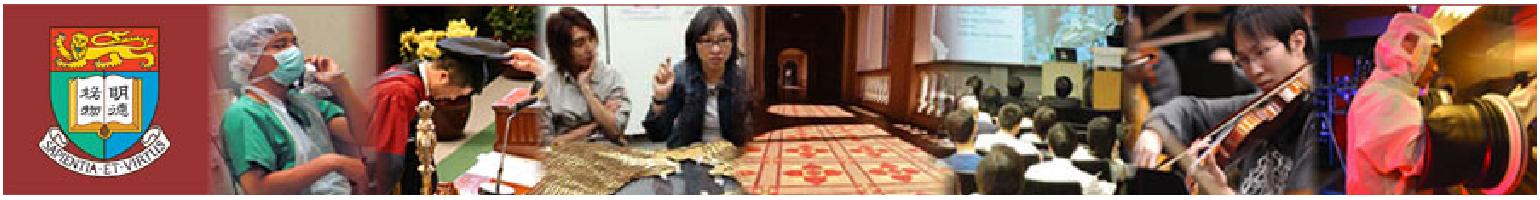

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THE UNIVERSITY OF HONG KONG

THE ADOPTION OF ADVANCED TECHNOLOGIES FOR HONG KONG CONSTRUCTION INDUSTRY

A DISSERTATION SUBMITTED TO
THE FACULTY OF ARCHITECTURE
IN CANDIDACY FOR THE DEGREE OF
BACHELOR OF SCIENCE IN SURVEYING

DEPARTMENT OF REAL ESTATE AND CONSTRUCTION

BY
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HONG KONG
APRIL 2005

Declaration

I declare that this dissertation represents my own work, except where due acknowledge is made, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for a degree, diploma or other qualification.

Signed: ______________________________

Name: _______________________________

Date: ________________________________

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ABSTRACT

This study addresses the problems of Hong Kong construction industry's labour-intensive nature, examines the possibility of using advanced construction technologies to solve this problem and identifies the barriers to the use of these technologies.

Hong Kong construction industry is often regarded as a labour-intensive industry and it has been underachieving, but no research has been done on proving this statement. Therefore, a Cobb-Douglas Production Function is applied to find out the ratio of labour input and capital input so as to determine the factor intensity of local construction industry. The result affirms the labour-intensive nature of the industry. This Production Function is also used to calculate the value added total factor productivity (VATFP) growths of the construction industry. It is observed that the VATFPs of the industry have sustained positive growth in the period 1985-2002. The above two findings imply that even there are technical changes, the construction industry still relies on plenty of labour resources to increase productivity.

Contractors refuse to use advanced construction technologies because they think they are white elephants. Four advanced construction technologies are studied and the economic analyses show that they can offer users tangible benefits like enhancement in productivity and reduction in cost, as well as intangible benefits like improvement in quality and safer work environment. Contractors are not interested in these technologies because they cannot utilize them frequently, which can result in negative return. Other obstacles to the use of advanced technologies are identified, they are: lack of client's motivation, financial constraint, project timeframe, labour's incapability and lack of knowledge sharing in the industry. As a result, it is recommended that the government should allocate more resources on training and R&D to initiate other practitioners to develop and adopt advanced technologies.

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1 INTRODUCTION

In terms of construction spending per capita Hong Kong was ranked 9^{th} in 1998 after Japan and Singapore within Asia, with Japan leading at US$4,975 (Bon & Crosthwaite 2000). Over the years, the total construction market expanded by about half, in real terms, in 1996 when compared with 1990 (AsiaConstruct Team 2003, p.19). Unfortunately, the completion of the Hong Kong International Airport and its related facilities, and the Asia Financial Crisis in 1997 doomed the construction industry in Hong Kong. The total value of construction works has followed a downward trend[1]since then.

Although the construction sector accounted for only 4.4% of the Gross Domestic Product (GDP) of Hong Kong in 2002 (Census and Statistics Department 2004c), practically other sectors of the economy like tourist industry, manufacturing industry, financing and real estate services, community services, etc. all depend on the construction sector to accommodate their needs for growth and expansion (Voon & Ho 1998). Actually, the construction industry interacts with other industries to form a basis for establishing our society. Therefore, the construction industry plays an important role in Hong Kong's economy and its significance cannot be neglected despite of its relatively small share in GDP.

However, there are many shortcomings in the industry's operations and in the quality of its products. As identified by CIRC (2001), local construction activities are labour-intensive, dangerous and polluting; built products are often defective; high construction costs; practitioners are lack of long-term view on business development and the industry is lack of adoption of new technologies to cope with new challenges. In addition, productivity growth of the construction industry has been declining. As a

[1] This trend is deduced from Census and Statistics Department (2004c).

result, one of the CIRC's recommendations to the industry is to use more modern construction methods and techniques as well as information technology (IT) so as to enhance efficiency and productivity.

Then why the industry is short of such new technologies and practices? Are they too costly to adopt? Are their advantages overestimated? By understanding more about new construction practices and technologies and the actual benefits they bring to the users, some insights to the current technology adoption situation in the industry can be provided. It is the main theme of this study to investigate the feasibility of adoption of modern construction methods and techniques and the reasons for the unpopularity of such new methods and techniques in the industry. Before that, two things about local construction industry have to find out.

Firstly, it is necessary to show that local construction industry is labour-intensive; otherwise, the recommendation of the adoption of new technologies could be inappropriate if the industry is actually capital-intensive.

Secondly, the examination of the growth of productivity of the construction industry is essential because it is used for the formulation of strategies for, and the evaluation of the effectiveness of, productivity improvement policies and programmes (Chau and Walker 1988). Enhancing productivity is one of the means to achieve economics growth and higher living standard in a society. It can also give some implications on the effect of technical changes on the industry.

1.1 Objectives of This Study

1. To use a scientific approach to determine the labour-intensity of Hong Kong construction industry.
2. To calculate the productivity growth in local construction industry.

3. To analyse new construction practices and technologies to ascertain their economic feasibility and benefits to user.
4. To investigate and explain the phenomenon of slow spreading of new construction practices and technologies in the industry.
5. To propose methods to accelerate the adoption of new construction practices and technologies in the industry.

1.2 Hypotheses of This Study

1. Hong Kong construction industry is labour-intensive.
2. Labour is difficult to be substituted by capital or other factors in construction industry.
3. Decline in productivity in construction industry is due to the low quality of labour (lack of general knowledge) and poor project management.
4. The benefits brought by most advanced construction technologies or practices to users cannot compensate for the cost of using these technologies or practices. Thus they are unpopular as they are not worthwhile to adopt.

1.3 Structure of This Study

This research will start by reviewing concepts and theories concerning factor intensity. Literature on labour utilization of the construction industry will be covered. Theories on productivity and methods of calculating productivity will also be studied. Afterwards, literature on advanced construction technologies and practices will be reviewed. All these aim at providing a theoretical base for the methodology section. The results obtained from the methodology section will then be analysed and discussed; recommendations will be made too. Finally, conclusions will be drawn.

2 FACTORS OF PRODUCTION IN HONG KONG CONSTRUCTION INDUSTRY

2.1 Introduction

Every production process is concerned with transforming inputs into outputs using the resources at the command of each firm. Economists group the inputs used into three main categories: labour, which encompasses all working people, ranging from the most unskilled labour to the most highly trained professionals; capital, which includes all the manufactured inputs into the production process, such as machinery, partly finished goods and factories; and land, which encompasses all the natural resources used in production, including non-renewable resources such as fossil fuels, renewable resources such as trees, and the land itself (Cooke 1996, p.109). Collectively, these three resources are known as factors of production. That is, annual output depends on the input quantities of these productive factors in the same year; and the quantity produced reflects the productive powers and capacity of these factors (Ive and Gruneberg 2000, p.13).

Labour and capital are often the main concerns in literature related to economic analyses of the production processes in construction industry (Cooke 1996; Ganesan *et al.* 1996; Chiang *et al.* 1998; Voon and Ho 1998; Ganesan 2000; Ive and Gruneberg 2000). As stated by Ive and Gruneberg (2000, p.73), in order to work out the production function of the construction industry, it is important to obtain the ratios of output to labour as a measure of productivity and capital to labour, which can be used to compare the capital intensities of various industries. Therefore, labour and capital are focused in this literature research.

2.2 Labour

2.2.1 Concept of labour

Labour is any kind of human effort that inputs to a production system. Such effort may be manual or mental, skilled or unskilled. The labour force refers to the land-based non-institutional population aged 15 and over who satisfies the criteria for inclusion in the employed population or the unemployed population (Census and Statistics Department 2004b).

In construction industry, the workforce (particularly foreman and craftsman), that through their skills and efforts, working individually or in crews directed by foreman or project manager, transform the directions depicted in plans and specifications into reality. Therefore, labour is an important input in any construction processes. Labour market is distinct from other markets where goods (i.e. labour) are only hired; ownership of goods is not transferred. Construction labour market is about the hiring of services carried out by people on a variety of tasks, undertaken in the course of a construction project.

2.2.2 The demand for labour in construction industry

Demand reflects the marginal value the consumer places on a unit of a good or service (Lai and Yu 2003, p.53). Thus, demand for labour is derived from the demand of its product and its marginal schedule - the lower the price of an input; the larger the amount of that input is demanded. Labour is not wanted for its own sake but only in response to demand for the products or services it ultimately provides.

Labour demand also depends greatly on amount, quality, type of other jointly used inputs and the ability to substitute among factors which is the replacement of one factor of production by another in the process of production. Ive and Gruneberg (2000, p.34) suggest that the number of people employed depends on the technology used and the rate of pay (including the indirect costs of employment). When more technologies are used in a production process the less labour is required in order to produce a given output. When wages are relatively high firms tend to adopt more technologies to increase the productivity of labour. An increase in work loads can be met through the greater use of plant and machinery, rather than by employing more people. On the other hand, when wages are low the incentive to substitute labour with technologies is reduced and demand for labour is more responsive to changes in the work load of firms.

2.2.3 The supply of labour in construction industry

The supply of labour depends on the number of people with a particular type and level of skill, experience and training, who are willing and able to offer themselves for hire in return for a given contract of employment. The effective supply of labour at a certain wage is comprised of those workers who are willing and able to offer firms the current average or marginal productivity of existing workers employed at similar wages (Ive and Gruneberg 2000, p.33). Bargaining for a specific employment package by specific job seekers is a typical method applied by the employers to detect the minimum amount of value or cost the labour are prepared to give up for their services at a given time for a certain wage (Lai and Yu 2003, p.58).

Labour supply also depends on factors such as population, age and sex distribution, but these demographic issues are out of the scope of this study.

2.2.4 Labour wage and employment situation

Labour Cost Index (LCI) complied by the Architectural Services Department (ASD) is a weighted average of the daily wages of different types of construction workers such as labourers, carpenters, concretors and scaffolders (Chau 1998). Therefore, the LCI reflects the labour wage trend of local construction industry. From Figure 2.1, it shows that there was a continuous rise in labour wages starting from 1994, and this growth has finally leveled off since 2000.

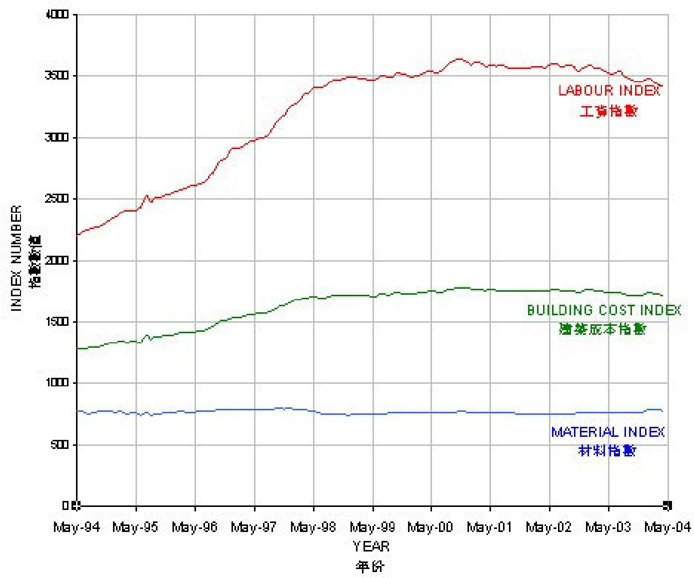

Figure 2.1 Labour Cost Index[2]

Different kinds of construction works were carried out in the territory at early 90s, for example, the development of the Hong Kong International Airport in Chek Lap Kok and related infrastructure, port expansion, reclamation and many residential building projects. Consequently, lots of construction workers and professionals were required. Voon and Ho (1998) identify there has been a shortage in construction labour in Hong Kong since 1987. They list out three main reasons for this shortage:

1. Uncertainty of employment;
2. Unattractiveness of working conditions; and
3. Strong competition from other industries which provide more stable and better working conditions.

---

2 Architectural Services Department (2004)

Under such circumstances, as the supply of labour were quite inelastic at that time while there was increasing demand for construction workers due to a surge in construction output, construction labour wages went up.

Following the accomplishment of major infrastructure projects, the shrinkage of local real estate market after the financial turmoil and the cessation of production of Home Ownership Scheme (HOS) flats, the ratio of construction employment to active labour force has been decreased, as shown by the declining trend in Table 2.1. When the labour shortage problem was relieved, the wage level stopped rising.

			%
Industry sector	***1998***	***2002***	***2003***
Manufacturing	8.5	6.0	5.4
Construction	10.2	9.1	8.6
Restaurants & hotels	6.9	6.7	6.3
Financing, insurance, real estate and business services	13.7	15.1	15.1
Total employment ('000)	3127.2	3235.2	3222.6

Table 2.1 Employment distribution by industry sector[3]

Despite of this, a large number of people still work in this sector in Hong Kong. Hong Kong construction industry employed about 277,000 people in 2003, which was 8.6% of the total workforce[4]. This employment distribution was greater than that of restaurants and hotels sector (6.3%) and that of manufacturing sector (5.4%) in the same year[5]. In fact, from 1998 to 2003, the employment distribution of construction industry was always greater than those of the above mentioned sectors (Table 2.1). Moreover, manpower requirement in construction is projected to be 307,600 people in 2007 (Education and Manpower Bureau 2003), which accounts for 9.5% of the total working population at that time. All these figures reflect the rising trend of the number of people engaged in construction industry in Hong Kong.

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[3] Census and Statistics Department (2004e)
[4] *ibid.*
[5] *ibid.*

2.2.5 The significance of labour cost in a construction project

Ganesan *et al.* (1996, p.49) estimate that the breakdown of total construction expenditure is approximately materials 35%, labour and plant 45%, and overheads and profit 20%. Total expenditure in this context covers building and civil engineering projects, and these percentages may vary significantly from one project to another especially in the civil engineering sector. Voon and Ho (1998) say that a typical building contract has 40% labour while a typical civil engineering contract has 20% labour. CIRC (2001)'s benchmark study on the construction cost of building projects in Hong Kong reveals that the average labour component costs in normal building projects are 25% of the total construction costs Hong Kong while they are, 20% and 40% in Singapore and the USA respectively. This shows that the labour cost input of a building project is relatively higher in Hong Kong as compared to Singapore but lower than that in the USA.

Though the figures provided by the above authors are different as they were calculated in different periods, one implication they give is that labour contributes to a substantial amount of cost in a construction project, irrespective of the type of work.

2.3 Capital

2.3.1 Concept of capital

Capital refers to all man-made resources used for further production, which includes buildings, plant and equipment, and stocks of materials. The quality and quantity of capital influence not only the productivity of capital but also that of labour and total output (Kulshreshtha and Malhotra 1998). When we talk about productivity in construction, capital often refers to the amount of technologies adopted in a construction process because other elements such as buildings or stocks of materials owned by contractors do not have a direct impact on construction productivity on site.

Unlike labour, capital will depreciate over time. Depreciation measures the loss in value of a capital good as it ages. A capital good will also experience efficiency decline, which reflects the loss of productive services that can be drawn from itself (Schreyer 2001, p.53).

2.3.2 The demand for capital in construction industry

Similar to labour, the demand for construction plant is derived from the demand for its products and services it ultimately provides. In addition, spending on capital goods like construction plant often requires large monetary outlays with profits dependent on the flow of future revenues and costs. Because of the magnitude of the funds required, investment spending tends to be influenced by interest rate (Bumas 1999, p.421) and the financial capacity of the investors.

Contractors in Hong Kong are reluctant to purchase sporadically used plant since it is difficult to amortise the investments involved. They tend to hire them. On the other hand, plant that are frequently specified by contracts such as air compressors and concrete pumps have high utilization rates and justify direct purchases by local contractors (Ganesan *et al*. 1996, p.52). The nature and volume of work dictate the type and capacity of plant purchased by a firm.

2.3.3 The supply of capital in construction industry

Most construction plant and technologies in Hong Kong are acquired from overseas (Chau and Walker 1988; Ganesan *et al*. 1996; AsiaConstruct Team 2003). These plant and technologies are either directly owned by the contractors or on short term hire (Ganesan *et al.* 1996, p.53). In most cases, local contractors own only the most commonly-used plant, such as tower cranes and hoists, in order to increase utilization rates and reduce unit costs.

Contractors may also invest in research and development (R&D) activities to look for new technologies. However, as reported by both CIRC (2001) and AsiaConstruct Team (2003), Hong Kong construction industry's undertaking in R&D is low, which means practitioners seldom invent or improve construction technologies.

2.4 Factor Intensity

After making a brief review of the factors of production: labour and capital, then we concern which factor is more commonly used in the construction process. To look for the answer, the concept of factor intensity will help.

2.4.1 Concept of factor intensity

Factor intensity is the proportion of a factor used in the production of any one final good. In economics, the concept of factor intensity tells us that in order to rank commodities, what is important is the proportion in which labour and capital are used, not their absolute quantities (Chacholiades 1990, p.67). Therefore, it is necessary to find out the labour and capital ratio before drawing any conclusion on factor intensity matters, e.g. labour intensity of an industry.

2.4.2 Labour utilization and capital utilization in local construction industry

Many construction activities still depend heavily on skilled and unskilled labour. Ganesan *et al.* (1996, p.42) and Chiang *et al.* (1998) identify several labour-intensive construction activities such as concreting, steel fixing, carpentry, rendering, planting, acoustical ceiling work, pipe work, etc. Thus, it is not surprising to find so many people involve in the construction industry as mentioned in Section 2.2.4. In addition, various kinds of labour are employed; usually referred to as building trades, e.g. concretor, steel bender, plumber, painter, electrical and mechanical (E&M) workers and so on. Most of them are construction site workers, the remaining are the managerial, administrative and professional workforce, such as project managers and surveyors.

Hong Kong's civil engineering industry is more mechanized than its building construction counterpart. Expenditure on plant in the building sector is less since labour has been comparatively more plentiful and economical in Hong Kong (Ganesan *et al*. 1996, p.52). Because of the large-scale nature and special requirements of civil engineering projects, it favours the use of construction machinery. According to Chau and Lai (1994), the use of plant and machinery becomes more common and labour productivity has been improved through substitution of capital for labour, though the process is slow.

2.4.3 Is Hong Kong's construction industry really labour-intensive?

Construction industry in Hong Kong is considered labour-intensive by many researchers (Rowlinson and Walker 1995; Ganesan *et al.* 1996; Chiang *et al*. 1998; Voon and Ho 1998; CIRC 2001; AsiaConstruct Team 2003). Although the above authors think that construction industry is labour-intensive, they do not provide any verification of the industry's labour intensity. One can thus argue that when more construction technologies are adopted nowadays, is the construction industry still labour-intensive?

The definition of factor intensity tells us that only labour-capital ratio genuinely reflects one factor's intensity, not its absolute quantity. Therefore, a large number of labour involved in construction industry does not necessary mean that the industry is labour-intensive in nature. Chacholiades (1990, p.67) provides a meaning for "labour-intensive" when explaining the Heckscher-Ohlin Model in macroeconomics. Take labour-capital ratio as an example. The labour-capital ratio is the quantity of labour required to produce one commodity divided by the quantity of capital required to produce that commodity. Larger labour-capital ratio means more labour-intensive, and vice versa; but with a larger number of labour does not mean that an industry is more labour-intensive than that one with less labour.

