Application of Barcode Technology for An Incentive Reward Program to Reduce Construction Wastes in Hong Kong

By Heng Li,[1] Zhen Chen,[2] and Conrad T C Wong[3]

Abstract: A group-based incentive reward program (IRP) has been implemented to minimize avoidable wastes of construction materials by rewarding workers according to the amounts and values of materials they saved. The barcode technique is used to facilitate the effective management of construction materials on site. An experiment is conducted on a residential project in Hong Kong and results from the experiment demonstrate the effectiveness of the IRP in motivating workers to reduce construction wastes. Discussions on the relationship between construction waste reduction and time and cost performances of the project are presented. Difficulties and challenges of applying the IRP and barcode technology are also included.

INTRODUCTION

Construction waste is a serious environmental problem in many large cities. According to statistical data, C&D debris frequently makes up 10 to 30 percent of the waste received at landfill sites around the world (Fishbein 1998). However, in Hong Kong, an average of 7,030 tons of construction and demolition (C&D) waste were disposed of at landfills everyday in 1998, representing about 42% of total waste intake at landfills; and in 1999, there were 7,890 tons of C&D waste disposed of at landfills every day, representing about 44% of total waste intake at landfills (EPD 1999, 2000). Contrasted to the percentage in other advanced countries, for example, C&D debris makes up only 12 percent of the waste received at Metro Park East Sanitary Landfill of Iowa State in the United States (MWA 2000), the quantity of C&D waste in Hong Kong is much higher. As there are increasing demands on residential buildings in Hong Kong, a 13-year production program has been established by the Hong Kong SAR Government in 1998, which has been rolled forward to produce an average of 50,000 flats by

[1] Associate Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong.
[2] Doctoral Candidate, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong.
[3] Managing Director, Yau Lee Construction Co., Ltd., Kowloon Bay, Kowloon, Hong Kong.

the public sector and 35,000 flats by the private sector each year (HB 1999). How to reduce construction waste is thus becoming more important in Hong Kong. In order to reduce construction related wastes, a new policy on the disposal of C&D waste has been established and enacted in 2001 in Hong Kong. This policy enables the government to charge contractors who dispose C&D waste for about HK$100 per ton at public landfills. Therefore, how to reduce C&D waste disposal from construction sites has become an important concern for contractors.

There have been many research efforts studying construction waste control in Hong Kong. For example, a study that investigated construction waste generated from public housing projects in Hong Kong was conducted in 1992 (Cheung *et al* 1993). Methods for construction waste minimization in Hong Kong were discussed by Poon *et al* (1996). These waste minimization methods emphasize the use of modern technologies in building construction, such as precast concrete, steel form and scaffold, drywall partition panel, etc. However, surveys show that local construction firms in Hong Kong feel it is expensive to use new machinery and automation technologies (Ho 1997); most (68~85%) local construction firms will adopt these new technologies only when they are demanded and compelled by the designers, the specifications, or the clients (Poon *et al* 1999). As a result, construction waste control in Hong Kong is still a major problem to be solved.

Previous studies have established a set of waste prevention strategies in building construction. These strategies mainly focus on the effective coordination of materials management, including efficient purchase and ordering of materials; just-in-time delivery; careful storage and the use of materials to minimize loss, maximize reuse, prevention of undoing and redoing, and reduction of packaging waste; *etc* (Fishbein 1998, Coventry, *et al* 1999).

As another important factor, design coordination has a major impact on the waste generation. Incorrect or unconstructable designs result in significant amounts of wastes. A study on the relationship between causes and costs of rework indicates that, among other factors, design coordination is predominantly important (Love and Li 2000). However, as the housing projects in Hong Kong adopt a series of standard designs developed by the Housing Authority of the Hong Kong Special Administrative Region, the effect of design coordination is minimized, if not negligible. Therefore, in this study, the impact of design coordination on waste generation is not considered.

The objective of this paper is to present an on-site material management system using an incentive reward program (IRP) and barcode technology to control and reduce construction wastes. The IRP is designed to encourage construction workers, who are directly involved in producing construction wastes, to reduce wastes by rewarding them based on the amounts and values of the materials they saved. The bar-coding technology is used to facilitate easy data recording and transfer.

