45	100%	352,222.71	72%	253,462.18	105.39	32.22	22%	77,497.95		8.84	6%	21,262.58
RC Bldg	**US Rates from RSMeans(2012)**														
100	**Slab (185mm thk)**														
101	steel reinforcement (Y12,16)	kg	26,775	1.59	42,571.65	1.05	28,113.35	0.01	294.52	49.00	14,431.52	-	-	-	-
102	concrete	cu.m	307.53	160.40	49,328.04	134.40	41,332.22	0.52	160.53	37.75	6,060.06	1.00	307.53	6.30	1,937.45
103	formwork	sq.m	1,662.33	50.63	84,163.87	11.07	18,402.02	0.93	1,537.66	42.80	65,811.72	-	-	-	-
200	**Beam (800-2400 wide)**														
201	steel reinforcement (Y20,24,28)	kg	11,305	1.96	22,157.50	0.98	11,078.75	0.02	226.10	49.00	11,078.75	-	-	-	-
202	concrete	cu.m	208.69	180.80	37,730.61	134.40	28,047.53	0.93	193.66	38.00	7,359.14	1.00	208.69	11.16	2,328.95
203	formwork	sq.m	697.36	88.37	61,622.31	12.04	8,396.23	1.79	1,244.79	42.80	53,276.99	-	-	-	-
300	**Column**														
301	steel reinforcement (Y24,R10)	kg	7,971	1.67	13,272.06	0.98	7,811.79	0.01	111.60	49.00	5,468.25	-	-	-	-
302	concrete	cu.m	39.89	179.30	7,152.28	134.40	5,361.22	0.91	36.30	37.40	1,357.62	1.00	39.89	10.96	437.19
303	formwork	sq.m	309.96	69.45	21,526.72	8.17	2,532.37	1.46	453.16	42.00	19,032.78	-	-	-	-
	Structure (cost per sq.m, %, total)		141.17	100%	339,525.04	44%	151,075.48	62.82	76.46	54%	183,876.84		1.96	1%	4,703.59

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A further analysis into the three different structural concrete systems in Australia is shown in Table 3. The cost for the cast-in-place reinforced concrete system was calculated as AUD 309 per square metre. The proportion for material, labour and plant was 50%, 45% and 5%, respectively. The cast study with a precast concrete system, which consists of precast prestressed hollowcore planks, precast inverted-T beams and precast columns resulted in a 9% higher cost at AUD 336 per square metre. The material cost has increased to AUD 207 due to higher manufacturing and transportation costs for the precast elements, but there is a consequential reduction in onsite labour costs for the assembly of these elements. The plant costs have increased nearly three-fold due to the necessity of a larger capacity crane for the assembly process.

Table 3: Unit cost (per square metre) of different structural systems in Australia and Malaysia

	Total	*Material*	*Labour*	*Plant*
***Australia** (in AUD)*				
Cast-in-place Reinforced Concrete	*309*	*154 (50%)*	*138 (45%)*	*17 (5%)*
Precast planks, beams and columns	*336*	*207 (62%)*	*85 (25%)*	*44 (13%)*
PT slabs, beams and RC columns	*388*	*235 (61%)*	*152 (39%)*	*n.a.*
***Malaysia** (in MYR)*				
Cast-in-place Reinforced Concrete	*146*	*105 (72%)*	*32 (22%)*	*9 (6%)*
Precast planks, beams and columns	*384*	*336 (88%)*	*21 (6%)*	*26 (7%)*
PT slabs, beams and RC columns	*n.a.*	*n.a.*	*n.a.*	*n.a.*

An alternative cast-in-place concrete system which is commonly utilised in Melbourne is post-tensioned (PT) slab and beam. This usually results in thinner structural sections, reduced steel reinforcements quantities, simpler steel layout, reduced deflections or greater spans in the structure. However, the PT slab and beam system requires extensive engineering input and higher technical skills to achieve a satisfactory solution. When compared to the conventional reinforced concrete system, the PT slab and beam solution is 25% more costly on a per square metre basis. The prestressing tendons are significantly more expensive (approximately 2.5 times the as-installed cost on a per ton basis) compared to the steel reinforcements, but a smaller quantity is normally required as the tendons are highly stressed. The material and labour costs are AUD 235 and AUD 152 per square metre, respectively. The high labour component is again indicative of the high cost of labour to erect scaffolding and formwork.

A similar comparison of the cast-in-place and precast system in Malaysia yields very interesting results. There is an analogous increase in total cost when a precast system in utilised in place of the conventional reinforced concrete system. This is to be expected as the cost of precast elements are expected to be higher than cast-in-place elements due to additional connecting elements and increased cost of transportation and handling. A comparable decrease in site labour, that is to be expected, is also observed. The remarkable difference is in the sizeable increase in material cost for precast elements in Malaysia. The material cost for precast was shown to be three times the cost of cast-in-place materials whereas the precast elements in Australia were only 34% more expensive. This resulted in a total system cost that was 163% higher than the conventional system, negating any

obvious advantages in speedier construction, increased productivity or improved quality with precasting.

The derived ratios for concrete/skilled worker and steel reinforcement/skilled worker indicate clearly that concrete and steel reinforcements are relatively cheap compared to the cost of labour in both the US and Australia. It is apparent that with a concrete/skilled worker ratio of 2.11, and steel reinforcement/skilled worker ratio of 26.52, it is more economical to adopt conventional cast-in-place concrete practices instead of precast systems. This study has also shown that similar ratios of 0.32 and 3.02, respectively, will lead to a precast system cost that is only marginally higher than cast-in-place systems, and the additional benefits of quicker construction, better control over quality, and reduced exposure to weather risk can be achieved.

6. Conclusions and Further Work

The construction cost – construction technology choice approach identified in this project may provide the context for the choice of construction technology. While the focus is initially concerned with reinforced concrete methods of construction, the derived ratios may be extend to inform on a wide range of construction choices, either locally developed or imported from overseas, available to developing economies. A working cost-technology model will provide the construction industry with a much needed tool to evaluate the most appropriate options to deliver residential, commercial and institutional buildings, especially for rapidly developing economies facing constraints of labour, capital or resources.

The small set of derived ratios based on skilled worker wages, and basic construction materials such as concrete, steel reinforcements and structural steel is able to adequately rationalise the choice between cast-in-place and precast systems of construction. The large material/skilled worker ratios for a developing country like Malaysia clearly highlight the motivation to economise on construction materials instead of investing in labour reducing processes. Conversely, the developed economies of Australia, UK and the US will attempt to reduce the use of labour by investing in industrialised building systems.

Future work will focus on obtaining additional project cost data for the three concrete structural systems in Malaysia, UK and the US to enable a similar comparison to be made. This research project is part of a broader study to determine derived ratios to develop a framework to analyse a wider range of construction technologies.

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