No doubt statistics demonstrate that lots of people work in the construction sector and there is a wide range of labour involved, it is risky to conclude that construction is labour-intensive in nature merely based on these two findings, without considering capital inputs which is crucial for the determination of factor intensity. Although one can easily anticipate that the construction industry is labour-intensive with one's experience and observations, it should be more cautious in doing scientific research as any subsequent interpretations or recommendations are likely to be faulty if a wrong analysis of the construction industry is made at the very beginning. As a result, more appropriate methods will be introduced for analyzing the labour intensity of the construction industry in next chapter.

2.5 Summary

In construction industry, we usually concern two factors of production - labour and capital. They are the major inputs to a production system. It is believed that labour is utilized more than capital throughout the construction process. However, it does not necessarily mean that construction industry is labour-intensive. Economic theory tells us that factor intensity is judged by labour-capital ratio, not by absolute quantities; as a result, we have to prove that construction industry is labour-intensive before doing any further analyses of the industry.

3 PRODUCTIVITY AND PRODUCTION FUNCTION

3.1 Introduction

When we describe how "advance" an industry is, we usually refer to its productivity. Productivity plays a crucial role in determining the level and rate of profitability (Savidis and Mills 2001). Economists calculate the productivity of an industry with the aid of production functions to examine the technological change in that industry. A production function can also serve as a mean to reflect the factor intensity of an industry. Before we go on to introduce production function, it is necessary to understand the concept of productivity first.

3.2 Productivity

3.2.1 Definitions of productivity

The Organization for European Economic Cooperation (OEEC) (1950) issues a formal definition for productivity: the quotient obtained by dividing output by one of the factors of production. In this way it is possible to speak of the productivity of capital, investment, or raw materials, according to whether output is being considered in relation to capital, investment or raw materials, etc. Edison (1999) defines productivity as an all embracing term which refers to the overall net yield of goods and services during a specified period, achieved with a given volume of resources. Ive and Gruneberg (2000, p.61) define productivity as the quantity of output per unit of labour in a given period of work and the output can be measured in terms of the physical units produced. Schwartzkopf (2004, p.5) defines it as the units of work accomplished for the units of labour expended and hence the author expresses productivity in the following formula:

Labour productivity= outputs/labour [3.1]

Ganesan (1984) and Ganesan *et al.* (1996, p.5) also adopt the same formula in calculating labour productivity. Output for any year may be taken as Gross Domestic Fixed Capital Formation; input is labour in man-years.

It seems that there are many versions of the definitions of productivity; however, the concept behind is the same, i.e. the ratio of output to critical input, holding other inputs constant. Olomolaiye *et al.* (1998, p.3) suggest that no matter which definition is used, it should bring out three distinct concepts; they are:

(i) the capacity to produce,
(ii) effectiveness of productive effort and
(iii) the production per unit of effort.

3.2.2 Productivity measures

It is generally perceived that productivity analysis aims at identifying the changes in efficiency of a production process. In fact, productivity can tell more. According to Schreyer (2001, p.11), technical change, real cost savings and change in living standards can be reflected from productivity measures. As a result, understanding the movements in productivity and designing the right policies to enhance it is important for sustaining economic growth. Edison (1999) also emphasizes the importance of productivity analysis, with similar points of view as Schreyer (2001)'s. Chapter One of this study mentions the importance of construction industry to Hong Kong's economy, therefore, we must analyse the industry's productivity so that we can target the weak points of the industry and look for solutions accordingly. In order to facilitate this process of understanding the movements in productivity it is critical to be able to first get a handle on how to measure it.

There are many different productivity measures. The choice between them depends on the purpose of productivity measurement and the availability of data (Schreyer 2001, p.12). Generally, productivity measures can be classified as single factor productivity measures or multiple factor productivity (MFP) measures.

3.2.2.1 Single factor productivity

Single factor productivity is a measure of output to a single measure of input (Schreyer 2001, p.12). It can be calculated as labour or capital productivity, that is, net or gross output per unit of the respective input. For calculating construction labour productivity, the output of a firm or the industry is in monetary term because if it is in terms of physical units produced, it becomes meaningless where each building or project is unique.

Labour productivity relates to the single most important factor of production and is relatively easy to measure. It is also a key determinant of living standards, measured as per capita income, and from this perspective is of significant policy relevance. Labour productivity is thus more commonly adopted in research on construction industry; researchers aim at finding out construction industry's impact on the economy by analyzing productivity trends. Stokes (1981) examines the labour productivity in construction industry and analyses the sources of productivity decline. Chau and Lai (1994) test whether labour productivity growth in the construction industry compares favourably with that in the economy. Ganesan *et al.* (1996) study the construction labour productivity trends from 1972-1992 in Hong Kong to find out the labour utilization situation. Teicholz (2001) studies the labour productivity trend in the US construction industry to call for initiatives to solve the structural problems found in the industry.

Although labour productivity is popular and easy to use, its use has been challenged by many scholars. Schreyer (2001, p.12) says that it only partially reflects the productivity of labour in terms of the personal capacities of workers or the intensity of their efforts. Chau and Walker (1988) assert that different analytical standpoints will give rise to different meanings of productivity; therefore, the authors regard the above said “labour productivity” as partial factor productivity because it is only a comparison of output to one specific input factor. They criticize labour productivity because it is a biased measure as the effect of factor substitution and change in relative prices are ignored; data collection is also found to be difficult as physical measurement of inputs and outputs is not possible. Edison (1999) also points out that labour productivity can only reflect part of a firm’s productivity while the effects of other factors such as technical improvement and better organization of work are not reflected. Owyong (2000) then explains that labour productivity suffers from obvious limitations because in most industries or sectors there may be several factors of production that are of almost equal importance, in which case it might be difficult to choose among them; the relative importance of inputs may also change over time. For instance, the relative importance of labour may be low in the initial stages of development when unemployment is high, but may become critical as the country becomes more developed because of declining birth rates and an aging labour force. Labour productivity is challenged even on technical aspect. For example, Rojas and Aramvareekul (2003) suspect the validity and reliability of labour productivity values calculated from macroeconomic data.

Because of the incomprehensiveness of labour productivity measures, another measure – MFP, is proposed.

3.2.2.2 Multifactor productivity

MFP relates a measure of output to a bundle of inputs. It helps disentangle the direct growth contributions of labour, capital, intermediate inputs and technology (Schreyer

2001, p.20). Total factor productivity (TFP) is a kind of MFP. The distinction between the two is that the latter includes the joint productivity of labour, capital and intermediate inputs, and the former considers the joint productivity of labour and capital only (Mahadevan 2004, p.6). Chau and Walker (1990) suggest that MFP is often used interchangeably with TFP.

The concept of TFP was first introduced by Stigler (1947). It was later developed by other researchers such as Kendrick (1956), Dacy (1965) and Christensen *et al*. (1980). It is the comparison of output with all identifiable inputs (e.g. labour, material, capital and so on) (Chau and Walker 1988). Productivity increases when the growth in output is greater than the growth in input, or when the rate of growth of output minus the rate of growth of the composite input is positive. Economic growth can be obtained either by increasing inputs or by improving productivity factor. Productivity growth occurs when a higher output can be attained with a given amount of input, or a certain level of output can be attained with smaller amounts of factor input (Singh and Trieu 1996). The TFP can also reflect change in real output resulting from changes in intangible inputs such as economies of scale, change in qualities of inputs and advance in technology. Therefore, TFP has been widely accepted as a much better indicator of productive efficiency than labour productivity.

Chau and Walker (1988) estimate the TFP of the Hong Kong construction industry using various construction cost and price indices and show that property market boom may lead to decrease in productivity of the construction industry. Chau and Walker (1990) use the trend of TFP together with that of labour productivity to demonstrate the phenomenon of factor substitution in Hong Kong construction industry. If the two trends are similar, it is probably the result of low factor substitution. Chau (1993) also applies similar methodology to show the substitution possibility between labour and other inputs. It is observed that labour in Hong Kong's building industry was not substituted greatly by other inputs, e.g. capital, during the period 1972-1987 and hence Hong Kong's building industry was labour-intensive at that time. Pedersen (1990) applies TFP to point out the structural problems arose in Denmark's construction industry like the poor performance of repair and maintenance sector, but no attempt was made to investigate the factor intensity of the industry. The above papers show that TFP can tell us more information on an industry apart from its productivity, e.g. market situation and factor substitution. TFP can also be applied to other industries. Liao *et al.* (2002) calculate the TFP growth of the manufacturing sector in eight East Asia economies and find out the TFPs in these economies are driven by efficiency change. Hence, the authors propose a higher priority to booster economic growth through the enhancement of productivity-based catching-up capability. It is expected that TFP can also be applied to construction industry to provide such implications for policy makers.

3.2.3 Measuring total factor productivity

According to Mahadevan (2004, p.5), TFP can be calculated as:

$$Q/(aL+bK) \qquad [3.2]$$

where Q is value added output, L is labour input, K is capital input and a and b are weights given by input shares. Mahadevan (2004, p.16) categorizes the measurements of TFP into frontier approach and non-frontier approach. The frontier approach decomposes output growth into input growth and TFP growth and further decomposes TFP growth into various efficiency components while the non-frontier approach uses the standard growth accounting framework which separates the growth of real output into an input component and a productivity component. One feature shared by these two approaches is that both of them can be estimated using either the parametric or the non-parametric method.

Schreyer (2001) focuses on explaining the methodology in measuring productivity at the industry level. The non-frontier non-parametric approach is used. However, owing to data limitations, it is not applicable to measure TFP in Hong Kong construction industry. Consequently, researchers tend to use indirect ways to calculate TFP.

Chau and Walker (1988) measure TFP of Hong Kong construction industry indirectly through construction cost, price indices and other statistics, including value share of individual inputs, labour cost index, material cost index, public sector tender price index, private sector price index and average book profit margin of the construction industry, assuming the value share is constant over time. All these data are readily available from various government publications. Chau (1993) modifies the approach used to estimate TFP in Chau and Walker (1988). The new approach is less restrictive and does not rely on the constant value share assumption which has been proved to be unrealistic, as the ease of substitution between input pairs is likely to be overestimated. Moreover, it can be applied to calculate value added TFP (VATFP) by the same set of data used to calculate TFP. According to Chau (1993), the difference between VATFP and TFP is that in the former approach, intermediate inputs are subtracted from both the input and output side. Chau (1993)'s methodology can be adopted to test the extent of substitution of labour by other inputs. It is valid because apart from labour input, it also involves the consideration of capital input and other input factors in calculations.

In addition, the TFP of Hong Kong construction industry can be estimated by non-frontier parametric approach, i.e. the use of production function. This will be introduced in next section.

3.3 Production Function

3.3.1 Definition of production function

Bumas (1999, p.119) defines the production function as a function relates the maximum rate of production, Q, to the employment of the factors of production – labour, L, and capital, K – at a given level of technology, T:

$$Q = f(T; L, K) \qquad [3.3]$$

A production function indicates what outputs can be obtained from various amounts and combinations of factor inputs. In particular it shows the maximum possible amount of output that can be produced per unit of time with all combinations of factor inputs, given current factor endowments and the state of available technology. One factor of production - land is omitted because once a unit of land is worked on by labour or capital; it is no longer in its original or natural state and hence land is transformed into capital as the produced means of production. In some cases, materials purchased from other producers can also be a factor of production in a production function:

$$Q = f(T; L, K, M) \qquad [3.4]$$

No matter which form of production function is used, a crucial assumption in production function analysis is that the rate of production can be varied by altering the employment of a single factor, holding all others constant. The production function is also assumed to be homogeneous, that is, if labour and capital are increased by some proportion h, then Q may increase in the same proportion h, or by some larger or smaller proportion (Bairam ed. 1998, p.2).

3.3.2 Cobb-Douglas Production Function

The most common production function used in empirical research is the Cobb-Douglas Production Function because it is simple to estimate and is consistent with the economic theory of production (Lin 2002). It was first developed in Cobb and Douglas (1928). The production function is of the basic form:

$$Q = A L^{\alpha} K^{\beta} \qquad [3.5]$$

where Q is the real production and L and K are the amounts of labour and capital employed in producing it. The exponents α and β are parameters representing the elasticity of output due to labour and the elasticity of output due to capital respectively. According to Bairam ed. (1998, p.18), A is a time dependent 'scale parameter' which denotes a technological progress variable; as described by Link and Siegel (2003, p. 28), it absorbs like a sponge, all increases in output not accounted for by the growth of explicitly recognized inputs.

After acquiring data of Q, L and K, different parameters of the production function can be estimated as in linear relationship by using regression analysis.

3.3.3 Applications of Cobb-Douglas Production Function

Cobb and Douglas (1928) set up a first degree homogeneous function of the form as [3.5]. This function builds up a yearly production index (P') for the manufacturing sector of the US from 1899 to 1922, making use of the labour and capital indices published annually by the US government. The authors then compare P' with the actual indices of the physical volume of manufactures in the US (P) and find that the trends of P' and P are much alike, which shows that the estimates of the function are reasonably close to that which actually existed. This function is the basic form of the

"Cobb-Douglas Production Function". This is also an attempt to calculate productivity based on a production function; thus form the basis for future application of this form of function. In addition, the authors prove that their model follow constant returns to scale, i.e. when inputs are increased by h, outputs are also increased by h. This fulfils the assumption of homogeneity of a production function.

Solow (1957) justifies the use of the Cobb-Douglas Production Function in theoretical and applied research. The author applies the production function, with two factors of production: labour and capital, assuming perfect competition and constant returns to scale, to investigate the technical change in the US from 1909-1949. He studies changes in the scale parameter "A" of the production function (see [3.5]). Although there is no data for parameter A, he shows that growth in technology can nonetheless be inferred from growth in output, capital and hours worked. The impact of technological change on production can be approximated as a residual growth rate, as "the percentage change in output per year that is not explained by the annual percentage change in capital and labour" (Link and Siegel 2003, p.28). Solow also demonstrates most of the growth output per worker is due to technological progress. This Solow residual measure of TFP growth has formed the foundation for an extensive body of empirical literature. However, despite of its widespread use, this measure is criticized by Link and Siegel (2003, p.28) as it cannot distinguish between pure technological change and changes in efficiency with which properly measured resources, including technology, are used. The authors also list other shortcomings of the Solow residual measure, such as the effects of sub-optimal capacity utilization, incorrect measurement of inputs and outputs and imperfect competition.

The Cobb-Douglas Production Function has been generalized to form a transcendental logarithmic (translog) function for estimating technological change. Christensen *et al.* (1973) have been able to capture more accurately the effect of scale economies and input substitution on a measure of technological change with the translog production function. Christensen *et al.* (1980) compare aggregate growth patterns among different countries including the US, Canada, France, Italy, the UK, Japan, etc. between 1960 to 1973 and conclude that any analysis that fails to incorporate quality changes in input measures will overstate the contribution of TFP growth to the growth of real output. However, since quality changes are difficult to quantify, it is hard to make adjustments in measuring TFP. Consequently, estimated TFP growth is often incorporated with embodied technical changes.

Bende-Nabende *et al.* (2002) employ the translog production function to examine the TFP index in growth accounting as a proxy for productivity growth in different Asian economies, including Hong Kong, during the period of 1965-1997. The authors observe that TFP's contribution to Hong Kong's output growth has been declining. They suggest that if Hong Kong is to continue sustaining productivity, Hong Kong has to devote more resources to investment in R&D. Contrary, TFP and capital stocks are the dominant contributors to output growth in Japan. This reflects that Japan has made more efforts on R&D to improve productivity.

Apart from Solow residual measure and translog production function, TFP growth can also be measured by using the parameters of the Cobb-Douglas Production Function. Bumas (1999, p.147) attempts to measure TFP growth by subtracting a later calculation of growths in capital and labour from growth in output. This approach has been followed by Mahadevan (2004) to calculate the TFP growth of Hong Kong's manufacturing sector from 1984-1999.

One important implication of a Cobb-Douglas Production Function is its ability to reflect factor intensity of a firm or an industry. Mahadevan (2004) estimates the capital and labour shares of Hong Kong's manufacturing industry by means of a Cobb-Douglas Production Function. The coefficients (i.e. the exponents α and β in [3.5]) of the independent variables can show us which production factor is more intensive. For example, if the coefficient of labour is larger than that of capital, according to the definition of factor intensity[6], the firm or the industry is labour intensive as labour is utilized in a larger proportion than capital. In Mahadevan's study, he finds out the capital input share is higher than labour input share and he concludes that the manufacturing activities in Hong Kong are capital intensive.

One interesting point to notice in Mahadevan's study is the adoption of value added measure. Let's recall the basic form of a Cobb-Douglas Production Function. The dependent variable Q represents the real output (see [3.5]), which means the gross output of a firm or an industry (an industry in Mahadevan's case). Since the parametric estimation of the Cobb-Douglas Production Function provides an implausible negative intermediate consumption share coefficient and there is no appropriate deflator for intermediate consumption, Mahadevan uses the value added output instead. Therefore, only labour and capital are selected as factors of production in the model. Mahadevan shows that TFP growth is the driving force of manufacturing output growth and this finding coincides with that of Bende-Nabende *et al.* (2002).

Bacchini *et al*. (2002) aim at producing a new index of production in construction in Italy. To achieve this goal, the authors estimate a production function between input indicators (hours worked, raw materials purchased and technical fixed assets) and output. The authors compare the factor intensity among various construction activities using the coefficients of the independent variables and they discover that the "building installation" and the "building completion" are more labour intensive compared to "building of complete construction; civil engineering" in Italy. In fact, Bacchini *et al*. apply the same approach to determine factor intensity of an industry as Mahadevan does.

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[6] Refer to Chapter Two, Section 2.4.1

A Cobb-Douglas Production Function can provide other implications. In Lin (2002), the Cobb-Douglas model is specified and estimated for Taiwan and Japan's construction industries using firm-level data. Moreover, the author selects two different product inputs: asset and labour, for construction firms because of the unique characteristics of the construction industry. He creates cost functions for the construction industries in Taiwan and Japan with the aid of the coefficients of the independent variables obtained from the estimation of Cobb-Douglas Production Functions. He concludes that Taiwan's firms have a lower cost than Japan's when output is small. However, Japan's firms can have the cost advantage over Taiwan's firm when output becomes bigger and bigger. These results could match the real situation in construction nowadays because the economy of scale for Japan's firms is much larger than Taiwan's.

Ruben and Leyman (2004) base on a representative survey of landed households located in Nicaragua, where agriculture is an important component of rural livelihoods, to analyze the underlying differences in farm household characteristics, assets and wealth, and efficiency of production systems as possible reasons for staying in or exiting from the cooperative framework. For detecting the factor productivity of different farms, the authors apply the Cobb-Douglas Production Function to test the significance of various variables like labour, machinery, animals, etc. They obtain a negative and statistically insignificant coefficient for the independent variable labour and explain that such result may be due to excessive labour on Nicaraguan farms. This overloading problem is common as in rural areas land quality is poor and off-farm employment options are limited.

3.4 Summary

TFP can help formulating strategies because it reflects information like efficiency and technical change, so it shall be adopted in this study. Labour productivity is not chosen because of its incomprehensiveness. To measure TFP, both Chau and Walker (1988)'s methodology and Cobb-Douglas Production Function are applicable. Chau and Walker's methodology requires more data and is more complicated while Cobb-Douglas Production Function requires less and is simpler. Therefore, for the purposes of this study, which are the determination of labour-intensiveness of Hong Kong's construction industry and the evaluation of the industry's productivity, the Cobb-Douglas Production Function will be good enough. Furthermore, a Cobb-Douglas Production Function can give us plenty of implications which allow us to get an insight of a firm or an industry.