BARCODE APPLICATIONS IN CONSTRUCTION

Bar Coding is an automatic identification (Auto ID) technology that streamlines identification and data collection, and the technology of barcode has been applied to many fields since early 1960s, such as assembly checking, fixed asset inventory control, job costing and tracking, labor distribution, library automation, records management, remittance processing, stock taking, time and attendance, warehouse picking, warranty and service tracking, work-in-process inventory tracking, check-in and billing, receiving, and shipping, etc. (SunMax 2001). In the construction industry, barcode technology has been introduced since later 1980s when the Construction Industry Institute (CII) funded a research project to explore the potential applications and the resulting cost-saving benefits of barcode use in construction (Bell and McCullouch, 1988).

From then on, barcode technology has been applied in many areas in the construction industry. These areas include quantity takeoff, field material control, warehouse inventory and maintenance, equipment/tool and consumable material issue, timekeeping and cost engineering, purchasing and accounting, scheduling, document control, office operations, and other information management in construction processes of projects (Bell and McCullouch 1988, Bernold 1991, Anderson 1993, McCullouch and Lueprasert 1995, Stukhart 1995, *etc*.). Some published studies and applications of barcode technology in the construction industry are listed in Table 1.

Table 1 Research and Applications of Barcode Technology in Construction

Researchers	Year	Research and Applications
L. C. Bell and B. G. McCullouch	1988	Summarization of the findings of potential applications and the resulting cost-saving benefits of barcode in construction, including field material control, equipment and tool control, document control, office operations, etc.
G. Stukhart, *et al*.	1988~ 1992	A series of studies on barcode standardization in construction, and two summary reports submitted to the CII about barcode standardization in construction, including potential barcode applications, need for barcode standards, approaches to barcode standardization, methodology for developing industry standards, applications of barcode system and barcode standards.
E. J. Lundberg and Y. J. Beliveau	1989	A barcode application system for automated lay-down yard control to reduce loss, theft, misplacement, and misidentification of material and equipment in construction projects.
W. J. Rasdorf and M. J. Herbert	1989~ 1990	A barcode application system for a construction information management system, including jobsite resource and activity identification, transfer of data acquisition, work force involvement, and inventory improvement.
L. H. Blakey	1990	A report on the results of an application of barcode in a construction-related field, that of facility maintenance, repair, and minor construction.
L. E. Bernold	1990	A research on testing barcode technology in construction environment, including field-testing of barcode labels and adhesives, laboratory testing of barcode labels and adhesives, and the design and development of a pilot yard control system that utilizes the bar-coding concept.
T. L. Brandon and R. A. Stadler	1991	A barcode application system to aid in geotechnical data collection and reduction for conventional sieve analyses.
M. J. Skibniewski, *et al*.	1992	Application of barcode technology in robotic materials handling system for automated building construction systems.
A. N. Baldwin, *et al*.	1994	An overview of bar-coding techniques and describes in detail the results from a feasibility study undertaken for a major UK supplier of prestressed, precast flooring beams. The research confirmed the technical, economic and operational feasibility of introducing bar coding for materials management within the construction industry.
B. G. McCullouch and K. Lueprasert	1994	Application of two-dimensional (2D) barcode in construction, including hardware, software, symbology, and using.
D. Echeverry, *et al*.	1996~ 1998	Implement barcode control in construction projects in Colombia, including a discussion about adaptation of barcode for construction project control, and barcode control of construction field personnel and construction materials.

M. R. Kemme	1998	A barcode tracking system for hazardous waste, including tracking information on hazardous material consumption and generation.
D. Wirt, *et al*.	1999	A barcode application system of a wastewater treatment plant project, where barcodes are used to track equipment from receipt to installation, and then is used to interface with an electronic operation and maintenance manual.

Although the barcode technology has been used to control hazardous waste, including tracking information on hazardous material consumption and hazardous waste generation in the United States (Kemme, 1998), no previous study has attempted to integrate barcode technology with IRP to minimize C&D wastes on sites. This study aims to integrate environmental management with project management in construction by implementing the IRP to minimize construction wastes.