4 ADVANCED CONSTRUCTION TECHNOLOGIES

4.1 Introduction

Construction industry always gives us such impressions: backward, low productivity and labour intensive. It seems that construction industry has a poor record on innovation, when compared with other manufacturing industries such as automobile or electronics. However, some people have doubts on the justification of this charge. No matter this charge is right or wrong, innovations of building processes and methods are increasingly viewed, industry-wide, as a critical means for achieving greater productivity (Ganesan *et al*. 1996, p.99). One type of innovations of building processes is the adoption of advanced construction technologies.

4.2 Common Problems Relating to Labour and Capital

4.2.1 Poor labour quality

Rowlinson (2003, p.241) lists out the unique features of the Hong Kong construction industry; one of them is the low levels of skill development and training of workers. The skill levels of local construction workers have been declining. CIRC (2001) points out the reluctance of workers in construction industry to upgrade their skills due to an absence of a clear career path. The industry also faces difficulty in retaining quality workers as a result of unstable employment. As a consequence, the productivity and workmanship of the workforce are adversely affected.

In fact, poor labour quality also has negative impact on safety performance of contractors, and hence lowers their productivity. Rowlinson (2003, p.226) identifies this problem and suggests that staff training on safety standards, statutory requirements and craft skills will be able to reduce risk.

4.2.2 Lack of new technology

Sumanth (1998, p.3) defines technology as "means to accomplish an objective or task". There are four basic types of technologies: product technology, process technology, information technology and managerial technology. In this study, product technology and process technology are concerned.

Unlike factory-based industries like car manufacturing and food production, technological development in construction industry is slow. Paulson (1985) emphasizes that fast-changing, field-based, project-oriented industries like construction are severely handicapped by their lack of accurate, timely and systematic technical, cost, and production data from ongoing operations. Rowlinson and Walker (1995, p.18) describe construction industry as a "relatively low technology" industry. Although advanced technologies are available in Hong Kong, they are not commonly adopted in practice. For example, traditional reinforced concrete with timber formwork is still used in many buildings in Hong Kong.

4.3 Call for an Efficient, Innovative and Productive Construction Industry

4.3.1 What can advanced technology bring to us?

Due to poor labour quality and low technological level, people involving in the construction sector have requested a reform for the industry – to reduce the use of labour and to adopt new construction methods and new technologies.

CIRC (2001) identifies ten cost drivers which give rise to high construction cost in Hong Kong. Two of them relate to factor intensity of construction industry and labour quality. The problems arose in the construction workforce in Hong Kong are:

(i) Prevalent use of labour-intensive, in-situ construction methods, which necessitates more supervisory efforts and leads to high material wastage; and
(ii) low labour productivity and shortage of skilled labour supply during construction peaks

CIRC (2001) then suggests eight measures to improve the cost-competitiveness of local construction. Among those measures four of them relate to new construction methods or advanced technologies:

(a) Wider use of standardisation in component design and processes to eliminate waste and inefficiencies;
(b) a manufacturing approach to construction through wider use of prefabrication;
(c) wider application of information technology in project implementation; and
(d) investment in construction-related R&D.

In fact, before CIRC's report, many researchers have advocated adopting modern construction technologies. Paulson (1985) recommends the construction industry to give more attention to automation and robotics as promising means to solve, or facilitate, some of the major problems emerged in productivity, safety and quality aspects of the industry. It is believed that automation will contribute to increased productivity and improved quality and safety. Skibniewski and Chao (1992) affirm this point and assure that new technology can offer long-term opportunities, business competitiveness, or even survival of the company. Navon *et al.* (1993) think that this belief has led both practitioners and especially researchers to develop automated systems for well over a decade, yielding results that can eventually be implemented in the field. Ganesan *et al.* (1996, p.6) propose that labour requires replacement, especially the unskilled and to a lesser degree the skilled grades of labour, with other resources such as construction plant, energy, management personnel, sophisticated computer systems and so on. The authors list out many labour intensive activities commonly found in construction industry, such as excavation, piling, concreting, rendering, painting, building services works, etc. and urge for further reduction of labour use through mechanization, prefabrication and standardization.

Kangari and Halpin (1989) say that the benefits of advanced construction technologies are basically due to productivity improvement, quality improvement, and savings in skilled labour. These technologies can help to solve the labour-intensive problem and succeed in substituting labour in dangerous or unhealthy working environments. Examples are given in Paulson (1985), Pau *et al.* (1993), Warszawski and Rosenfeld (1994), Nam and Tatum (1992), IAARC (1998), Coble and Haupt (2000), and Kahane and Rosenfeld (2004). However, as mentioned in previous section, the use of these technologies is not common in Hong Kong, though they are available in the market.

4.3.2 Reasons for the "backwardness" of construction industry

Plenty of new construction technologies and techniques are available in the market. According to Webster (1994), many construction robotics and innovative construction methods are present in Japan's construction industry, including steel-welding machines, super concrete column, robotized wall erection system, Obayashi's Automated Building Construction System, Fujita's Automatic Vertical Transport System, etc. The author outlines Japanese firms' technological capabilities, their R&D activities, and various aspects of Japan's construction industry. His works show that Japanese industry's best R&D efforts are creative and significant, and the radical automation systems explored promise potentially huge gains in productivity. Kangari and Miyatake (1997) also describe the smart building automation technology (SMART) and its application and adoption in Japan's construction industry. IAARC (1998) lists and describes 76 working robots and automated machines in construction industry. The list of companies contributing to the catalog includes Japanese construction companies and a large contingent from France, Sweden, the UK and

USA. This catalog shows that advanced technologies in construction are not rare.

Backward is a relative term and so has to relate to something. The term implies that technological advance is a comparable process along which all productive activities can be ranked, with building seen as much lower down the scale than other industries (Ball 1988, p.31). Hong Kong construction industry is backward because it does not use so many construction robotics as Japan or other developed countries do; even practitioners in Hong Kong have tried some new construction methods, e.g. prefabrication of building structures and slip-form construction, there is still lots of room for improvement. According to AsiaConstruct Team (2002), the construction industry in Hong Kong has remained prudently conservative when it comes to application and research of new technology. Some degree of mechanization could be seen with public housing construction where large panel formwork, tower cranes, concrete pumps and other mechanical equipment and plants are used. The use of standardized and modular building components can also be found in many construction projects, particularly in public housing developments by the Hong Kong Housing Authority. However local contractor's technological ability is poor compared to international standards.

Although the introduction of mechanization and prefabrication has successfully reduced the labour-intensive nature of part of the construction procedures, many construction activities still rely heavily on skilled and unskilled site-based labour. Both Rowlinson and Walker (1995, p.27) and Ganesan *et al*. (1996, p.41) recognize such labour utilization trend in the construction industry of Hong Kong.

AsiaConstruct Team (2002) reports that the Hong Kong construction industry undertakes a negligible amount of R&D activities. There are no major efforts coordinated by the Hong Kong Government or the industry to raise the general technology level in construction. Expenditures on R&D by local contractors, particularly the indigenous local contractors, are practically nil. In 1998, Hong Kong's expenditure on scientific and technological R&D amounted to only 0.25% of its GDP and ranked fortieth among forty seven major countries and regions. Serious competitors of Hong Kong, such as Taiwan and Singapore, ranked eleventh and fourteenth respectively, while China ranked thirtieth and India, thirty-second. Only 1.5 persons per one thousand Hong Kong people were engaged in R&D work (AsiaConstruct Team 2002). Even there are new construction methods found in Hong Kong, Ganesan *et al.* (1996, p.51) point out that advanced construction techniques used locally are acquired when foreign construction firms form joint-ventures with large local contractors. Hong Kong construction practitioners have not developed any new technologies or techniques for themselves.

Rowlinson and Walker (1995, p.18) provide two reasons for the lack of investment in R&D work and modernization in Hong Kong construction industry, they are:

(i) the ease of entry into the industry, which requires minimum capital, resulting in the proliferation of small firms; and

(ii) the unpredictability of the market leading to an uneven workload and lack of stability in companies.

Rowlinson and Walker focus on the market or industry levels and their explanations do not touch the issues of contractor's or client's attitude. On the other hand, Skibniewski and Chao (1992) try to analyse the problem from construction practitioners' points of view. They say that the process of introducing new technologies to the construction industry has been seriously hindered by conservative attitude because the inherent risk of applying a new, unproven device or technique is often deemed to be prohibitive for a construction firm. Equally important is the fact that the industry is frequently unable to appreciate the strategic significance that innovative technologies can bring. Kangari and Halpin (1990) also indicate that the industry traditionally has modified existing and proven practice to achieve improvement rather that trying entirely new methods.

Navon *et al.* (1993) make a summary of the resistance to automation and robotics in manufacturing and apply it to construction industry. The authors think that fear of employment instability is the most common reason for resistance because construction workers may fear that labour-cost savings brought about by automation may be at the expense of their job and automation could lead to discontinuous employment. The authors also think that workers may doubt their ability to make the necessary adjustments required for automation. One interesting point raised by the authors is the impact of technology on social and interpersonal relationships. The authors recognize that making social work relationships is an important element of job satisfaction; hence, it is expected that construction workers fear the loss of these relationships due to the introduction of technologies since technologies are expected to reduce crew sizes.

While Navon *et al.* try to analyse the problem from worker's psychological point of view, Mezher *et al.* (1998) address project constraints and owner-induced constraints to the use of advanced technologies. The authors identify that bidding practices, construction specifications, financial constraints, site-related conditions and government regulations could be potential obstacles to the adoption of advanced construction technologies. For bidding practices, a client usually awards projects on the basis of the lowest-bid price so technologies that may offer both marginal schedule and quality benefits but not to reduce bid prices will most probably be deemed infeasible by contractors. The descriptive specification method would also severely hinder the application of newer techniques as outdated requirements may be specified by clients. Financial constraint is obviously an obstacle because without money, the contractors cannot invest in technologies and maintain them afterwards. Regarding the technical problems, since different sites have different features, it is difficult to make new construction equipment that can fit for any site conditions. The authors regard governmental economic policies such as high taxes on imported goods as obstacles to the diffusion of technologies. However, this reason is not applicable to Hong Kong because the government imposes no tax on imported construction technologies.

From Navon *et al.* and Mezher *et al.*, we get a comprehensive overview of the barriers to the adoption of advanced construction technologies. These barriers contribute infeasible the use of technologies and cause the industry to become backward.

4.4 Feasibility Studies of Advanced Construction Technologies

Ganesan (2000, p.6) considers a technology is appropriate for construction if it represents that combination of resources, techniques and procedures most likely to satisfy the social and economic goals of the sector. Researchers have strived to formulate better feasibility analysis techniques which can be applied to construction technologies. However, in a business world like Hong Kong, contractors usually concern the economic goals that can be achieved by using advanced technologies more. Therefore, an advanced technology will only be adopted if it is economically feasible. Ball (1988, p.40) pinpoints this issue, he says: “Under capitalism, building is for profit, so those products will be constructed which yield the greatest profit, using techniques that do the same.”

Kangari and Halpin (1989) present a feasibility analysis of robotization of different construction processes by evaluating these processes and assigning feasibility ratings to various aspects of these processes, with high ratings indicating a feasibility of automation. Kangari and Halpin (1990) then construct a fuzzy set evaluation model consists of three parts: linguistic analysis, evaluation and translation, for feasibility analysis of construction robotics. Major factors in robotization of construction processes are identified as: need, technology and economics. Skibniewski and Chao (1992) think that it is difficult to quantify the intangible benefits of advanced construction technologies and the risks involved in implementing such technologies with the use of traditional economic analysis techniques. Therefore, they propose using the analytical hierarchy process (AHP) to compare the relative influence or contribution of each technology alternative, favourable and unfavourable, on the decision maker's goals and concerns. Mezher *et al*. (1998) apply a heuristic rule-based procedure for identifying the barriers in adopting advanced construction technologies and the results are used to evaluate the feasibility of an advanced technology.

However, the authors do not provide a clear technique for assessing economic feasibility. From a client's point of view, methods like AHP or heuristic rule-based procedure are logical and scientific but do not have any particular significance because they fail to convey an important message to the client – the actual amount of benefits. Warszawski (1999, p.400) emphasizes the importance of this matter: "In the risky, volatile and highly conservative construction environment the economic benefits of robotization must be clearly visible to management, even when not easily quantifiable, to justify the significant long-range commitment to implementation."

As a consequence, Warszawski (1999, p.408) proposes another method to assess the economic feasibility of robotization. The author breaks down the total cost of robotization into the direct cost of robotized work and the indirect costs: the capital cost of the robotized system, the cost of maintenance of the robot, and the cost of the robot's setup and transfers. This total cost will then be compared with the total cost incurred using conventional method. Warszawski (1999, p. 413) also presents a simplified economic valuation by equating the amount of benefit with the sum of total cost and initial investment, which aims at finding out the maximum feasible investment (breakeven value) for robotization. In fact, Warszawski and Rosenfeld

(1994) have applied similar method to study the feasibility of a robot for interior-finishing works in building before. Such approach is then followed by Kahane and Rosenfeld (2004) in examining and comparing the viability of block laying and wall painting robotic systems.

4.5 Summary

Low labour quality and low technological level have rendered Hong Kong construction industry underachieving. It is generally believed that substituting advanced construction technologies for labour is a way to remedy the current situation and sustain the competitiveness of firms in the industry because advanced construction technologies can help improving productivity, quality and safety. Unfortunately, due to contractor's conservative attitude and their lack of financial backup as well as client's outdated specifications, even there are plenty of applicable technologies, the construction industry remains backward.

To persuade practitioners to use advanced technologies, it is necessary to prove these technologies' feasibility. However, many researchers' methodologies may not be useful to clients because they simply underestimate the importance of providing a clear figure on the amount of benefits that an advanced technology can bring. Warszawski (1999)'s method seems more convincing than the others because it can come up with a breakeven value which can actually tell the client the amount of money he/she should invest in a technology.

5 METHODOLOGY

5.1 Phase I – Testing the Labour Intensity and VATFP of Hong Kong Construction Industry

5.1.1 Cobb-Douglas Production Function

Which factor of production is utilized in a larger proportion in Hong Kong construction industry? Labour or capital? If we cannot answer this question, then we cannot tell whether the industry is labour intensive or not. Fortunately, the Cobb-Douglas Production Function provides us a convenient way to get the answer.

Cobb and Douglas (1928) first proposed a production function to measure the changes in the amount of labour and capital which have been used to turn out a certain amount of construction products and to determine what relationships existed between the three factors of labour, capital and product. Consider a production function with two inputs - capital (K) and labour (L) which are combined to produce a unique maximum quantity of output (Q):

$Q = f(K, L)$ [5.1]

The function f defines the technical relationship between the two inputs and output. A Cobb-Douglas Production Function has the following form:

$Q = AK^{\alpha}L^{\beta}$ [5.2] where A, α and β are constants.

In Equation [5.2], α and β represent the capital and labour shares respectively. The production function is then estimated by ordinary least square (OLS) regression as a line of best fit through the sample data. The data are from a sample period. This is a kind of parametric estimation. To make regression easier, Equation [5.2] is transformed into Equation [5.3] by taking natural logarithm on both sides of the equation which yields:

$$\ln(Q) = A + \alpha \ln(K) + \beta \ln(L) \qquad [5.3]$$

A is a residual which absorbs any increases in output not accounted for by the growth of explicitly recognized inputs. The estimates of α and β are interpreted as output elasticities with respect to inputs and usual assumption is that constant returns to scale prevail, i.e. $\alpha + \beta = 1$.

5.1.2 Value added measure

In construction industry, apart from capital and labour, there are many other inputs including materials, energy, overheads, etc. They are collectively known as intermediate inputs. Therefore, intermediate inputs should be included on the right hand side of Equation [5.2] as independent variables to make it become the true production function for construction industry. However, intermediate inputs comprise of many different kinds of things, there is no appropriate deflator for intermediate consumption in Hong Kong and perhaps the choice of a general price deflator like GDP deflator could result in an implausible coefficient for intermediate inputs or even distort the validity of the production function. Because of the undesirable effects created by intermediate inputs to the model, Mahadevan (2004, p.84) applies the value added method to eliminate the use of intermediate inputs in estimating a Cobb-Douglas Production Function for Hong Kong's manufacturing sector from 1983-1999. Hence, this value added measure is adopted in this study for similar reasons. This is valid because the aim of this analysis is to investigate the influences of labour and capital on output only.

According to Census and Statistics Department (2004f), Hong Kong construction industry's value added equals to:

gross output - value of sub-contract work rendered by fee sub-contractors - consumption of materials and supplies; fuels, electricity and water; and maintenance services - rent, rates and government rent for land and buildings - rentals for hiring machinery and equipment - other operating expenses (excluding interest payments)

In other words, value added is the difference between gross output and intermediate inputs. If value added is used to substitute the quantity of output (Q), then only capital and labour will be needed to count as inputs in the production function. As a result, intermediate inputs can be ignored and the production function for construction industry remains the same form as Equation [5.2] (and so for Equation [5.3]), while Q becomes the value added construction output. In this case, any change in value added will be due to changes in labour and/or capital proportionately.

5.1.3 Dependent variable and independent variables

Then how can we prepare suitable data for the Cobb-Douglas Production Function so as to achieve the objective of this study?

The dependent variable in the value added production function is the value added construction output (Q). Its meaning is defined in previous section. It is deflated by an output price index (OPI) constructed based on the methodology proposed by Chau and Walker (1988). The methodology is outlined below:

The OPI is obtained by adjustment of a combined tender price index which is a weighted average of the public sector ASD tender price index (TPI) and private sector tender price indices, where the weights are calculated as relative proportions of total expenditure in all building works in private and public sectors. The TPI for private sector is calculated as a geometric mean of tender price indices constructed by two quantity surveying firms in Hong Kong - Levett & Bailey Chartered Quantity Surveyors Ltd and Davis Langdon & Seah Hong Kong.

Capital (K) is one of the independent variables of the production function. Since the book values of plant and machinery owned by construction firms in Hong Kong are not published by the Census and Statistics Department or any other bodies, it seems that gross additions to fixed assets is by far the most suitable data to represent capital stock owned by construction firms because fixed assets include construction plant and machinery. According to Census and Statistics Department (2004f), gross additions to fixed assets equal to acquisitions of fixed assets minus proceeds from disposal of fixed assets, i.e. the net amount of capital stock owned by a construction firm in a particular year. Chau and Walker (1998) say nearly all plant used in the construction industry is imported and hence unit value index (UVI) of imported capital goods is used to deflate capital prices.

Another independent variable is labour (L) which represents the number of people directly engaged in the construction industry in a particular year. According to Census and Statistics Department (2004f), number of persons directly engaged = number of working proprietors, active partners and unpaid family workers + number of direct employees, comprising operatives and other employees.

All prices are to be deflated to constant prices as at the year 2000 to strip out the effect of inflation.

5.1.4 Determination of factor intensities

The production function (Equation [5.3]) will be set into the statistical package

(EView 3.0) and all data will be inputted accordingly.

It is expected that both capital (K) and labour (L) will have positive coefficients in the OLS estimation because they are both inputs to the production system. More inputs will generate more outputs. After obtaining the estimates of α and β, the factor intensity of labour input can be known. As β is the index for labour input, if it is larger than that of capital input, i.e. α, it means labour has a greater influence on construction output. This result implies that the industry is labour-intensive as the trend is to use more labour than capital. Otherwise, the industry is capital-intensive.

5.1.5 Test statistics

Three test statistics, which are t-statistics, the coefficient of determination (R^2) and F-statistics will be employed in the model. These three tests are used to investigate the significance of the coefficient of each independent variable, which indicate the effect of the independent variables on the dependent variable and the proportion of the variation of the dependent variable explained by the independent variables. The theoretical framework behind these three tests is described below:

5.1.5.1 Coefficient of determination – R^2 and adjusted R^2

R^2 ranges from 0 to 1 and it indicates the proportion of variation in the independent variable explained by the variation in the independent variables. It is often used as a measure of goodness of fit. However, R^2 increases as more independent variables are added to the model irrespective of whether these variables are significant, so adjusted R^2 gives more plausible result.

Adjusted R^2 is a measure of the proportion of variance of the dependent variable explained by the variance of independent variables. The higher the value of adjusted

R^2, the more explainable the model is. For example, if $R^2 = 0.98$, that means 98% of the variation in the dependent variable is due to the independent variables. The remaining 2% variation of the dependent variable cannot be explained by the independent variables in the model.

5.1.5.2 F-statistic

The F-statistic is used to test the significance of the R^2 statistics. The null hypothesis is none of the independent variables helps to explain the variations of the dependent variable about its mean. If this null hypothesis is rejected, it means at least one independent variable helps to explain the variation.

Like t-test, whether the null hypothesis is rejected or not depends on the critical value with respect to a given degree of freedom and level of significant (5% in this study). If the calculated F-value is greater than the critical one, the null hypothesis is rejected. It is the additional evidence to show the significance of the results.

5.1.5.3 t-test and p-value

It tests the statistical significance of the effect of the independent variable Xi on the dependent variable Q. The value of t depends on b_i and Sb_i and $t_i = |b_i/Sb_i|$ where b_i is the beta coefficient and Sb_i is standard error of coefficient. Hence, the larger the t-value, the more likely that the hypothesis of zero coefficient is rejected; and thus the estimate is more accurate. Before doing the test, an accepted confidence interval has to be established first. A 95% confidence level (CL) is used in this study. The calculated t-value is then compared with a critical t-value for a given degree of freedom and a given confidence level. If the calculated t-value is higher than the critical t-value for a 5% significance level, then the coefficient bi is said to be significant at the 95% CL.

Probability value (p-value) is also used to find out the significant level of the coefficients. It shows the chance that the estimated coefficient is equal to zero. The smaller the p-value, the more significant the estimated coefficient is. Given a p-value, the estimated coefficient is significant at the x(x>p) level.

It should be emphasized that the statistical significance shown by t-values or p-values is conceptually different from the magnitude of the effect of X_i on Q because the coefficient of X_i can be significant but its effects on Q can be small.

5.1.6 Diagnosis tests

After estimating the coefficients of the production function, the validity of the results has to be tested to ensure any subsequent interpretations made based on the results are reliable. OLS estimation has 3 major technical problems related to data. They are autocorrelation, multicollinearity and heteroskedasticity. The diagnosis tests aim at identifying these problems. If such problems are found in the OLS estimation model, the model will be corrected with appropriate methods as specified below.

5.1.6.1 Autocorrelation

Autocorrelation arises if error terms of the observations are correlated, i.e. cov $(e_i, e_j) \neq 0$ for all i, j and $i \neq j$. It occurs most likely in time series data. Positive autocorrelation is exhibited when a positive (negative) disturbance term in one period may be associated with a positive (negative) disturbance term in the next. Negative autocorrelation is exhibited when a positive (negative) disturbance term in one period is associated with a negative (positive) disturbance term in the next. Positive autocorrelation can result in obtaining larger t-value than the actual t-value. Subsequently, the coefficients that are in fact insignificant may be shown to be significant using standard t-test.

First order auto-correlation can be tested using Durbin-Watson test (DW test). The closer the DW value to 2, the less likely that there is first order autocorrelation. Second order auto-correlation can be tested using the Breusch-Godfrey Lagrange multiplier test.

To remedy autocorrelation, autoregressive components acting as regressors can be added to the model and EView 3.0 has such a built-in function.

5.1.6.2 Heteroskedasticity

Heteroskedasticity occurs when variance of the error terms are not the same, i.e. Var (e_i) ≠ constant. This will make the partial regression coefficients to be either too large or too small, depending on the exact pattern representing the heteroskedasticity. It is because heteroskedastic conditions mean that some variances are larger than others. If all variances are assumed to be of equal size and equal weight, as they are done in OLS, then the variances will be overweight in their importance. This means although the variance still has a mean of zero and is normally distributed, the OLS estimator is no longer the best estimator.

White Heteroskedasticity Test examines the problem of heteroskedasticity in a model. The multiple of observations and R^2 (Obs* R-squared) will be compared with the critical value of Chi-squared test at a particular degree of freedom and at a particular confidence level. If the Obs*R-squared value does not exceed that critical value, the null hypothesis of no heteroskedasticity is not rejected. To remedy heteroskedasticity, weighted least squares method can be used.

5.1.6.3 Multicollinearity

When two or more independent variables are highly correlated with each other, multicollinearity arises. This will cause the t-values to be underestimated and create difficulties in replicating results with slightly different data sets on the same variables. Multicollinearity can be tested with the examination of correlation matrix. The closer the correlation value between two independent variables to 1, the more likely that these two variables are correlated.

To remedy multicollinearity, correlated variables are dropped or ridge regression is used. If hypotheses are confirmed irrespective of the underestimated t-values, this problem can be ignored.

5.1.7 Calculating VATFP growth

Many people claim that the productivity of Hong Kong construction industry has been declining, but lots of buildings have also been accomplished in a rate faster than a decade ago. Which statement is correct then? Therefore, after testing the labour-intensiveness of the construction industry, it is necessary to investigate the industry's VATFP growth to see how productive it performs.

VATFP growth reflects the combined effects of disembodied technical change, economies of scale, efficiency change, variations in capacity utilization and measurement errors (Schreyer 2001, p.16). Based on the parameter estimates, the sources of value added output growth in Hong Kong construction industry can be calculated as follows:

$dT/T = dQ/Q - (\alpha\ dK/K + \beta\ dL/L)$ [5.4] where dT/T = change in VATFP

Through Equation [5.4], the change in VATFP can be calculated by knowing the changes in value added output, capital and labour. The change in VATFP will be measured in a 3-year period.

5.1.7.1 Data sources and data series

Hong Kong construction industry's value added outputs, gross additions to fixed assets and number of labour engaged are collected from Census and Statistics Department (2004f). The UVIs are obtained from Census and Statistics Department (2004g). Regarding the public TPIs, they are collected from the Architectural Services Department (2004) while the private TPIs are collected from the two quantity surveying firms – Levett & Bailey Chartered Quantity Surveying Ltd (2004) and Davis Langdon & Seah Hong Kong (2004).

The data used are published annually; if not, they are converted to annual basis to assure unity. All data series are from 1985 to 2002.

5.2 Phase II – Economic Analysis of Advanced Construction Technologies

5.2.1 Introduction

When we talk about innovation in the construction industry, advanced construction technology is always one of its elements; and it has been treated as a possible way to tackle the labour-intensive problem arisen in the industry. However, not many people acknowledge the effectiveness of these technologies. Therefore, the purpose of this analysis is to investigate the economic feasibility and user benefits of different advanced construction methods. An economic evaluation model proposed by Warszawski (1999) is adopted in this study. For simplicity, the term "robot" in this section means any new construction machineries which are more advanced and productive which may not be a pure robot in common sense.

Ganesan *et al.* (1996) identify several labour-intensive construction activities and suggest they could be replaced by more advanced construction methods. Warszawski and Navon (1998) investigate the applications of robots in different areas of construction. Four construction activities with robot applications which are currently employed in other countries are selected for this study:

A. Concrete placing,
B. Pile driving,
C. Painting; and
D. Placement of boards.

5.2.2 Cost of robotization

The most important barrier to the implementation of advanced technologies in building construction is its utilization costs. In simple terms it requires that the benefits – preferably tangible benefits like reduction in cost or gain in efficiency – derived from the technology's employment will exceed its utilization costs.

Warszawski (1999, p.408) suggests that the total cost of robotization of a construction task is composed of the direct cost of robotized work: the costs of operator, materials, auxiliary labour, etc. and the indirect costs: the capital cost of the robotized system, the cost of maintenance of the robot, and the cost of the robot's setup and transfers. He then focuses on several key parameters – the cost of labour saved, the cost of transfer and the extent of employment to derive a model to judge the economic potential for robotization.

5.2.3 Assumptions of Warszawski's model

1. A uniform labour wage for all types of labour engaged in robotization is assumed.
2. The total transfer cost is assumed as being directly proportionate to the number of transfers between sites. The cost of transfer between the sites includes the dismantling of the robot, its transfer to the new site, and its setup. It is in most cases the dominant component of the total transfer cost. The cost per transfer in the model will include therefore the transfer cost between the sites and the average cost of transfer onsite. The latter comprises the transfer between locations and between workstations and depends on the nature of the building and of the composition of its finishing operations.
3. The terminal value of the robot at the end of its economic life is negligible.

The above assumptions enable approximate calculation of the maximum feasible investment in the robotization of construction processes under different circumstances pertaining to its most important variables: labour wages, the number of work hours per year, the size of an average project, and the cost per transfer of the robot.

5.2.4 Assessment of economic feasibility

In Warszawski's model, the maximum feasible investment is calculated in Equation [5.5] as a breakeven value of the investment for which the annual benefit B from the robot's use cove its annual cost C.

$C = V \times pr(i,n) + C_m + (H/h) \times C_t + H \times C_e$ [5.5]

$B = H \times k \times C_l + I$ [5.6] where

V = the maximum economically feasible investment in a robot (breakeven value)

H = the total number of robot working hours per year

$pr(i,n) = i(1+i)^n/[(1+i)^n-1]$, a capital recovery factor of the investment over a period of n years with an interest rate i. It is used to find out the opportunity costs associated with the decision to adopt a robot because the money invested can be saved into a bank for interest.

h = the average number or robot working hours per site

C_t = an average setup and transfer cost per site (all types of transfers)

C_e = the energy cost of the robot per hour

k = the number of labour hours saved per hour of robotized work

C_l = average labour cost per hour

I = intangible gains of robotization per year

C_m = the cost of maintenance per year = $0.1V + 0.06H \times C_l$, i.e. the annual maintenance includes repairs and replaced parts at 10% of the initial investment in the robot, and a routine maintenance equivalent to the cost of 6% of the working hours of the robot per year (Warszawski and Rosenfeld 1994)

When C=B, that means the annual cost C is covered by the benefit B and hence a breakeven point is achieved. If C>B, the V value will be negative or smaller than the market price of the robot, so the benefits of robotization cannot cover the cost and the robot is not economically feasible. On the other hand, if C<B, the V value will be larger than the market price and the amount of benefits is greater than the cost so the robot is economically feasible.

Sometimes contractors do not own a robot; instead, they rent it from the owners. If they want to know if the rents they paid for the robots are reasonable, the above model cannot help because it is for assessing the feasibility of investing a robot; it does not assess that of renting a robot. Therefore, it is modified to make it suit for this purpose.

Since the robot is rented, it is expected that it will be fully utilized on site by the contractor. In such case, the H/h ratio is 1. H in this case will be the total number of robot working hours during the rental period. In addition, if a contractor rents a robot, he does not need to spend money on robot maintenance, i.e. C_m can be omitted. As a result, Equation [5.5] can be modified as:

$$C = R \times pr(i,n) + C_t + H \times C_e \qquad [5.7]$$

where R = the maximum economically feasible rent for a robot (from a borrower's point of view)

Equation [5.6] remains unchanged in the modified version of the model. If R=B then the rental cost is covered by the benefits of robotization and thus a breakeven value is achieved.

In the result tables, all V (R) values of the robots which are greater than or equal to market price (rent) of the robots will be bold and Italic.

5.2.5 Parameter values assumptions

In this study, the following parameter values are assumed:

1. The transfer cost of robot is $2,000 per site; if the robot is delicate, say it incorporates a computer system, the cost will then be $5,000 per site.
2. The energy cost of using the robot is $16 per hour. This rate is estimated from Warszawski (1999, p.414).
3. The interest rates used in the model are of two types: HKD deposit rate (0.01%) for long term saving, fixed deposit rate (0.5%) for short term saving[7]. As a result, two capital recovery factors are obtained – for long term, the recovery factor is 0.203 while for short term the recovery factor is 1.0001.
4. Since intangible gains are difficult to be quantified, they are assumed to be zero in calculations.

5.2.6 Possible cost reduction calculation

This calculation can be served as a sample to show that how much benefits an advanced technology can give to user. In this section, a brief description is given to both conventional and advanced construction methods. Both methods will be applied to the same construction task and the total construction cost is estimated for each method. The total construction cost is estimated by breaking it down to three elements: labour cost, material cost and plant cost, as mentioned in Spence (1996, p.10).

Total costs of performing the task by conventional and advanced methods will then be compared and the possible cost reduction can be obtained consequently. If advanced methods do not generate any cost reduction, that means they are not worthwhile to

[7] The interest rates are obtained from HSBC's website. Available from http://www.hsbc.com.hk/script/hk/personal/invest/deposit/defaultb.asp#fold [Accessed on 25 December 2004]

use.

5.2.6.1 Data sources

All the cost data and rates used in this study are collected from Wessex Electronic Publishing Ltd (2002) and Davis Langdon & Everest ed. (2001), unless or otherwise specified. Since the cost data in these sources are expressed in London GBP, so the unit is changed back to Hong Kong Dollar (HKD) in this study. The exchange rate of HKD against London GBP is provided by HSBC as at 20 November 2004[8].

[8] Available from http://www.hsbc.com.hk/hk/commercial/intbiz/import/ib10905s.htm [Accessed on 20 November 2004]

5.3 Phase III – Examining Construction Practitioners' Viewpoints towards Advanced Technologies

One of the purposes of this study is to investigate and explain the phenomenon of slow spreading of new construction practices and technologies in the industry. The previous quantitative analyses can only reflect the current situations, but they cannot explain them. Therefore, it is necessary to interview construction practitioners so as to find out the reasons that lead to their attitude and behaviour.

Mezher *et al.* (1998) identify different forms of constraints hindering the adoption of advanced technologies in construction industry. These constraints are:

1. Bidding practices and contract specification – contractors are not motivated by clients to adopt advanced construction technologies and sometimes contractors are told to use outdated construction methods.
2. Financial constraints – contractors cannot afford heavy investment on advanced technologies
3. Human resources – current practitioners are not technically competent to adapt to new technologies.

Interview questions 1-5 will be set according to these aspects to examine the attitude of interviewees while questions 6-7 let interviewees express their opinions on the slow diffusion of advanced technologies in the industry (see Appendix 4). Contractors (including sub-contractors) are the parties that use advanced construction technologies, so their viewpoints have direct impacts on the adoption and diffusion of technologies, and they should be well aware of the pros and cons of advanced technologies. In order to minimize possible variation, professionals on client's side (e.g. developer's project manager or quantity surveyor) will not be interviewed because they have different opinions on the adoption of technologies.

6 FINDINGS AND ANALYSES

6.1 Phase I – Testing the Labour Intensity and VATFP of Hong Kong Construction Industry

6.1.1 Ordinary least square estimation

The data are regressed by using ordinary least square (OLS) method and a parametric estimation of the production function (Equation [5.3]) are shown as follows:

$$\ln(Q) = A + \alpha \ln(K) + \beta \ln(L) \qquad [5.3]$$

Dependent Variable: LOG(Q)
Method: Least Squares
Sample: 1985 2002
Included observations: 18

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(L)	1.325727	0.266169	4.980766	0.0002
LOG(K)	0.201248	0.083842	2.400340	0.0298
A	-0.815987	2.613416	-0.312230	0.7592

R-squared	0.822548	Mean dependent var	17.68697
Adjusted R-squared	0.798888	S.D. dependent var	0.292350
S.E. of regression	0.131106	Akaike info criterion	-1.074615
Sum squared resid	0.257830	Schwarz criterion	-0.926219
Log likelihood	12.67153	F-statistic	34.76506
Durbin-Watson stat	0.663113	Prob(F-statistic)	0.000002

Table 6.1 OLS estimation of the coefficients of transformed Cobb-Douglas Production Function

6.1.2 Diagnosis tests

Before analyzing the results, the reliability of the OLS estimation model has to be tested to ensure any interpretations made subsequently are valid.

The result of the Durbin-Watson test shown in Table 6.1 shows that the problem of positive correlation is serious in this model because the value (0.66) is much smaller than 2.

The Breusch-Godfrey Lagrange multiplier test was carried out for determining second-order autocorrelation problem in the model and the results are as follows:

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	3.804563	Probability	0.050032
Obs*R-squared	6.645806	Probability	0.036048

Table 6.2 Breusch-Godfrey LM test results

Since the test value (Obs*R-squared value) is 6.65 which exceeds the critical value 5.99 [9], the null hypothesis of no serial correlation is rejected up to lag order 2 at 95% CL. Therefore, second-order autocorrelation exists.

White heteroskedasticity test (cross terms) was performed to test the heteroskedasticity of the model.

White Heteroskedasticity Test:			
F-statistic	0.879417	Probability	0.523493
Obs*R-squared	4.826927	Probability	0.437365

Table 6.3 White heteroskedasticity test (cross terms) results

The Obs*R-squared value is 4.83 which does not exceed the critical value 11.07 [10] of Chi-squared test, so the null hypothesis of no heteroskedasticity is not rejected at 95% CL.

A correlation matrix of the model is constructed to investigate the multicollinearity

[9] This critical value is computed by EViews, up to lag order 2 at 95% CL.
[10] Chi-squared distributed with degrees of freedom 5, at 95% CL.

problem. The results are as follows:

	LOG(K)	LOG(L)
LOG(K)	1.000000	0.488629
LOG(L)	0.488629	1.000000

Table 6.4 Correlation matrix of the Cobb-Douglas Production Function's independent variables

The results show that the independent variables are not highly correlated and multicollinearity is not severe.

The diagnostic tests showed that the OLS estimation does not suffer from heteroskedasticity and multicollinearity. However, there are first- and second-order autocorrelation problems so the model is corrected by adding first- and second-order autoregressive components to it.

Dependent Variable: LOG(Q)
Method: Least Squares
Sample: 1985 2002
Included observations: 18
Convergence achieved after 41 iterations

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(K)	0.168139	0.063218	2.659658	0.0196
LOG(L)	1.272809	0.285006	4.465899	0.0006
A	0.282284	3.673901	0.076835	0.9399
AR(1)	0.995013	0.266816	3.729212	0.0025
AR(2)	-0.497293	0.266048	-1.869190	0.0843

R-squared	0.916237	Mean dependent var	17.68697
Adjusted R-squared	0.890463	S.D. dependent var	0.292350
S.E. of regression	0.096757	Akaike info criterion	-1.603096
Sum squared resid	0.121705	Schwarz criterion	-1.355770
Log likelihood	19.42786	F-statistic	35.54985
Durbin-Watson stat	2.157300	Prob(F-statistic)	0.000001

Inverted AR Roots	.50+.50i	.50 -.50i

Table 6.5 OLS estimation of the coefficients of transformed Cobb-Douglas Production Function (with autoregressive error specification)

After all, it can be concluded that the OLS estimation in Table 6.5 is reliable and no further refinement of the model is required. Based on the parameter estimates, the sources of value added output growth in Hong Kong's construction industry was then calculated using Equation [5.4]: $dT/T = dQ/Q - (\alpha\ dK/K + \beta\ dL/L)$. The results are tabulated:

Period	*Value added growth*	*Capital input growth*	*Labour input growth*	*VATFP growth*
1985-1987	7.46%	24.75%	20.06%	-22.2%
1988-1990	29.52%	5.67%	8.87%	17.3%
1991-1993	31.90%	29.75%	11.17%	12.7%
1994-1996	12.72%	-21.79%	12.73%	0.3%
1997-1999	-0.32%	-6.08%	-6.39%	8.8%
2000-2002	-3.81%	-33.42%	-12.16%	17.3%
1985-2002	104.38%	59.45%	39.86%	43.7%

Table 6.6 The parametric estimation on sources of value added growth

6.1.3 Analysis of OLS estimation of production function

Table 6.5 shows that the adjusted coefficient of determination is about 0.92 which indicates that about 92% of the variations in construction output can be explained by the independent variables in the production function, which means this functional form is a good fit for the data. The F-statistic also confirms the significance of the R^2 statistic. The degree of freedom of this production function is 19 and the critical value at 95% CL is 2.131 [11]. We can notice that all t-statistics of the independent variables are larger than the critical value and are large enough to reject the hypothesis that the respective coefficients are zero at 5% level, i.e. all the empirical results of the independent variables are significant. The p-values which indicate the chance that the estimated coefficient is equal to zero further consolidates the validity of the

[11] Degree of freedom (df) =no. of observations - no. of independent variables (excluding constant) - 1=18-2-1=15. If the smallest t statistic obtained from the model is greater than the critical t statistic at 95% CL and 19df, then the null hypothesis of coefficient=0 can be rejected. Since $|t_{0.5/2,\ 15}|=2.131<$ 2.660, the hypothesis can still be confirmed.

coefficients because the smaller the p-value is, the more significant is the estimated coefficient. As a result, the independent variables' coefficients are statistically significant at 95% CL. However, constant A has a low p-value and it is statistically insignificant, which means the null hypothesis of zero coefficient cannot be rejected at 5% level.