IRP FOR REDUCING CONSTRUCTION WASTE

On-site Construction Wastes from Housing Projects

Although there is no generally accepted definition, construction waste can be loosely defined as the debris of construction and demolition (C&D) (EPA 2000). Specifically, construction waste refers to solid waste containing no liquids and hazardous substances, resulting from the process of construction of structures, including buildings of all types (both residential and nonresidential) as well as roads and bridges. Construction waste does not include cleanup materials contaminated with hazardous substances, friable asbestos-containing materials, lead, waste paints, solvents, sealers, adhesives, living garbage, furniture, appliances, or similar materials.

A typical public housing block in Hong Kong is a multi-storey reinforced concrete (RC) residential building with about 40 floors. The construction technologies/processes for constructing public housing blocks are summarized in Table 2.

Table 2 Construction technologies of Public Housing Block in Hong Kong

Stage	Technologies
Site formation & clearance works	Demolition, site leveling
Foundation works	Precast RC pile, excavation, in-situ RC foundation
Superstructure works	Precast RC external wall panel, in-situ RC load-bearing wall, corridor and slab, semi-precast RC slab, precast concrete internal drywall, precast RC staircase, precast concrete block
Finish works	In-situ external and internal plastering and coating, external wall and floor tile,
Other works	Batching plant, tyrewasher system, precast plant, transportation

According to our site surveys as well as surveys conducted by other researchers (Poon and Ng. 1999), construction waste generated mainly includes wastage of cement, concrete rubbles, drywall scraps, wood scraps, rebar scraps, concrete block scraps, plastic conduit tailings, material packing and containers, nails and some other unused materials. Table 3 indicates the construction processes involved in public housing construction projects and the types of wastes generated from the construction processes.

Table 3. Construction Waste Generated from Construction Processes

Construction Process	**Construction Waste**								
	Concrete rubble	Drywall scrap	Block scrap	Cement wastage	Wood scrap	Rebar tailing	Nail	Plastic conduit tailing	Material packing & container
Fix wall rebar						✓		✓	
Place precast facade									✓
Place wall form					✓	✓*			
Concrete wall	✓			✓					✓
Strip wall form	✓								
Place precast slab									
Fix timber slab				✓	✓		✓		
Fix slab rebar						✓		✓	
Concrete slab	✓			✓					✓
Fix drywall		✓							
Bond block			✓						

Note: * when through-wall sleeve can't be fixed easily, wall rebar will be cut.

Avoidable Material Wastes Caused by Workers

Workers are executors of construction operations. Site surveys (Poon and Ng 1999) show that workers' attitude towards construction operations and materials can make a significant difference to the amount of construction wastes generated. Without careful control and rewarding systems, construction workers may become careless in handling construction materials. As a result, reusable materials such as reinforcement bars, half-bags of cement, nails and timber pieces are often thrown around the sites. Table 4 lists the avoidable wastes caused by workers in public housing projects in Hong Kong.

Table 4. Avoidable Wastes Caused by Workers in Public Housing Projects in HK

Construction Process	Avoidable Wastes Caused by Workers
Fix wall rebar	Extra processed rebar, arbitrarily cut rebar, abandoned rebar tailing, etc.
Place precast facade	Damaged facade board, broken scraps during erection.
Place wall form	Arbitrarily cut & drilled plywood board, abandoned plywood board.
Concrete wall	Left-over mixed concrete, excess concreting, etc.
Strip wall form	Damaged forms.
Place precast slab	Damaged slab boards, broken scraps during erection.
Fix timber slab	Arbitrarily cut & drilled plywood boards, abandoned plywood boards.
Fix slab rebar	Extra processed rebar, arbitrarily cut rebar, abandoned rebar tailing, etc.
Concrete slab	Left-over mixed concrete, excessive concreting, etc.
Fix drywall	Arbitrarily cut drywall board, damaged drywall board, broken scraps during erection.
Bond block	Extra mortar, extra delivered blocks, cut & abandoned blocks, etc.