By estimating the coefficients using OLS method and substituting the values into Equation [5.3], Hong Kong construction industry's production function can be written as:

$$\ln Q = 0 + 0.17 \ln K + 1.27 \ln L \quad [6.1]$$

Take the antilogarithms of Equation [6.1] to convert back the original form of the Cobb-Douglas production function in the form of Equation [5.2]:

$$Q = K^{0.17} L^{1.27} \quad [6.2]$$

In the empirical results, all the signs of the coefficients of the independent variables are the same as expected and significant. To increase construction output, it is necessary to increase inputs like capital resources and labour, holding technological level of the industry constant. Therefore, the variables ln K (capital) and ln L (labour) have positive coefficients (thus positive indices for K and L in the production function), which means when capital inputs and/or labour inputs increase, construction output will increase too.

The magnitudes of the coefficients also indicate the significance of the inputs in the industry. From the industry's production function, labour input has a larger coefficient than that of capital input, which means labour has a higher input share. Larger magnitude implies labour inputs have greater influence on construction output. This confirms that the construction industry in Hong Kong is labour-intensive as the industry will try to vary the amount of labour to control the output, rather than varying the amount of capital stock.

When both capital input and labour input are increased by m, then output will become:

$Q' = (Km)^{0.17}(Lm)^{1.27} = m^{(0.17+1.27)}K^{0.17}L^{1.27} = m^{1.44}Q$ where $m>1$

Obviously, an increase in inputs will lead to an increase output more than proportionately. The sum of elasticity of inputs ($\alpha+\beta$) is greater than 1. For a normal Cobb-Douglas Production Function, the sum of elasticity of inputs should be equal to 1 with constant returns to scale. Hence, the production function obtained exhibits increasing returns to scale. In this case, if fewer than h units are constructed, the unit price will be higher than that of exactly h units. This coincides with the current situation at firm-level that construction companies, including consultants and contractors, tend to pursue more jobs and produce more products like services and buildings, in order to achieve lower average cost per unit product. This can be done by sharing resources such as plant and machinery, personnel and materials, as well as spreading overheads over a large number of projects. Of course, another purpose of such action is to maintain cash flow for the company.

6.1.4 Parametric estimations on value added growth and VATFP

If the construction industry is really labour-intensive, then is its productivity declining as pointed out by some researchers?

The value added construction output grew from 1985-1996 reflecting the blooming stage of the construction industry in Hong Kong, but it dropped after 1997 (particularly after Asian Financial Crisis). This fall can be explained by 2 reasons: (i) in the private sector, Hong Kong was facing recession and the property market hit a trough, so less building and construction works were carried out and (ii) major infrastructure projects like the Hong Kong International Airport and Tsing Ma Bridge had been completed. As a result, both capital and labour input growth fell in this period.

Capital input growth was positive from 1985-1993 because construction firms acquired more plant and machinery to do construction works when the industry was blooming. From 1994-2002, capital input generally dropped more than labour input. This reflects that labour was difficult to be substituted by other inputs, or practitioners were reluctant to do so at that time. In addition, it may imply that labour was used to substitute capital stock, as plant and equipment required heavy investment which not many contractors had such ability and interest. As a consequence, labour did not drop as fast as capital did in that period. Again, this coincides with previous finding that Hong Kong construction industry is labour-intensive.

Except the period of 1985-1987, VATFP growth has remained positive over time. Since VATFP growth reflects the combined effects of disembodied technical change, economies of scale, efficiency change, variations in capacity utilization and measurement errors (Schreyer 2001, p.16), it shows that the construction industry has been able to sustain certain degree of productivity through improvements in general knowledge of labour, better management and organizational change which are disembodied technical changes as mentioned in Schreyer (2001, p.20), as well as gain in technical efficiency. Thus, the hypothesis: low productivity in construction industry is due to the lack of general knowledge of labour and poor project management, is rebutted.

It is interesting to observe a downtrend of VATFP growth in the period of 1994-1996, when the building industry was blooming. It is expected that contractors would increase their productivity so they could build faster and more in order to maximize their profits. Contrary, VATFP growth reduced in this period. This downtrend during construction industry boom can be explained as follows:

(i) The speed of construction was increased at the expense of a decrease in productivity, as there were overloading problems of workers on sites, lack of control of material wastage and efficient use of resources due to poor project management.

(ii) The capacity of the construction industry was not able to cope with the sudden extra demand for services and products, so less productive resources were attracted to the industry.

Overall, VATFP growth shows that there have been some improvements in productivity resulting from disembodied technical changes; however, labour is still difficult to be substituted or even be used to substitute capital stock in construction industry. Therefore, the labour-intensive nature of the industry is confirmed. Based on these findings, we then go on to find out the reason why labour is more preferred by testing the feasibility of adopting new technologies in construction works.

6.2 Phase II – Economic Analysis of Advanced Construction Technologies

Have you ever dreamed of a construction site without any humans but only robots working on it? In fact, there are lots of construction robots available in the market, so this dream may come true in future. But a contractor may ask: what can robots give to me? Are they white elephants? In this section, four advanced construction technologies are studied to see what benefits they can give to their users. Samples of advanced construction technologies are provided in Appendix 3.

6.2.1 (A) Concrete Placing

6.2.1.1 Concrete formation

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. The proportions of each material control the strength and quality of the resultant concrete.

To cast concrete of a specific mix to form a structure, the following procedures are commonly adopted:

1. Batching – measuring the quantities of different ingredients by weight or by volume, required to produce concrete of a specific mix.
2. Mixing – each constituent is thoroughly distributed inside a mixer.
3. Transportation – After the constituents are properly mixed, concrete is formed. The concrete is then transported to the work place by wheel barrow, dumper, tipper truck, ready-mixed truck or skips and buckets. If concrete is to be poured at higher levels, crane and hopper may be used.
4. Placing – concrete is distributed at its final position, e.g. formwork, in uniform layers and within a short period of time.

5. Vibration – concrete is properly compacted or vibrated to remove excessive air voids to ensure that it can develop the required strength.
6. Curing – it is a practical measure to keep concrete in a moist condition during its early life after placing to allow it to consolidate and develop its full strength.

6.2.1.2 Conventional practice

Conventionally, concrete is transferred and placed to its final position by wheel barrows or hoists. If it is to be placed at much higher levels, cranes with hoppers are used. However, this method is not efficient as the delivery speed is constrained by the productivity of the workers and operation of the cranes.

6.2.1.3 Advanced method – concrete pumping

Concrete pumping can replace the traditional method for the delivery of concrete on site (Ganesan *et al*. 1996, p.44). Large volumes of concrete are transported from point of supply to placing position in one continuous operation through a concrete pump. In addition, faster pours can be achieved by controlling the rate of the pump, using a two-person crew consisting of the pump operator and an operator at the discharge end. Example of actual use of concret pump is a computer controlled mobile concrete distributor developed by Putzmeister AG (IAARC 1998, p.71) which allows operations at difficult worksites where the outriggers cannot be folded out completely and ensures a uniform placement of the concrete.

Concrete can be formed in situ or ready-mixed. Ready-mixed concrete is supplied to sites in specially designed truck mixers which are basically a mobile mixing drum mounted on a lorry chassis. Hence, the use of ready-mixed concrete eliminates the batching and mixing procedures on site. When large amount of concrete is required, ready-mixed concrete is often preferred because it is more convenient and thus accelerates the construction process.

6.2.1.4 Cost of concrete

According to Peurifoy and Oberlender (1989, p.190), the cost of concrete in a structure includes the cost of aggregate, cement, water, equipment, and of labour mixing, transporting, and placing the concrete. When ready-mixed concrete is used, some of the costs are transferred from the job to the central mixing plant. The cost of the several items just listed will vary with the size of the job, location, quality of the concrete, extent to which equipment is used instead of labour, and distribution of concrete within the job.

6.2.1.5 Economic analysis[12]

Economic feasibility – concrete pumping

The market rate of a lorry mounted concrete pump with a 23m maximum distance is HKD516.6/hr.

$C=R \times pr(i,n) + C_t + H \times C_e$ [5.7]

$B=H \times k \times C_l$ [5.6]

When C=B, i.e. equation [5.6] = equation [5.7], then R is the breakeven rate of the concrete pump to the user. If R of a particular situation is larger than the market rent, it means the concrete pump is economically feasible in that situation.

In this case,

[12] Unless or otherwise specified, the rates are adopted from Wessex Electronic Publishing (2002). The currency unit for the rates is GBP. Therefore, the rates will be converted to HKD in calculations.

C_l: Concretor hourly rate= HKD109.63/hr

k: time saved per hour of robotized work[13]= 80/11.1-1=6.2hr

H	C_l	k	pr	C_t	C_e	R
2	109.63	6.2	1.0001	2000	16	-336.26
3	109.63	6.2	1.0001	2000	16	-2.96
4	109.63	6.2	1.0001	2000	16	163.69
5	109.63	6.2	1.0001	2000	16	263.68
10	109.63	6.2	1.0001	2000	16	463.66
13	109.63	6.2	1.0001	2000	16	509.81
14	109.63	6.2	1.0001	2000	16	***520.80***

Table 6.7 The breakeven rates of a concrete pump under different situations

Possible cost reduction – with reference to a construction task

Assume there is a construction project which 500 m^3 of ready-mixed concrete of grading 20N/mm^2 is to be placed at 18m above ground level. Since grading of concrete is the same, labour and equipment used in transporting and placing ready-mixed concrete make the difference in cost.

Conventional method – wheel barrows and hoist/crane

Material:

Ready-mixed concrete – dense natural aggregate BS 5328; grade: 20N/mm^2

Labour:

1 crane operator

1 operator for handling the skip

1 concretor

[13] Time input of placing concrete: (a) conventional=11.1m^3/hr (derived from Peurifoy and Oberlender 1989, p.196); (b) concrete pump=80m^3/hr (derived from Chudley 1999, p.122)

Equipment:

1 track-mounted tower crane (capacity: 25 metre/tonnes; height under hook above ground up to 20m)

A 2 m^3 hand-levered concrete skip

Cost of 500m^3 ready-mixed concrete:

HKD840.05/m^3 x 500m^3 = HKD420, 024.50

According to Peurifoy and Oberlender (1989, p.196), the labour hour of a crane operator required to place 1 yd^3 of ready-mixed concrete is 0.07, i.e., 0.09hr/m^3 , which means a crane operator takes 0.09 hour to place 1m^3 of ready-mixed concrete. Therefore, to place 500m^3 ready-mixed concrete, 0.09x500=45hr are required.

Rate of a track-mounted tower crane (inclusive of driver)[14]: HKD165.89/hr

The cost of operating the crane in this project:

HKD165.89/hr x 45 hr = HKD7, 465.05

The cost of the hand-levered concrete skip:

HKD23.68/hr x 45hr = HKD1, 065.49

The costs of the worker who handles the skip and the concretor:

HKD109.63/hr x 45hr x 2 = HKD9, 867.06

Total project cost:

HKD420, 324.50 + HKD7, 465.05 + HKD1, 065.49 + HKD9, 867.06

= **HKD 438, 422.1**

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[14] The rate is intended to apply solely to daywork carried out under and incidental to a building contract. The cost of drivers and attendants are included.

New method – Concrete pumping

Material:

Ready-mixed concrete – dense natural aggregate BS 5328; grade: 20N/mm^2

Labour:

1 pump operator

1 operator at the discharge end

1 concretor

Equipment:

1 concrete pump including hose, valve and couplers mounted on lorry, with a maximum distance of 23m

Cost of 500m^3 ready-mixed concrete:

HKD840.05/m^3 x 500m^3 = HKD420, 024.50

Chudley (1999, p.122) says that the hour output of a concrete pump ranges from 60m^3 to 100m^3. Assume the rate of the concrete pump used in this project is 80m^3/hr:

To deliver 500m^3 ready-mixed concrete, it takes 500/80 hr = 6.25hr

The rate of a lorry mounted concrete pump with a 23m maximum distance: HKD516.6/hr

The salary for the pump operator[15]: HKD100.19/hr

The cost of running the concrete pump in this project:

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[15] Levett and Bailey Chartered Quantity Surveyors Ltd, *Cost data.* Available from http://www.levettandbailey.com/cost-data/hongkong/cost-labourwages-data-recent12mths.html [Accessed on 20 November 2004]. To be consistent with the base date of the rates published in Wessex Electronic Publishing (2002), the rate of plant operator in July 2003 is taken.

HKD516.6/hr x 6.25hr + HKD100.19/hr x 6.25 hr = HKD3, 854.94

The salary for the operator and the concretor at the discharge end:

HKD109.63/hr x 6.25hr x 2 = HKD1, 370.43

Total project cost:

HKD420, 024.50 + HKD3, 854.94 + HKD1, 370.43

= **HKD425, 249.9**

In applying concrete pumps for placing concrete, the following limitations have to be concerned:

1. Concrete supply must be consistent and regular; therefore well-planned and organized deliveries of ready-mixed concrete are crucial to ensure a smooth running of the system.
2. Concrete mix must be properly designed and controlled since not all concrete mixes can be pumped. The concrete is pumped under high pressure which can cause bleeding and segregation of the mix; therefore the mix must be properly designed to avoid these problems as well as having good cohesiveness, plasticity and self-lubricating properties to enable it to be pumped through the system without excessive pressure and without causing blockages.

6.2.2 (B) Pile Driving

Piles are used to transmit foundation loads to strata of adequate bearing capacity and to eliminate settlement from the consolidation of overlying materials (RS Means 1990, p.62). This is the case when soils near the ground are too weak to support the load and excessive settlement will cause damages to the structure.

Piles can be made of timber, concrete, prestressed concrete and steel. In Hong Kong, most of the buildings are high-rise structures and thus impose a substantial loading to the ground; stronger piles like prestressed concrete piles or steel H-columns are more commonly used.

In addition, piles can also be interlocked together to form a cofferdam in earth or water to exclude soil and/or water from a construction area.

Piles can be classified according to the mode of pile installation.

- Displacement pile - a solid pile, or hollow pile driven with its tip closed, which displaces an equivalent soil volume by compaction or by lateral or vertical displacement of the soil. No soil is removed from the ground.

- Replacement pile - constructed by excavating a shaft and replacing the soil with concrete and reinforcement.

- Hand-dug caisson - a cylinder shaft formed in the ground and the shaft is excavated in stages by hand

In this section, we will focus on displacement pile.

6.2.2.1 Pile driving plant

Displacement piles are generally driven into the ground by holding them in the correct position against the piling frame and applying hammer blows to the head of the pile. Piles can also be driven into the ground by vibration where soft clays, sands and gravels are encountered.

Pile-driving plant consists of:

- Piling frames – steel frames are commonly used, these being mounted on swiveling traveling wheels, fitted with screw jacks, so that the frame leaders to which the pile is attached and which guided the pile may be plumbed to a true vertical position. Frames are adjustable which the leaders may be canted to an angle, thus permitting the piles to be driven on the rake.

- Hanging leaders – constructed of channels suitably held together so as to form leaders for the pile. They are suspended from the jib of a crane or derrick.

- Pile hammers – there are four types of hammers (Chudley 1999, p.217):

  (a) Drop hammers are blocks of cast iron or steel and are raised by a cable attached to a winch. The hammer is allowed to fall freely by gravity onto the pile head.

  (b) Single-acting hammers are activated by steam or compressed air; these have much the same effect as drop hammers in that the hammer falls freely by gravity through a distance. The hammer can be lifted by a piston rod or in the other case, the piston is static and the cylinder is raised and allowed to fall freely.

  (c) Double-acting hammers are activated by steam or compressed air and consist of a heavy fixed cylinder in which there is a light piston or ram which delivers a large number of rapid light blows in a short space of time.

(d) Diesel hammers are suspended from a crane or mounted in the leaders of a piling frame. A measured amount of liquid fuel is fed into a cup formed in the based of the cylinder. The air being compressed by the falling ram is trapped between the ram and the anvil which applies a preloading force to the pile. The displaced fuel, at the precise moment of impact, results in an explosion which applies a downward force to the pile and an upward force on the ram, which returns to its starting position to recommence the complete cycle.

6.2.2.2 Conventional practices

To construct a sheet pile cofferdam, it is popular to use vibratory hammer to drive the steel sheet piles into the ground. The procedures of installing a steel sheet pile by a vibratory hammer are as follows:

1. A sheet pile is lifted up by cable to the correct position.
2. The sheet pile is lowered onto the ground.
3. After checking the verticality of the pile, a vibrating unit is mounted on the pile head.
4. The vibrating unit transmits vibrations of a required frequency and amplitude down the length of the pile by two eccentric rotors propelled in opposite directions to generate vertical vibrations.
5. The sheet pile sinks into the ground under its own weight and that of the vibrating unit under the aid of continuous vibrations.

For a high-rise building's foundation, stronger steel H-piles are used. H-piles are often driven into the ground onto the bearing rock by diesel hammers. The procedures of installing a steel H-pile by a diesel hammer are as follows:

1. A steel H-pile is lifted up by cable from piling rig.
2. The H-pile is held in position against the piling frame.
3. The piling rig moves the pile to the correct position marked on for driving.
4. The H-pile is lowered on the ground.
5. Engineers check the verticality of the H-pile by means of a spirit level. If the pile is not vertical, adjustments have to be made.
6. When everything is checked properly and ready, the hammer starts driving the H-pile into the ground until the required level is reached.
7. The diesel hammer is lifted and the H-pile is installed.

6.2.2.3 Advanced method – SideGrip Vibratory Pile Driver

Sonic SideGrip Vibratory Pile Driver with Movax Robotic Technology is an excavator-mounted attachment with articulating arms and side-gripping jaws that speed and simplify the pile driving process. It grips sheet pile and pipe and H-beam piles from the side to perform all operations, including lifting, driving, and extracting piles and compacting[16]. According to Hercules Machinery Corporation (2004), the articulating features of Side Grip Pile Driver (SGPD) allows the operator to load, unload, separate, stack, place, drive and extract sheets of piling without ever leaving the cab. The 360° rotation and the 3-axis of movement make it possible to pick up piling, transport it across the jobsite, place it into position and drive it into the soil with one motion. In addition to being a safety benefit, this capability eliminates the need for peripheral equipment such as cranes, loaders and lulls. It also significantly reduces the manpower that has typically been used in piling operation.

[16] This system was the winner of the "2001 NOVA Award" instituted by the Construction Innovation Forum. More details available from http://www.cif.org/Nom2001/PreWin01.htm#SideGripPileDriver [Accessed on 6 December 2004]

The SGPD mounts on an 18-ton excavator or larger using the same pins as a bucket. It comes in a variety of sizes with dynamic drive forces ranging from 40 to 100 tons. High frequency vibration of 3,000 cycles per minute coupled with the 15 tons of crowd force produced by the excavator effectively drive pile into different types of soil condition.

In addition, a computerized steering system with a digital real-time graphic display assists the operator when driving the pile. By utilizing boom and stick sensors, it allows the operator to automatically drive pile to within 1° of plumb.

6.2.2.4 Cost of pile driving work

According to Spence (1996, p.56), several factors contribute to the total cost of pile driving work. These factors are:

- The cost involved in hauling the piling plant.
- The cost involved in the way of site excavation, leveling, etc. in readiness for the erection of the piling plant, should this be necessary.
- The cost of erecting and of the dismantling of the piling plant.
- The cost of preparing the piles.
- The cost of pitching and driving the piles to the requisite depths.

6.2.2.5 Economic analysis[17]

<u>Economic feasibility – SGPD</u>

The market rate of SGPD is HKD486.25/hr.

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[17] Unless otherwise specified, the rates are adopted from Davis Langdon & Everest ed. (2001). The currency unit for the rates is GBP. Therefore, the rates will be converted to HKD in calculations.

$C = R \times pr(i,n) + C_t + H \times C_e$ [5.7]

$B = H \times k \times C_l$ [5.6]

When C=B, i.e. equation [5.6] = equation [5.7], then R is the breakeven rate of SGPD to the user. If R of a particular situation is larger than the market rent, it means SGPD is economically feasible in that situation.

In this case,

C_l: Vibratory hammer operator hourly rate= HKD163.45/hr

k: time saved per hour of robotized work[18]= 78.13/10.42-1=6.5hr

H	**C_l**	**k**	**pr**	**C_t**	**C_e**	**R**
2	163.45	6.5	1.0001	2000	16	46.42
3	163.45	6.5	1.0001	2000	16	379.72
4	163.45	6.5	1.0001	2000	16	***546.37***
5	163.45	6.5	1.0001	2000	16	***646.36***
10	163.45	6.5	1.0001	2000	16	***846.34***

Table 6.8 The breakeven rates of SGPD under different situations

Possible cost reduction – with reference to a construction task

Assume a steel sheet pile cofferdam of 5,000 sq.ft. is to be constructed. The job dimension is 200 wall feet, 25 ft long. Since material used, i.e., interlocking steel sheet piles are the same, only labour and plant costs are calculated.

Conventional method – vibratory hammer

Labour:

2 operators for operating the crane and the vibratory hammer respectively

[18] Time input of placing concrete: (a) conventional=10.42sq.ft/hr (derived from from RS Means 1990, p.82); (b) SGPD=78.13sq. ft/hr (derived from Hercules Machinery Corporation 2004)

1 attendee for handling the sheet piles

4 pile drivers

Plant:

1 40-ton truck mounted mobile crane

1 vibratory hammer – cent. force 59 tonne, pulling force 36 tonne

Production rate for using 4 pile drivers: 10.42 sq.ft/man-hr x 4 = 41.68 sq.ft/man-hr

Hours to complete the project: 5,000/41.68= 119.96 hr

Hourly rate of a crane operator: HKD171.77/hr

Hourly rate of a vibratory hammer operator: HKD163.45/hr

Hourly rate of an attendee at loading: HKD136.33/hr

Hourly rate of a pile driver: HKD 163.45/hr

The project labour cost

= HKD (171.77 + 163.45 + 136.33 + 4 x 163.45)/hr x 119.96 hr

= HKD134, 996.99

Hourly rate of a 40-ton crane: HKD705.59

Hourly rate of a vibratory hammer: HKD1043.39

The project plant cost

= HKD (705.59 + 1043.39)/hr x 119.96 hr

= HKD209, 807.64

Total project labour and plant cost

= HKD134, 996.99 + HKD 209, 807.64

= HKD344, 804.63

New method – SGPD

Labour:

1 operator for operating the excavator

1 labour for handling the sheet piles

Plant:

1 40-ton excavator

1 SGPD

Production rate: 78.13 sq.ft/man-hr

Hours to complete the project: 5000/78.13 = 64.00 hr

Hourly rate of an excavator operator: HKD163.45/hr

Hourly rate of an attendee at loading: HKD136.33/hr

Total project labour cost: HKD (163.45 + 136.33) x 64hr = HKD19, 185.92

Hourly rate of an excavator: HKD848.23/hr

Hourly rate of a SGPD[19]: HKD486.25/hr

Total project plant cost

=HKD (848.23 + 486.25)/hr x 64hr

=HKD85, 406.72

Total labour and plant cost:

=HKD19, 185.92 + HKD85, 406.72

=**HKD104, 592.64**

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19 *Ibid*

6.2.3 (C) Painting

The functions of applying paint to the elements, components, trims and fittings of a building are to impart colour and to provide a protective coating which will increase the durability of the member (Chudley 1999, p.356).

Most paints are liquids containing pigments and may be applied in one, two, three or more coats, with sufficient time allowed between successive coats to permit the prior coat to dry thoroughly. To achieve a good durable finish the preparation of the applying surface and the correct application of the paint are of the utmost importance. The first coat (prime coat) should fill the pores of the surface, if such exist, and bond securely to the surface to serve as a base for the other coats. Paints can be applied onto a surface with a brush, a roller, or a spray gun.

6.2.3.1 Conventional method

As mentioned before, paints can be applied onto a surface by brushing, rolling or spraying; the first two methods involve direct contact of apparatus with the surface to be painted while spraying does not. Generally, painting is done by brushing or rolling in Hong Kong.

Ganesan *et al*. (1996, p.42) regarded the trade "painter" as a labour intensive activity. Painter's skills determine the quality of the finish and any acceleration of the works may lead to sub-standard finish; however, each painter can only brush on his/her own. If one wants to increase productivity, one must employ more painters to do the works. Hence, preparing a quality painted surface could be a time-consuming and labour intensive process.

The operations required to prepare a surface for painting in order to apply complete paint coverage will vary with the kind of surface to be painted, number of coats to be applied, and kind of paint used. For example, before paint is applied to a plaster surface, sealer is often applied first to fill the pores and neutralize the alkali in the plaster; or the surface of new metal may be covered with a thin layer of oil which must be removed with warm water and soap prior to applying the prime coat of paint.

In addition, access equipment such as ladders, scaffold and foot boards will be required if surfaces going to be painted are of higher levels.

6.2.3.2 Advanced painting methods

(a) Robotic system for painting

Spraying can decrease the application time, hence increase the productivity of the painting process. The whole spray painting process can be twice as fast as those conventional application methods[20]. As a result, spray painting has already started to substitute brush painting or roller painting in other developed countries like the USA and Japan.

A basic spray painting system consists of a spray painting gun, a pressurized paint container, a compressed air system, and flexible tubes connecting it all together. The system uses air to atomize paint and to provide a spray or fan pattern. Paint flows through a tube from a pressurized paint pot. Atomizing air is supplied to the gun tip. The pressure in the paint pot pushes the required amount of paint through the paint lines to the gun tip. There, the atomizing air breaks the paint into small particles and propels it to the surface that is being painted (Crumpler 1997). By keeping the distance between the gun tip and the surface around 6-8 inches and moving the spray

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[20] RS Means (1990, p.502) lists out the application time in man-hours for painting. The time required for painting concrete wall with a roller is 0.004 man-hours per square foot while that with a spray gun is 0.002 man-hours per square foot.

gun, the surface can be painted easily.

Technological advancements allow further improvement in productivity; powerful computers and complex mechanical engineering technologies have led to the appearance of applicable robots in construction industry. The International Association for Automation and Robotics in Construction (IAARC) (1998) contains a catalogue of construction robots, which lists and describes 76 working robots and automated machines in construction. 2 of these 76 robots are painting robots, produced and utilized by Japan-based construction companies Kajima Corporation and Taisei Corporation respectively. This shows that such technologies are actually not new and have been adopted in the construction industry for some time; however, their applications are rare in Hong Kong.

Another factor which stimulated the robotization of painting is that spray painting will create unhealthy cloud of paint sprayed in the air which is hazardous to humans (Kahane and Rosenfeld 2004); such situation will be even worse in interior working environment without proper ventilation. Therefore, it is necessary to substitute labour with robots in this case.

A robotic painting system consists of a robot with sprayers mounted as an end-tool on its arm. The robot’s ability to carry heavy tools allows designing an end-effector that combines several sprayers, able to spray simultaneously. This is achieved by mounting the sprayers on a metal bar fixed to the manipulator of the robot. Although the end of the manipulator can only move within the nominal work envelope of the robot, the metal bar with the sprayers can cover surface beyond the nominal work envelope of the robot (Kahane and Rosenfeld 2004). In this way, the output of the robot can be increased.

To paint a surface, various kinds of information such as dimensions and features of the object and the plan of the workstation will be inputted into the robot. For locating the robot its actual location, navigation method suggested by Pritschow *et al.* (1996) can be used - by measuring the distance to two nearby nonparallel walls using distance sensors, the robot's position is determined accordingly. The robot will then divide the surface into several painting strips. The robot will move the end-effector along each strip. During the movement, each sprayer is activated or de-activated according to the presence of openings (doors, windows) in front of it. After the robot finished one painting strip, it will move to the other strips until the work is finished.

(b) High-volume, low-pressure (HVLP) spray painting

Conventional spray painting systems use low volume of air at high pressure (LVHP) to atomize paint, which cause the paint to literally bounce back from the surface and create large amounts of overspray (clouds, mist). These clouds or mist will lead to an unhealthy environment for workers to work in and costly paint wastage. Paint wastage can be reflected from the transfer efficiency of the system, i.e., the theoretical coverage of paint versus the actual coverage after the paint is applied (Crumpler 1998). The transfer efficiency of LVHP systems ranges from 20% to 50% (Crumpler 1998), which means only half of the paint applied sticks to the surface. Although spraying can improve the speed of painting, wastage problem hinders the extensive use of this method.

High-volume, low-pressure (HVLP) spray systems replace the high-*pressure* air used in conventional spray systems with a high *volume* of air to atomize paint (Mulford 2002), so the spray is not blown out at high speed, thus it is softer and there is much less bounce-back. These results in less waste of material and less "fog" in the spray booth or spray area. The transfer efficiency of HVLP systems can be up to 90% for turbine HVLP guns (Crumpler 1998). The reason for the greater transfer efficiency is low velocity. Low velocity results in less bounce back, less blow-by, and reduced paint usage.

6.2.3.3 Cost of painting

The cost of painting includes materials, i.e. paints, labour, and equipment like brushes, roller or spray gun, depending on which method is used.

The covering capacity of paint is generally expressed as the area covered by the paint per volume of one coat (Peurifoy and Oberlender 1989, p.312). Since the covering capacity determines the amount of paint required for a surface, it will have influence on the cost of painting. The covering capacity of paint varies with several factors, according to Peurifoy and Oberlender (1989, p. 313), these factors are as follows:

1. The kind of surface painted;
2. The porosity of the surface;
3. The extent to which paint is spread as it is applied;
4. The extent to which a thinner is added to the paint; and
5. The temperature of the air - thinner coats are possible during warm weather, resulting in greater coverage.

6.2.3.4 Economic analysis[21]

<u>Economic feasibility – Robotic system for painting</u>

Since the robots are developed and used by the companies for their own projects, no lease or rental data is available; thus, an investment feasibility study is carried out. According to Warszawski (1999, p.416), the investment in such robot could be around

[21] Unless otherwise specified, the rates are adopted from Wessex Electronic Publishing (2002). The currency unit for the rates is GBP. Therefore, the rates will be converted to HKD in calculations.

HKD 661, 300. The initial capital investment, therefore, would not be lower than this figure.

$C=V \times pr(i,n) + C_m + (H/h) \times C_t + H \times C_e$ [5.5]

$B=H \times k \times C_l$ [5.6]

When C=B, i.e. equation [5.5] = equation [5.6], then V is the breakeven value of the robot to the user.

In this case,

C_l: Construction plant mechanic cost per hour[22] = HKD 825.6/8 = HKD 103.2/hr

k: time saved per hour of robotized work[23] = 0.086/0.019 – 1 = 3.52 hr

[22] Census and Statistics Department (2004a)

[23] Time input of painting a concrete wall for 2 coats of paint: (a)with a brush= 0.086hr/m^2 (RS Means 1990, p. 502); (b) with a painting robot= 0.019 hr/m^2 (Kahane and Rosenfeld 2004)

H	h	H/h	C_l	k	pr	C_m	C_t	C_e	V
600	120	5	103.2	3.52	0.203	63003.38	5000	16	592881.85
600	60	10	103.2	3.52	0.203	54752.56	5000	16	510373.60
600	30	20	103.2	3.52	0.203	38250.91	5000	16	345357.10
600	15	40	103.2	3.52	0.203	5247.61	5000	16	15324.09
700	140	5	103.2	3.52	0.203	74879.09	5000	16	***705446.86***
700	70	10	103.2	3.52	0.203	66628.26	5000	16	622938.61
700	35	20	103.2	3.52	0.203	50126.61	5000	16	457922.11
700	17.5	40	103.2	3.52	0.203	17123.31	5000	16	127889.11
800	160	5	103.2	3.52	0.203	86754.79	5000	16	***818011.88***
800	80	10	103.2	3.52	0.203	78503.96	5000	16	***735503.63***
800	40	20	103.2	3.52	0.203	62002.31	5000	16	570487.13
800	20	40	103.2	3.52	0.203	28999.01	5000	16	240454.13
1000	200	5	103.2	3.52	0.203	110506.19	5000	16	***1043141.91***
1000	100	10	103.2	3.52	0.203	102255.37	5000	16	***960633.66***
1000	50	20	103.2	3.52	0.203	85753.72	5000	16	***795617.16***
1000	25	40	103.2	3.52	0.203	52750.42	5000	16	465584.16
1100	220	5	103.2	3.52	0.203	122381.89	5000	16	***1155706.93***
1100	110	10	103.2	3.52	0.203	114131.07	5000	16	***1073198.68***
1100	55	20	103.2	3.52	0.203	97629.42	5000	16	***908182.18***
1100	27.5	40	103.2	3.52	0.203	64626.12	5000	16	578149.17
1200	240	5	103.2	3.52	0.203	134257.59	5000	16	***1268271.95***
1200	120	10	103.2	3.52	0.203	126006.77	5000	16	***1185763.70***
1200	60	20	103.2	3.52	0.203	109505.12	5000	16	***1020747.19***
1200	30	40	103.2	3.52	0.203	76501.82	5000	16	***690714.19***

Table 6.9 The breakeven values of a painting robot under different situations

If the V value of a particular situation is larger than the initial capital investment, which means the robot is economically feasible in that situation.

Possible cost reduction – with a reference to a construction task

Assume a flat with 200m^2 plastered wall area to be painted and the height of the wall is 2.70m. Two coats of emulsion paint are applied.

Conventional method – brushing

Material:

Emulsion paint

Labour:

Painter x 1

Equipment:

Ladder

Brush

Emulsion paint required:

According to E&FN Spon (1998, p.218), 1 litre of standard emulsion paint can cover up to 15 m^2. Hence, 200/15 x 2=26.67 L of emulsion paint is needed for this task.

Total Paint cost[24]

= 26.67 L x HKD 47.36/L = HKD1, 262.93

Time required to finish this task:

= 200 m^2 x 0.086 hr/m^2

= 17.2 hr

Total labour cost[25]

=17.2 hr x 2 x HKD110.3/hr

=HKD3, 794.32

[24] A 2.5 % waste factor per litre has been counted.
[25] Census and Statistics Department (2004a)

Total equipment cost

=HKD200

Total project cost

=HKD1, 262.93 + HKD3, 794.32 + HKD200

=**HKD5, 257.25**

(i) New method – robotic painting system

Material:

Emulsion paint

Labour:

Operator x 1

Equipment:

Painting robot

Total paint cost[26]= HKD1, 262.93/0.5=HKD2, 525.86

Time required to finish the task:

=200 m^2 x 0.019 hr/m^2

=3.8hr

Total labour cost for employing a construction plant operator[27]

=3.8hr x HKD103.2/hr

=HKD392.16

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[26] A 50% waste factor is assumed for the use of LVHP spray guns.

[27] Census and Statistics Department (2004a)

Total equipment cost

=Energy cost + transfer cost

=HKD2/hr x 3.8hr + HKD2, 000

=HKD2, 007.60

Total project cost

=HKD2, 525.86 + HKD392.16 + HKD2, 007.60

=**HKD4, 925.62**

(ii) New method - High-volume, low-pressure (HVLP) spray painting

Material:

Emulsion paint

Labour:

Painter x 1

Equipment:

HVLP spray gun

Emulsion paint required:

According to E&FN Spon (1998, p.218), 1 litre of standard emulsion paint can cover up to 15 m^2. Hence, 200/15 x 108%[28] x 2 = 28.8 L of emulsion paint is needed for this task.

Total Paint cost

= 28.8 L x HKD 47.36/L = HKD1, 364.0

[28] Difference in transfer efficiency between HVLP and brushing is 97.5%-90%=7.5%, so the amount of paint required in new method is 1/ (1-7.5%) = 108% of the conventional method.

Time required to finish this task:

= 200 m^2 x 0.043 hr/m^2 [29]

= 8.6 hr

Total labour cost[30]

=8.6 hr x HKD110.3/hr

=HKD948.6

Total equipment cost

=HKD23.68/hr x 8.6hr

=HKD203.7

Total project cost

=HKD1, 364.0 + HKD948.6 + HKD203.7

=**HKD2, 516.3**

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[29] Time input of painting a concrete wall for 2 coats of paint: (a)with a brush= 0.086hr/m^2; (b) with a spray gun=0.043hr/m^2 (RS Means 1990, p. 502)

[30] Census and Statistics Department (2004a)

6.2.4 (D) Placement of Boards

6.2.4.1 Conventional practice

Erection of partitions inside the building space is very important part of the building process. One of the most widely accepted methods is their erection with gypsum boards (plasterboards) which are attached to light steel framing with screws. Such finish allows placement of insulation, electricity conduits and other kinds of installations between the board and the main wall or floor element.

Plasterboard can weigh 8.3-17.1 kg/m^2 depending on its thickness (Wessex Electronic Publishing 2002). Hence, placing plasterboards on partitions, walls or ceilings is a strenuous task when performed manually; temporary staging composed of stepladders and staging boards have to be set up if plasterboards are to be placed at higher levels.

In 2003, among 4,546 of the construction injuries cases reported, about 16% of them were caused by lifting and carrying[31], which is the third major cause of injuries after slipping, tripping or falling on the same level (19%) and hitting by moving object (16.7%)[32]; while in 2002, injuries caused by lifting and carry accounted to 14% of total 6,369 construction accidents[33]. From these figures, it can be deduced that construction workers are susceptible to get hurt when moving or lifting heavy items. There are many chances which workers can hurt themselves during the placement of boards, for example, when workers are lifting plasterboards to construct ceiling, they may hurt their bodies due to improper movements or lose balance and fall down from work stage.

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[31] Labour Department (2004). *Occupational Injuries in Construction Industry in 2003 - analysed by Type of Accident.* Available from http://www.labour.gov.hk/eng/osh/statistics/content/st-oi-4.html [Accessed on 25 December 2004] See also Appendix 1

[32] *Ibid*

[33] *Ibid*

6.2.4.2 *Advanced method – light weight manipulator*

In order to reduce the chance of getting hurt, apart from adopting safe lifting procedures, one direct method is to substitute labour with robot. In Japan, Tokyu Construction Co. Ltd. developed a robotic manipulator for handling heavy equipment and machines, and to fit interior materials (IAARC 1998, p.103; Warszawski 1999, p.378). Similar robots have also been developed by Taisei Construction Corporation and Shimizu Corporation (Warszawski 1999, p.378). These robots are designated to do heavy tasks – pick a board from an adjacent carriage, place it at the required location and hold it until it is attached to the frame by the worker. They can handle boards much larger and heavier than humans and eliminate the physical effort associated with the placing and fixing process.

As reported by IAARC (1998, p.103), Tokyu Construction's manipulator can have a carrying capacity of 150kg and a workable ceiling height about 3m and can serve as a mobile staging with a strong and flat work stage, so the setting up of temporary staging is not necessary. It is operated by a worker using a handle near its tip. It is provided with a reversing arm that turns up and down by 180°, which makes it possible to suck and fit interior materials as they are. Suction grippers are used as end-effectors and a contact sensor is provided to monitor the pressing force, and if an excessive force is applied in fitting boards or other materials, the boom of the robot will stop operation to prevent damages.

It should be emphasized that in general, even with robotic assistance, a large part of the work like the fastening and fitting of boards near openings and corners, is done with manual labour. The main advantage of the manipulator is that it eliminates the heavy tasks in the procedure of placement of boards. Therefore, it is found to generate the greater productivity gain in ceiling work than work in partitions (Warszawski 1999, p.378), because lots of effort is saved in lifting up the plasterboards to ceiling level.