The skill and attitude of workers are the main factors affecting the amounts of wastes produced by workers (Pilcher 1992). Between these two factors, workers' attitude toward their work, including their enthusiasm and collectivism, is the most important in terms of waste generation. In other words, if workers do not take care of what they are doing then more materials will be wasted. So it is important to establish an on-site construction material management system to encourage construction workers to handle materials carefully, and to enhance their enthusiasm and collectivism by rewarding them based on their good performances in saving materials through reducing operational mistakes, returning unused materials for reuse or recycle, etc.

Incentive Reward Program

The current site practices in Hong Kong tolerate that construction materials are taken from the storages on site without effective control, and placed with poor organization, especially in large projects or during urgent construction processes. The incentive reward program (IRP) aims to provide an effective tool for the project manager to manage on-site materials, and to motivate workers to reduce material wastes.

Research on the relationship between motivation and productivity in the construction industry has been conducted over the last 40 years (Olomolaiye *et al* 1998). The relationship between motivation and productivity is summarized as that productivity is dependent upon motivation, and motivation is in turn dependent on productivity (Warren 1989). A comparison of labor productivity for masonry activities from seven countries, including Australia, Canada, England, Finland, Scotland, Sweden and the United States, reveals that there is little difference in productivity of the seven countries despite significant differences in labor practices, and the principal difference is the management influence (Thomas, *et al* 1992). This viewpoint is replenished with a case study focusing on the impact of material management on productivity, which shows that ineffective material management could incur losses of productivity (Thomas, *et al* 1990). On the other hand, a series of comparative evaluations of labor productivity rates amongst French, German and UK construction contractors indicate that German workers are likely to be highly motivated (because they are high paid and regarded as on a par with people doing intellectual and scientific work), and hence, more productive (Proverbs, *et al* 1998). All these research results reinforce that higher motivation brings higher productivity.

According to Maslow's motivation theory (Warren 1989), beyond their safety and health needs, workers require both emotional and financial rewards for exercising self-discipline in handling construction materials. There are many forms of rewards and punishments for worker's performance measure (Nelson 1994). Among these positive and negative rewarding (punishing) methods, some have been used on construction sites. For example, the use of special motivational program, and financial incentive programs (FIP) have been reported (Laufer and Jenkins 1983, Liska and Snell 1993, Carberry 1996, and Olomolaiye 1998). The FIP is an important method for motivating workers, and it has been proved to be effective in improving quality and reducing project time and cost (Laufer and Jenkins 1982). Furthermore, the FIP has been widely accepted as a performance-dependent monetary reward system in the construction industry (Merchant 1997). The IRP developed in this study is designed based on the principle of FIP, in order to meet the demand of on-site construction material management.

Fairness is an important consideration in designing the IRP; less fairness or unfairness would result in the failure of the IRP and may even have adverse effect on a construction project. Before the IRP is implemented, its fairness should be examined carefully. There are two aspects of fairness in the IRP; one is the fairness to workers, another is its fairness to the firm. The fairness to the firm is easy to investigate. Because the IRP relates to the amount of construction materials consumed on site and if the overall amounts of construction wastes are reduced, then the firm will be benefited. So the firm should share the benefits (saved money) with the contributors - workers.

The fairness of the IRP to workers is different. Workers are normally organized into gangs or groups according to their trades or types of work. Material is normally shared within the group. If an amount of material waste is detected, who should be punished, or, if there is a reduction of waste, who should be rewarded: the person who is responsible for shifting material from the storage, or the leader of the group? Based on discussions with the project managers and workers involved in the projects we surveyed, we decided to adopt a group-based IRP. In the group-based IRP, members of the group will be rewarded or punished equally should there be any reduction and increase of material wastes. Group-based rewards provide a common goal for group members and encourage cooperation among members to achieve a higher performance, and it avoids the difficulty in determining individual's contribution (Laufer and Jenkins 1982, Merchant 1997).

In the group-based IRP, each working group has a group leader who is responsible for withdrawing all the materials needed by his group from the storage keeper. The storage keeper records the amount of materials taken by each group. When a group finishes its work, the group leader is also responsible for arranging any unused materials to be returned back to the storage keeper for updating the records.

Once a construction operation is completed, the project manager can measure the amount of material waste reduced or increased by comparing the actual amount of material used by the group with the estimated amount. The actual amount of material used is recorded by the storage keeper, while the estimated amount of material is prepared by the contractor's quantity surveyors. The estimated amount includes a percentage that is considered as a normal amount of waste on site. The percentage is determined based on the contractor's experience from the levels of wastes in past projects.

For a particular type of material *i*, the performance of group *j* in terms of material wastage can be measured using set 1.

$$\Delta Q^i(j) = Q^i{}_{estimated}(j) - (Q^i{}_{delivered}(j) - Q^i{}_{returned}(j)) \quad (1)$$

Where $\Delta Q^i(j)$ is the extra amount of material *i* saved (if the amount is a positive value) or wasted (if the amount is a negative value) by group *j*; $Q^i{}_{delivered}(j)$ denotes the total quantity of material *i* requested by group *j*; and $Q^i{}_{estimated}(j)$ denotes the estimated quantity that includes the statistic amount of normal wastage. The value of $Q^i{}_{estimated}(j)$ has to be carefully decided according to the circumstances of construction projects and previous experience (Schuette and Liska 1994, CIOB 1997). The $Q^i{}_{returned}(j)$ is the quantity of unused construction materials returned to the storage by group *j*.

At the end of the project, the overall performance of group *j* can be measured by set 2.

$$C^i(j) = \sum_n \Delta Q^i(j) \times P_i \qquad (2)$$

Where $C^i(j)$ denotes the total amount of material *i* saved (if $C^i(j)$ is positive) or wasted (if $C^i(j)$ is negative) by group *j*; *n* is the total number of tasks in the project that need to use material *i*; and P_i is the unit price for material *i*.

The contracting company has to develop a policy to specify how the company shares with workers of the costs/benefits incurred from the reduction or increase of material wastes. For example, the company may decide that workers should share 40% of the $C^i(j)$. In other words, the company will give back 40% of the $C^i(j)$ to workers as rewards. The rewards can be positive if the value of $C^i(j)$ is positive; and it can be negative (penalties) if the value of $C^i(j)$ is negative.

IRP and quality Assurance

As the IRP focuses on waste reduction on site and there might be jerrybuilt construction process when a worker group wants to excessively save materials, it is important to integrate IRP with quality and time management during the project. In the Hong Kong construction industry, residential buildings are built based on standard designs; it is convenient for the quantity surveyors to accurately measure the exact amounts of materials consumed in each activity and process. Working groups and the group leaders will be seriously questioned if the groups reduced such much material consumption in certain activities or processes that the actual amounts of used materials were near or below the exact amounts measured by the quantity surveyors. In addition, rigorous quality assessment has to be conducted to ensure that the quality level is maintained.

IMPLEMENTAION OF IRP USING BAR-CODING TECHNOLOGY

Bar-coding system for IRP

The primary function of the bar-coding system is to provide instant and up-to-date information of quantities of materials exchanged between the storage keeper and the group leaders. Specifically, the bar-coding system can provide the following functions to implement IRP for reducing construction waste:

- Automatically tracking real-time data of new construction materials on the site;
- Automatically tracking real-time data of unused materials on the site;
- Automatically tracking real-time data of packing of materials and equipments;
- Automatically tracking real-time waste debris of materials on the site;
- Automatically recording historical data of construction materials consumed in the project;
- Automatically monitoring materials consumption of working groups;
- Automatically transferring real-time data of materials to head office via Intranet and/or Internet.

The architecture of the bar-coding system used in this implementation is illustrated in Figure 1.