6.2.4.3 Cost of placing plasterboards

The cost of placing plasterboards includes the cost of the plasterboards, labour, equipment costs like screws and electric screw driver, energy cost, and the cost of temporary work stage if the work is on ceiling.

6.2.4.4 Economics analysis[34]

<u>Economic feasibility – light weight manipulator</u>

The official announced price of this robot is about HKD523, 320 (IAARC 1998, p. 103).

$C=V \times pr(i,n) + C_m + (H/h) \times C_t + H \times C_e$ [5.5]

$B=H \times k \times C_l$ [5.6]

When C=B, i.e. equation [5.5] = equation [5.6], then V is the breakeven value of the robot to the user. If the V value of a particular situation is larger than the initial capital investment, it means the robot is economically feasible in that situation.

In this case,

C_l: Construction general worker hourly rate[35]= HKD578.5/8 = HKD72.3/hr

k: time saved per hour of robotized work[36]= 0.226/0.033-1=5.85hr

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[34] Unless otherwise specified, the rates are adopted from Wessex Electronic Publishing (2002). The currency unit for the rates is GBP. Therefore, the rates will be converted to HKD in calculations.

[35] Census and Statistics Department (2004a)

[36] Time input of placing plasterboard on ceiling of 3m high: (a) conventional=0.226hr/m^2 (derived from RS Means 1990, p.479); (b)robotic manipulator=0.033hr/m^2 (derived from Warszawski 1999, p.378)

H	h	H/h	C_l	k	pr	C_m	C_t	C_e	V
400	80	5	72.3	5.85	0.203	46635.13	5000	16	448999.34
500	100	5	72.3	5.85	0.203	60356.62	5000	16	***581876.24***
500	50	10	72.3	5.85	0.203	52105.80	5000	16	499367.99
500	25	20	72.3	5.85	0.203	35604.15	5000	16	334351.49
500	12.5	40	72.3	5.85	0.203	2600.85	5000	16	4318.48
600	120	5	72.3	5.85	0.203	74078.11	5000	16	***714753.14***
600	60	10	72.3	5.85	0.203	65827.29	5000	16	***632244.88***
600	30	20	72.3	5.85	0.203	49325.64	5000	16	467228.38
600	15	40	72.3	5.85	0.203	16322.34	5000	16	137195.38
700	140	5	72.3	5.85	0.203	87799.60	5000	16	***847630.03***
700	70	10	72.3	5.85	0.203	79548.78	5000	16	***765121.78***
700	35	20	72.3	5.85	0.203	63047.13	5000	16	***600105.28***
700	17.5	40	72.3	5.85	0.203	30043.83	5000	16	270072.28
800	160	5	72.3	5.85	0.203	101521.09	5000	16	***980506.93***
800	80	10	72.3	5.85	0.203	93270.27	5000	16	***897998.68***
800	40	20	72.3	5.85	0.203	76768.62	5000	16	***732982.18***
800	20	40	72.3	5.85	0.203	43765.32	5000	16	402949.17
900	180	5	72.3	5.85	0.203	115242.58	5000	16	***1113383.83***
900	90	10	72.3	5.85	0.203	106991.76	5000	16	***1030875.58***
900	45	20	72.3	5.85	0.203	90490.11	5000	16	***865859.08***
900	22.5	40	72.3	5.85	0.203	57486.81	5000	16	***535826.07***

Table 6.10 The breakeven values of a light weight manipulator under different situations

Possible cost reduction – with a reference to a construction task

Assume a ceiling of area $20m^2$ and height 3m is designed to be covered with plasterboards (12.5mm Gyproc wallboard in 1800x1900 panels) in one thickness. The channels of softwood joists have been installed. The plasterboards will be fixed to the joists by screws and all the joints will be filled, taped and finished flush; holes will be filled with joint filler.

Conventional method – manual placement of boards

Material:

Plasterboards

Screws

Equipment:

Access staging

Electric screw driver

Labour:

General workers x 2

The specialist price for one thickness of plasterboard fixed in accordance with the requirements[37]: HKD347.99/m^2

Total project cost:

= HKD347.99/m^2 x 20m^2

= **HKD6, 959.80**

New method – light weight manipulator

Material:

Plasterboards

Screws

Equipment:

Light weight manipulator

Electric screw driver

Labour:

General worker x 1

[37] The rates of supplying the plasterboards and filling of joints are counted.

Plasterboard cost = HKD33.15/m^2 x 20m^2=HKD663

Screw cost = HKD50

Total material cost = HKD663 + HKD50=HKD713

Time required to finish the job=20m2 x 0.033hr/m^2 = 0.66hr

Total equipment cost

= energy cost + transfer cost + electric screw driver cost

= HKD2/hr x 0.66hr + HKD2, 000 + HKD500 = HKD2, 501.32

Total labour cost (including the cost of assigning worker to fill and tape the joints)

= HKD129.44/m^2 x 20m^2 = HKD2, 588.74

Total project cost

=HKD713 + HKD2, 501.32 + HKD2, 588.74

=**HKD5, 803.06**

6.3 Evaluation of Phase II Results

Four types of construction work have been examined on their breakeven values for renting or capital investment and cost associated in using conventional and advanced methods with reference to a construction work. Based on these results, percentage of cost reduction compared with conventional method, cost per unit work and improvement acquired after adopting advanced methods are analyzed and exhibited in Table 6.11.

The minimum robot working hour to achieve breakeven rent for concrete pumping is 14hr/job, which means for delivering small amount of concrete, say a few metre cubes, it will not be cost-effective to use concrete pump; instead, traditional methods like wheeling or hoisting are preferred. From the cost per unit work, it is observed that concrete pumping can help to reduce the cost in transporting and placing concrete in large volumes at high levels. In this example, the cost is reduced by about 3.0% after adopting concrete pumping in delivering concrete. This tangible benefit is created due to the increase in productivity. Concrete pumping also provides intangible benefit like improvement in safety, as workers' chances of being hit by the moving buckets and falling objects from crane are eliminated. However, there are constraints related to concrete supply and concrete mix for this method so it may not be applicable even it is proved to be cost-effective in certain projects.

The minimum robot working hour to achieve breakeven rent for using SGPD is 4hr/job, which means it is suitable for jobs of medium to large scale. In the sheet pile driving example given in previous section, it demonstrates the advantage of SGPD – high production rate. Its production rate is nearly 7.5 times to that of conventional method using one pile driver. Obviously, by shortening the duration of construction process, the employment of labour is reduced and cost is saved. Moreover, SGPD reduces the plant cost because it helps avoid the use of expensive machinery like

	Construction work							
	(A) Concrete placing		(B) Sheet pile driving		(C) Painting		(D) Board placing	
	Conventional – crane & skip	Advanced - pumping	Conventional – vibratory hammer	Advanced - SGPD	Conventional - brushing	Advanced – (a) painting robot & (b) HVLP	Conventional - manual	Advanced – light weight manipulator
Price or rent of advanced equipment	/	HKD516.6/hr	/	HKD486.3/hr	/	(a) HKD661,300 (b) HKD23.7/hr	/	HKD523, 320
Minimum robot working hour to achieve breakeven price or rent to user	/	14hr/job	/	4hr/job	/	(a) 700hr/yr (b) Not applicable	/	500hr/yr
Construction cost (HKD)	438, 422.1	425, 249.9	811, 604.6	571, 392.6	5, 257.3	(a) 4, 925.6 (b) 2, 516.3	6, 959.8 (ceiling height 3m)	5, 803.1 (ceiling height 3m)
Cost per unit work (in HKD)	876.8/ m^3	850.5/m^3	1, 746.3/m^2	1, 229.9/m^2	26.3/m^2	(a) 24.6/m^2 (b) 12.58/m^2	348.0/m^2	290.2/m^2
Cost reduction compared with conventional method (%)	0%	3.0%	0%	29.6% (in total labour and plant cost)	0%	(a) 6.3% (b) 48.9%	0%	16.6%
Advantages of using advanced methods:								

Reduce labour use	/	No	/	Yes	/	(a) Yes (b) No	/	Yes
Increase productivity	/	Yes	/	Yes	/	(a) Yes (b) Yes	/	Yes
Reduce wastage	/	No	/	Yes. Less waste created due to errors	/	(a) Worse than conventional method (b) Worse than conventional method	/	No
Enhance safety	/	Yes	/	No	/	(a) Yes (b) No	/	Yes
Improve quality	/	No	/	Yes	/	(a) No (b) No	/	No

Table 6.11 The impacts of advanced technologies on different types of construction work

vibratory hammer. In this example, near 30% of the total labour and plant cost is saved after SGPD is adopted. SGPD's intangible advantage is its accuracy in driving piles. Since SGPD is equipped with a computerized steering system, it aids the operator to drive the piles precisely and thus errors can be reduced. As a result, reinstatement of piles, which is a waste of time and resources, can be avoided.

Although the paint cost and equipment cost of the robotic painting system are higher that those of brushing, labour cost is much reduced through the adoption of the painting robot because of improvement in productivity. After all, the cost per unit work after using the painting robot is lowered by 6.3%. It should be emphasized that though the robot working hour per year is 700hr, extensive employment of the robot on site, i.e. longer robot working hour per site (lower H/h ratio), is required to achieve the breakeven value. When the robot working hours per year is 1200 or above, the painting robot is found to be feasible disregarding its extent of application on site. Either figure of robot working hour per year implies the robot does not need to be used very frequently. Assume the robot works 8 hours a day, which means the owner has only to use it for around 88-150 days a year before he/she gets positive return from it.

The painting robot also enhances worker's safety because workers no longer need to climb ladders or work on temporary staging to paint surfaces at higher levels. However, one major disadvantage of this robot is the wastage problem. Pressurized spray painting (usually LVHP) has low transfer efficiency; lots of paint will not be able to stick onto the applied surface, so more paint is required and thus results in a higher material cost. Otherwise, this robot is expected to reduce more cost than the result shown.

Compared with conventional method, HVLP system increases the productivity so the job can be finished faster; hence labour hours employed are reduced. As a result, the total cost decreases by more than 60%. Nevertheless, HVLP spray gun system does not offer any benefit on labour or wastage reduction or quality improvement, so it is anticipated that in large-scale project, the productivity advantage will gradually fade out due to increase in labour and paint waste.

In addition, the prices or the rents of a LVHP spray gun and that of a HVLP spray gun are about the same. There are many occasions where HVLP spray gun can substitute LVHP spray gun. Therefore, HVLP spray gun can be used to reduce the paint waste when using the paint robot, which is equipped with a LVHP spray gun. If so, the total project cost in the painting job example can be lowered by 27.7% instead of just a few percents. Unfortunately, up till now, the HVLP technology and robotic painting system have not yet been integrated; otherwise, these two advanced technologies can complement with each other to further improve construction performance.

The minimum robot working hours per year for using the light weight manipulator is 500hr which means with a reasonable demand of this robot's service it is economically feasible. When the robot working hours per year is 900 or above, the painting robot is found to be feasible disregarding its extent of application on site. The manipulator helps to reduce the number of workers but its transfer cost is high, resulting in less significant cost reduction benefits. The cost reduction after adopting the manipulator is 16.6%. The intangible benefit obtained from using this manipulator is safety. With this manipulator, workers no longer need to lift or carry heavy items so the chance of getting hurt is lowered; moreover, the stable and flat working platform provided by the manipulator gives workers a safe access staging for working above the ground.

Table 6.11 shows that all advanced construction methods offer tangible benefit on cost reduction to different extents. Some intangible benefits like safety improvement and quality enhancement are also found. However, the amount of cost reduction obtained after using advanced construction methods is generally lower than expected. Except HVLP spray gun reduces the cost by nearly 50%, the others reduce not more than 30%. This can be explained by the imperfectness of the advanced construction methods. No doubt that these methods increase productivity, other costs associated or incurred such as transfer cost, equipment cost or even wastage have increased at the same time. For example, the production rate of painting robot is nearly 5 times faster than that of brushing, but the wastage is great; the production rate of concrete pumping is also faster than that of conventional concrete delivery method, but the rent of the concrete pump is high.

In addition, new construction methods do not always reduce the use of labour; in fact, sometimes the case may be machine operator substituting general worker. There is no difference on the number of people involved in construction task, though there is change in type of worker. For example, the substitution of crane operator by concrete pump operator in concrete pumping.

It does not mean these advanced methods are not valuable. Intangible benefits like safety and quality associated with the use of these methods bring unquantifiable advantages to the users; they bring money to users indirectly. For example, when less construction workers get injured, then the employer will have a workforce at full strength so productivity can be maintained and delay is reduced; provision of better quality of work may even make a contractor have higher chance to get a job during tendering.

In Phase I analysis, VATFP growth shows that construction productivity has been enhanced by disembodied technical changes. Nevertheless, Hong Kong construction industry Hong Kong is still labour-intensive and labour is difficult to be substituted or is even suspected to substitute for capital such as plant and machinery. Consider the results from Phase II analysis together with those from Phase I, it is interesting to observe that even new technologies can provide cost reduction and other benefits, not many practitioners want to adopt them in Hong Kong; even they are adopted, they will not be widely spread among the industry. In fact, construction industry practitioners still prefer to regulate the amount of labour to control outputs. Why are they reluctant to use new technologies? The breakeven values of advanced construction method adoption from Phase II analysis may give us some clues. Although the results show that the advanced methods (except concrete pumping) do not require very extensive employment for the user to attain positive return, this is only an analysis based on existing data and market prices; no macroeconomic and financial management factors has been considered.

Hong Kong's construction industry is under recession currently and the problem of lack of large-scale construction projects is not a secret. Since construction firms need jobs to maintain their cash flow, without large construction projects will certainly put them into financial troubles. The breakeven prices of the construction robot are in the order of hundred thousands dollars, but the bank accounts of some construction firms may only be in the order of million dollars. Therefore, even though robots are economically feasible, investing in such robots will greatly reduce the liquidity of these construction firms. If they borrow money for such investments, the loan and the interest associated will definitely be a burden to them. Owing to the high risk involved, construction firms refuse to invest in robots. Obviously, only those firms with strong financial back-up and human resources can make technology investments. Big firms can enjoy economies of scale by introducing advanced technologies as they can lower the average cost of products by producing more with productive machines or methods. In fact, large construction firms are rare in Hong Kong, and most local construction firms are only medium or small scales which are unable to afford the cost associated in developing advanced construction methods. The common way for these medium and small construction firms to control outputs is to regulate the utilization of labour because employment of labour does not require substantial investment and is easy to regulate. When market demand for construction products increases, they employ more labour; they simply employ less or sack some people they have when demand is low. However, if these firms own plant and machinery, they will not enjoy such flexibility. Problems arise when the market is under recession, when firms usually have difficulties in maintaining cash flow. It will be difficult to sell job-specific plant and machinery; moreover, they will depreciate even they are idling.

Renting plant and machinery from special suppliers or larger contractors seems to be a feasible way for medium or small firms to make use of technologies in construction works as this could avoid heavy capital investment. However, special trainings have to be provided to professionals and site workers to equip them with the necessary knowledge to use the machines. It takes significant time and effort for them to learn a new type of technology, especially when the technology is complicated. This is some sort of learning cost. While most decision-makers of medium or small firms could be risk-averse because of limitations on capital and human resources, spending plenty of money and time to train their employees will be a risky action to them because it does not guarantee that employees will be more productive with first adoption of new technologies. This learning cost is just too large for some of the decision makers.

Therefore, the spread of new technologies in Hong Kong construction industry is perceived to be driven by large construction firms. Smaller firms have less interest in developing or using new technologies because of their limitations on capital and human resources. They still prefer to use labour as the major input. As a consequence, the progress of new technologies adoption is rather slow in the construction industry.

6.4 Phase III - Examining Construction Practitioners' Viewpoints towards Advanced Technologies

6.4.1 Background

Two interviews were conducted for this study and the interviewees were:

1. Mr. George C.C. Cheung, quantity surveyor of Advance Specialist Treatment Engineering Ltd.
2. Mr. James Lee, quantity surveyor of Sanfield Building Contractors Ltd.

Since contractor quantity surveyors (QS) are responsible for working on tender documents, administrating the contract, agreeing interim payments and preparing final accounts, they have many chances to expose themselves to different aspects of a construction project and thus are well aware of various types of constraints facing by the contractor and client's attitude towards a project. Therefore, their opinions are valuable and reliable. The following is the summary of points raised during the conversations.

6.4.2 Opinions on local bidding practices and construction specifications

Both interviewees agreed that it was not a usual practice for clients in Hong Kong to motivate contractors to use advanced construction technologies by offering advantages to them. They said that lack of motivations, along with low bidding prices, had rendered contractors not to use advanced technologies because normally the contractors would not bear the risk in an unpredictable market like Hong Kong. They both addressed two things that clients concerned when awarding a contract: tender price and contractor's past performance. Clients only care about the product, i.e. the building, rather than the process. So long as a building is completed within budget and fully complied with all types of requirements, clients do not mind whether this building is built by automatic systems or conventional methods.

The interviewees also said that clients did not assume the responsibility to drive the construction industry forward because they supposed professionals would do this for the industry. Mr. Cheung described clients in Hong Kong as "result-oriented" people. He thought developing a technology needed money; if the client was reluctant to pay, professionals could not propose the use of technology. Therefore, it is not surprising to find outdated specifications.

6.4.3 Opinions on developing and adopting advanced technologies

Both interviewees agreed that developing, testing and using a new technology took a long period of time. As a result, a contractor will not be able to develop and use a new technology in a single project. Again, it is the client's requirements that restrict contractor's creativity – a client always wants the building to be accomplished as soon as possible so that he/she can start making money earlier.

Mr. Cheung considered the problem of high degree of sub-contracting caused the lack of new technologies in the industry. He thought that most construction works were done by sub-contractors who might not be financially strong enough to invest on technologies and prefer to carry the works based on their experience. Furthermore, lower layers sub-contractors are paid by unit price basis. They are paid when they finished a unit of work. This makes the lowest layer sub-contractors not only do not allocate resources on developing and maintaining new technologies, but also look for short cuts to make the work finished more quickly in order to work for another unit and earn the money. Owing to this, the quality of construction products is compromised and not many new technologies emerged in the construction industry.

In order to adopt new technologies, Mr. Lee suggested that the implementation method should not be direct changeover; it should be "project-by-project" or "trade-by-trade". For example, conduct a number of trials on several sites before applying a technology extensively. Similarly, in the case of automation, it is not appropriate to use automation in every trade suddenly, automation should be gradually implemented, say, start from excavation, then concreting, then painting and so on. The purpose of this is to allow the workers to have enough time to adapt to changes without seriously affecting their productivity, and thus avoid chaos on site.

6.4.4 Technical competence of practitioners

Mr. Cheung thought that most professionals would not have difficulties in adapting to advanced technologies; however, he worried about the competence and adaptability of unskilled labour who may not be well-educated. These workers may not be able to understand the details of the machine's user manuals by themselves and thus contractor has to spend lots of resources to train them, while such expenses may not be paid off at the end.

Mr. Lee generally had the same points of view as Mr. Cheung. Apart from doubting the ability of unskilled workers, Mr. Lee also concerned about the adaptability of elder workers. He said the elder workers might not be managed to learn new things quickly. Under such circumstances, training cannot solve the problem.

6.4.5 Contractor's attitude towards advanced construction technologies

Mr. Cheung showed affirmative attitude towards useful advanced construction technologies. He explained that advanced technologies could improve productivity of labour and these machines' reliability would be invaluable as quality of construction products could then be guaranteed.

Mr. Lee had different opinions. He thought even advanced technologies were proved to be useful and cost-effective, the utilization rate of these technologies was the utmost important issue for consideration. He said that unless a technology could be applied to 80% of the projects the company undertook, he would not recommend the use of it. He said only those large contractors could have such resources to develop and use an advanced technology.

6.4.6 Comments on the lack of knowledge sharing in the industry

Both interviewees thought that knowledge sharing was difficult among the construction industry because all firms wanted to acquire competitive advantages. Consequently, the technological level of construction industry has been progressing in a relatively slow rate. It would be very tough to change this situation.

As a result, Mr. Cheung suggested that Construction Industry Training Authority (CITA), the Environment, Transport and Works Bureau and other relevant government departments should actively participate in R&D in order to search for new technologies which could be shared within the industry. The industry could not just rely on several scholars' efforts.

6.4.7 Comments on the suggestion of setting up an independent body for testing and certifying advanced construction technologies

Mr. Cheung agreed this was a good suggestion. He said suppliers could provide misleading information about a new technology; an independent body could guarantee the technical products were of a certain standard. This could provide security to users and the users would be more willing to adopt new technologies, which could then achieve the goal of mobilization or automation.

Mr. Lee had some reservations on this suggestion. He said universities could assume the role of testing and certifying advanced technologies, there was no point in setting up another body to do this job.

6.4.8 Evaluation of the interviews

The attitude of the client towards advanced construction technologies is result-oriented while that of contractor's is positive, though there some reservations. Things that a contractor will concern before adopting advanced technologies can be:

- Motivations given by client
- Financial capacity
- Project timeframe
- Utilization rate of the technology
- The capability of labour

These points generally conform to those raised by Mezher *et al.* (1998), other researchers (see Section 4.3.2), as well as the interpretations made in Phase II. From Phase II analysis, we know that some advanced construction technologies can only provide a positive breakeven value when enough usage frequency is attained; it is suspected that contractor will not use these technologies (even there are both tangible and intangible benefits) if he cannot secure a certain amount of work to apply them. The interviewee's concern on the utilization rate of technology proves that Phase II's explanation is correct. However, Phase II analysis cannot find out the negative impact of high degree of sub-contracting on the development of advanced technologies in construction industry.

The previous analyses of this study, together with the interviewees' recommendations, can serve as some implications for policy makers and practitioners.

- The government should promote and participate in R&D activities in the construction industry actively. Loans or subsidies should be provided to private bodies which have a decent proposal to realize and apply a new construction technology. The current funding programmes of the Innovation and Technology Fund (ITF) seem not very attractive to practitioners in construction industry. When we look at the statistics provided by the ITF[38], we find that requests made by local contractors for research funding are rare; contrary, there are many applications for funding in projects related to manufacturing, software engineering, nanotechnology, textiles, etc. This phenomenon can be explained by contractor's lack of interest in advanced construction technology as reported in this study, and may also be due to the stringent vetting mechanisms of the ITF funding programmes. Therefore, a review of the current vetting mechanisms is necessary.
- The government should reinforce the current training courses offered to construction workers so that more workers can be equipped with the basic skills to handle a new construction technology. For example, the CITA can introduce more skill enhancement courses on advanced building systems or information technology.
- The setting up of an independent body to test and certify newly developed construction technology is worth consideration. In this way, the certificates issued by such body can serve as an assurance of quality and safety so that more people acknowledge its functions and are willing to use it. Local universities can also take similar roles.
- Private construction companies should cooperate more frequently with local universities to carry out collaborative projects. This allows better sharing of resources between private sector and academies.

[38] ITF (2005) *Project information*. Available from http://www.itf.gov.hk/eng/Intro.asp [Accessed on 24 March 2005]

7 CONCLUSION

Hong Kong's construction industry is one of the main pillars of its economy. However, the construction industry has long been criticized for its labour-intensive nature. Compared to other industries such as textile, automobile and food production, local construction industry is relatively backward in terms of technology; labour remains the major inputs to many construction processes. Labour-intensive construction activities can lead to problems in productivity, construction products' quality and occupational safety. As a result, many methods are proposed to remedy these problems and the adoption of advanced construction technologies is one of them. This study tries to verify the labour-intensity of Hong Kong construction industry and examine the feasibility of using advanced technologies so as to let readers gain some insights into the root of the problem.

Indicating construction industry as "labour-intensive" based on our observations seems a little bit risky; it means nothing but only a hypothesis in a scientific research. Therefore, a quantitative approach is used in Phase I analysis to test this hypothesis. A Cobb-Douglas Production Function is set up for Hong Kong construction industry and it shows that the proportion of labour input is larger than that of capital input in the industry's production process. Thus, we can confirm that Hong Kong construction industry is labour-intensive. From this production function, the construction industry's value added total factor productivity (VATFP) growths from 1985 – 2002 are also calculated. The trend shows that the VATFP growths for construction industry has increased by 43.7% in this period, which implies that the industry has been able to sustain certain degree of productivity through improvements in general knowledge of labour, better management and organizational change. The value added productivity of the industry has improved, but the industry remains labour-intensive. This fact further implies that labour can be difficult to be substituted in construction industry.

Substituting technologies for labour is a hot topic in construction industry. However, many people have doubts in using technologies like advanced machinery, automatic building systems or robotics because they think that they are white elephants. In Phase II analysis, four advanced construction technologies are investigated and the results show that they are cost-effective and productive; some of them also offer intangible benefits to user, e.g. better product quality and safer work environment. Then why people still treat them as white elephants? The economic analyses in Phase II give us some hints to answer this question. The results tell us that for some technologies, the user has to attain a certain utilization rate in order to achieve the breakeven point of investment. Hong Kong construction industry has hit the bottom over the past few years. Since the amount of works and resources available to contractors is limited, they may not have interest in investing in these technologies even they are proved to be applicable.

In Phase III analysis, two practitioners were interviewed to collect their opinions in order to understand contractor's attitude towards advanced technologies and serve as implications for policy makers and practitioners. From the findings of the interviews, we know that motivations offered by client, contractor's financial capacity, project timeframe, technology's utilization and the capability of labour are the concerns of contractors for the adoption of advanced technologies. It seems that the government inevitably has to initiate the construction industry into the use of advanced technologies; the realization and diffusion of technologies cannot be done without government's participation because private companies are reluctant to exchange research results, experience or other resources for the sake of competitive advantage. Therefore, it is recommended that the government should allocate more resources on R&D and offer more extensive training courses for construction workers so that they can readily adapt to new practices after introducing advanced technologies. Moreover, in order to guarantee users the functions, quality and safety of a new technology, an independent body for testing and certify new construction technologies is required.

There are several limitations in this study. First, due to inadequacy of local cost data, especially those about advanced construction technologies, the data used in this research are overseas data, which may not truly represent the price of a particular construction technology in Hong Kong because of differences in price levels and inflation rate. Nevertheless, it is expected that such differences are not great if the construction technology is sold in Hong Kong because most technologies are imported. Second, the interviewees' opinions may not be representative because only two practitioners were interviewed and they are from contractors of similar sizes. Contractors of various sizes should be interviewed to collect different viewpoints so that the analysis can be more comprehensive. Despite of all its limitations, this study provides a good example to apply simple economic analysis to examine the feasibility of using a technology and points out the major obstacles in using it. This can raise contractors' awareness of the need of a change in conventional practices and a way to assess the potential of a technology.

For future studies on the adoption of advanced construction technologies, researchers can try to use local cost data of advanced technologies. In case such data are not available, researchers can obtain quotations from suppliers as references. The impacts of other technologies such as prefabrication of building components can also be assessed by similar methods adopted in this study. Since this study only focuses on contractor's viewpoints towards advanced technologies, future researchers can try to compare the viewpoints of both clients and contractors to see if there is any solution for the conflicts between the two sides. Studies can also be done to assess the possible impacts of government's participation in promoting and initiating the adoption of advanced construction technologies. Researchers can adopt quantitative approach like investigating the economic performance of advanced construction technology in ITF funded projects, or qualitative approach like interviewing public and private practitioners.

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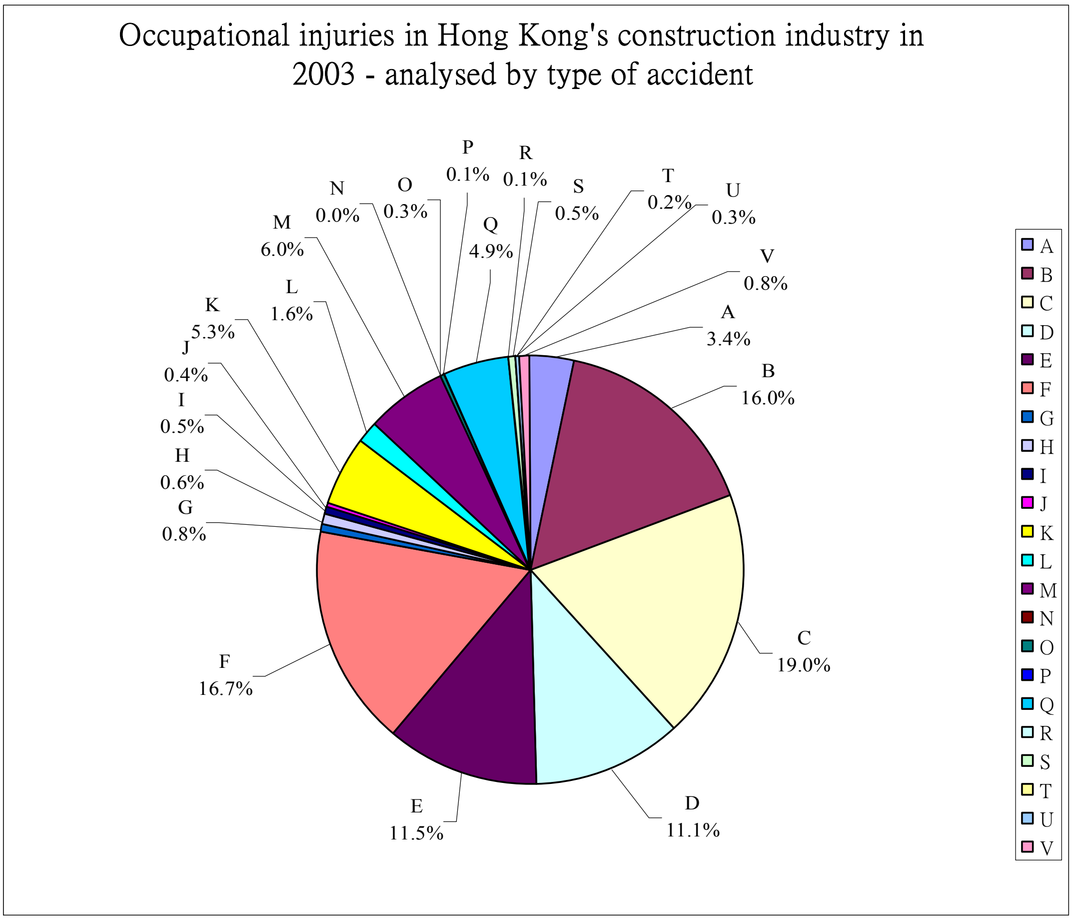
Appendix 1 – Occupation injuries in Hong Kong construction industry in 2003

Total number of injuries cases reported in 2003: 4,546



Legend:

A: Trapped in or between objects

B: Injured whilst lifting or carrying

C: Slip, trip or fall on same level

D: Fall of person from height

E: Striking against fixed or stationary object

F: Striking against or struck by moving object

G: Stepping on object

H: Exposure to or contact with harmful substance

I: Contact with electricity or electric discharge

J: Trapped by collapsing or overturning object

K: Struck by falling object

L: Struck by moving vehicle

M: Contact with moving machinery or object being machined

N: Drowning

O: Exposure to fire

P: Exposure to explosion

Q: Injured by hand tool

R: Injured by fall of ground

S: Contact with hot surface or substance

T: Injured by animal

U: Injured in workplace violence

V: Others

Source: LABOUR DEPARTMENT, HKSAR (2004) *Occupational Injuries in Construction Industry in 2003 - analysed by Type of Accident.* Available from http://www.labour.gov.hk/eng/osh/statistics/content/st-oi-4.html [Accessed on 25 December 2004]

Appendix 2 – Data for OLS estimation of production function

HK $ Thousand (unless otherwise specified); take 2000 as the base year.

Year	Value added output	ASD TPI	L&B TPI	DLS TPI	Private sector TPI	Private sector's share in output	Public sector's share in output	Gross output value	OPI	**Deflated value added**
1985	12053155	339	566	375	460.7	12257	6900	19157	417	29723059
1986	13538396	380	626	421	513.4	13484	7048	20532	468	29764488
1987	16449652	409	699	495	588.2	16734	8170	24904	529	31940685
1988	19926003	513	849	625	728.4	21110	10304	31414	658	31141275
1989	24945253	550	976	663	804.4	24450	13565	38015	714	35934036
1990	29838053	578	1044	706	858.5	29104	15636	44740	760	40334152
1991	34544801	572	1074	718	878.1	32407	15363	47770	780	45546663
1992	37357462	529	1026	690	841.4	31700	17438	49138	731	52569275
1993	43208439	545	1056	769	901.1	29458	24522	53980	739	60076964
1994	46300740	615	1151	843	985.0	36202	27197	63399	826	57603001
1995	54730168	725	1335	968	1136.8	35669	37916	73585	925	60850410
1996	65076673	830	1459	1091	1261.7	40469	46724	87193	1030	64928638
1997	71666522	976	1701	1310	1492.8	56837	42146	98983	1273	57886209
1998	69827989	1064	1734	1207	1446.7	61233	40742	101975	1294	55482453
1999	66138530	1017	1630	1130	1357.2	44380	49173	93553	1178	57698731
2000	63170206	884	1449	1020	1215.7	39094	50817	89911	1028	63155750
2001	58138528	808	1360	935	1127.7	40497	41793	82290	965	61914270
2002	52302639	714	1226	840	1014.8	42292	32070	74362	885	60748291

Year	Gross additions	UVI	**Deflated capital**	**No. of construction labour**
1985	408824	66.2	617113	97148
1986	518956	69.6	746053	110044
1987	557410	72.4	769831	116635
1988	698080	75.4	925729	117015
1989	1043159	78.1	1335671	118428
1990	803120	82.1	978222	127395
1991	2019045	83.2	2426737	119469
1992	2143890	86.5	2478486	131402
1993	3003961	95.4	3148806	132814
1994	2053902	95.7	2146188	138293
1995	2227908	104.9	2123840	152102
1996	1653452	98.5	1678631	155898
1997	1674396	97.3	1720859	168457
1998	2038067	90.8	2244567	155906
1999	1596878	98.8	1616273	157685
2000	1477778	100.0	1477778	154676
2001	1341263	90.7	1478791	141079
2002	791101	80.4	983956	135870

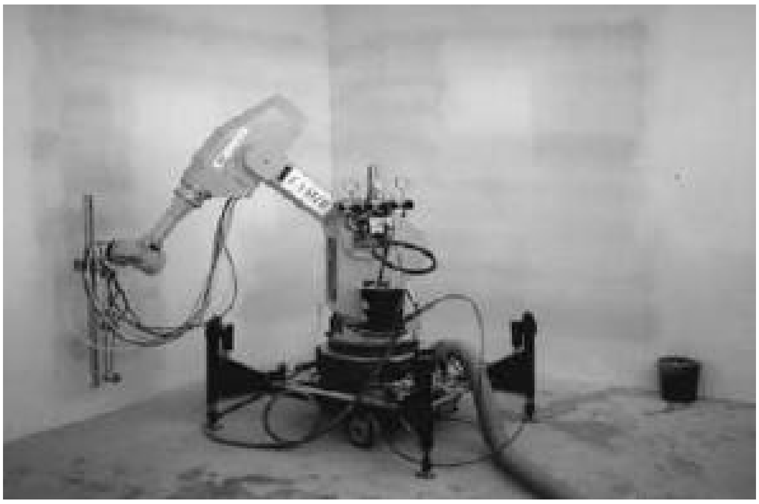
Appendix 3 – Samples of advanced construction technologies

Concrete pump developed by Putzmeister AG

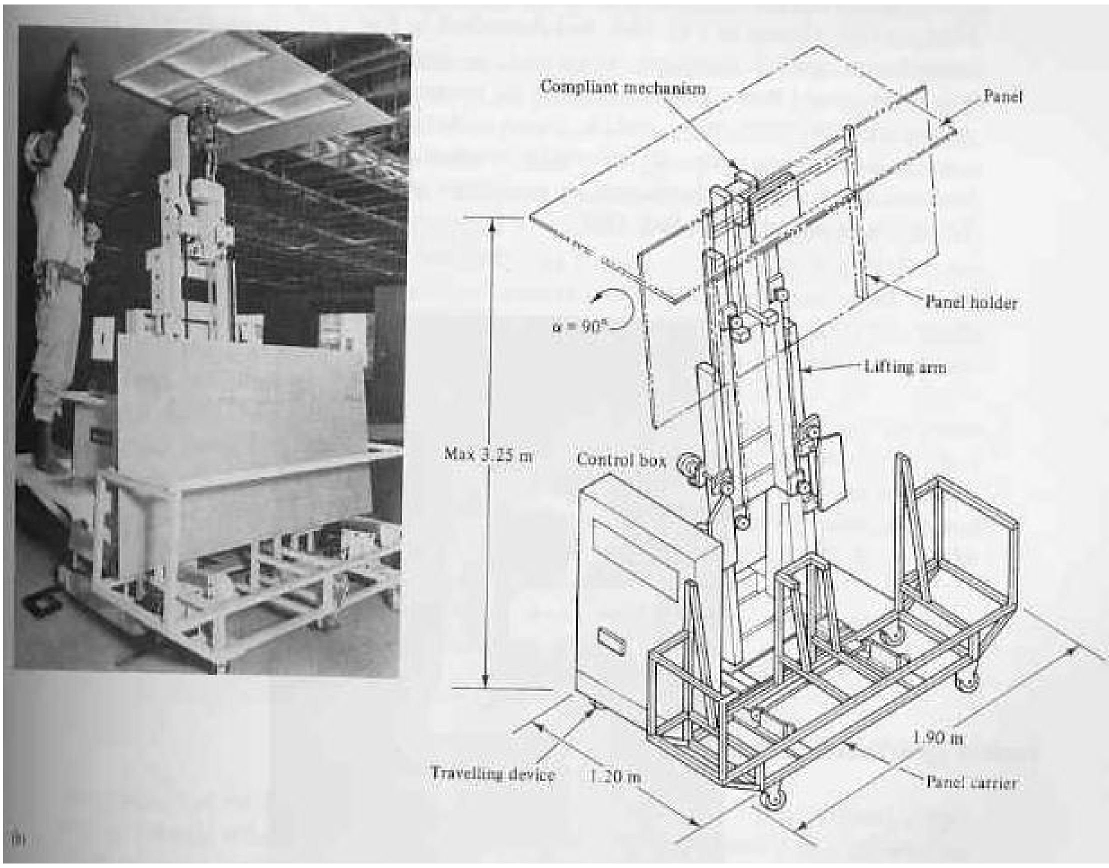
Source: http://www.putzmeister.de/images/news/werbung/2614_GB.jpg

The Sonic SideGrip Vibratory Pile Driver

Source: Hercules Machinery Corporation (2004)



Robotic system for painting
Source: Kahane and Rosenfeld (2004)



Board placing robots developed by Shimizu Corporation
Source: Warszawski (1999, p.378)

Appendix 4 - Questions for identifying the barriers in the adoption and diffusion of modern construction technology in Hong Kong

Interviewee's name:
Company:
Position in company:

1. It is believed that most clients do not encourage contractors to adopt modern construction technology, do you think so? And why do they have no such incentive?

2. Does developing and using a modern construction technology take a long period of time? Do you think most project timeframes are too tight for that?

3. Do you think your staff's current technical competence (e.g. IT knowledge) will be able to cope with the difficulties in using modern construction technology?

4. Do you think teaching staff to use a new technology is time-consuming and costly?

5. Will you still reject the use of new technology even if they are found to be useful and cost-effective? If yes, what are the reasons behind your decision?

6. Sharing information can benefit the development of construction industry in the long run. However, contractors in Hong Kong normally do not share technical knowledge and experience with the others. Why are they reluctant to do so?

7. It seems that many modern construction technologies have only been tested by their suppliers and their qualities and standards are not guaranteed; thus people have doubts on their functions. Do you agree that setting up an independent body (e.g. the National Research Council in Italy is this kind of organization) for testing and certifying these technologies, will help their diffusion among the industry?

- End -