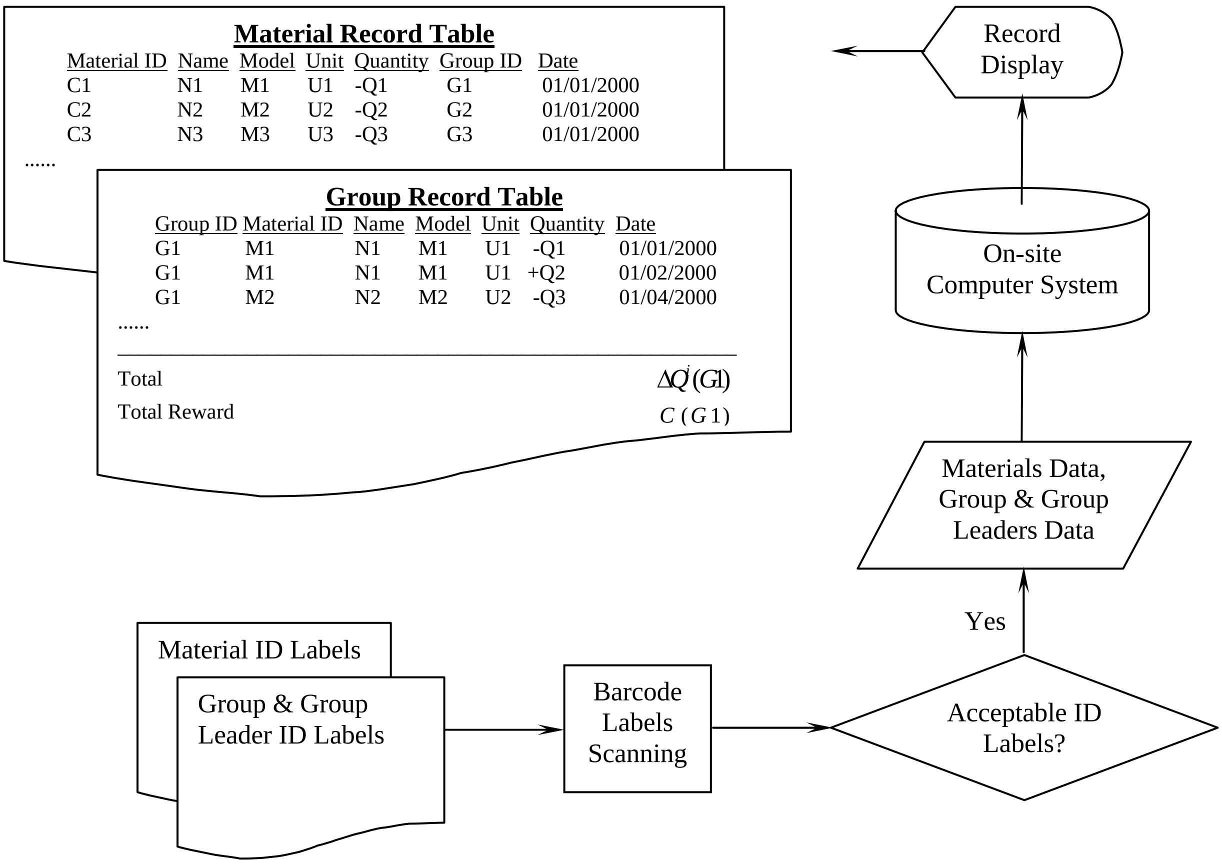


Figure 1. Data Flowchart of the bar-coding system for group-based IRP

From Figure 1, it can be seen that when the group leader goes to the storage to withdraw new materials or return surplus materials, the storage keeper scans the bar-coding labels for the materials as well as the bar-coding label of the group, so that the amounts of materials taken or returned by the group are registered in the database. Based on the amounts of materials initially ordered according to the estimated requirements, and the materials used by working groups, the computer system can calculate the value of $C^i(j)$ for each group *j*. Barcodes are given to each item (if it is big, e.g. door, window etc), or each pack (if the items are small, e.g. pack of nails, bolts and nuts).

Hardware and Software Used in Implementing the IRP

Hardware System

The hardware system of the bar-coding application consists of the barcode scanner and the computer. A basic barcode scanner consists of a scanner, a decoder, and a cable that interfaces between the decoder to the computer or terminal. Although there are four basic styles of barcode scanner: light pen (usually called wand), linear CCD (Charged Couple Device), laser and video (CCD array), the most versatile barcode scanners are laser scanners, and many scanners have the decoder logic incorporated into a chip within the scanner, eliminating the need for a separate piece of hardware (PIPS, 2001). The scanner we selected is PSC QuickScan 5385 scanner with keyboard wedge type of decoder integrated, which allows barcode scanning to be added to almost any application without modification to the application software (PIPS, 2001). Figure 2 describes schematic components of the bar-coding hardware system.

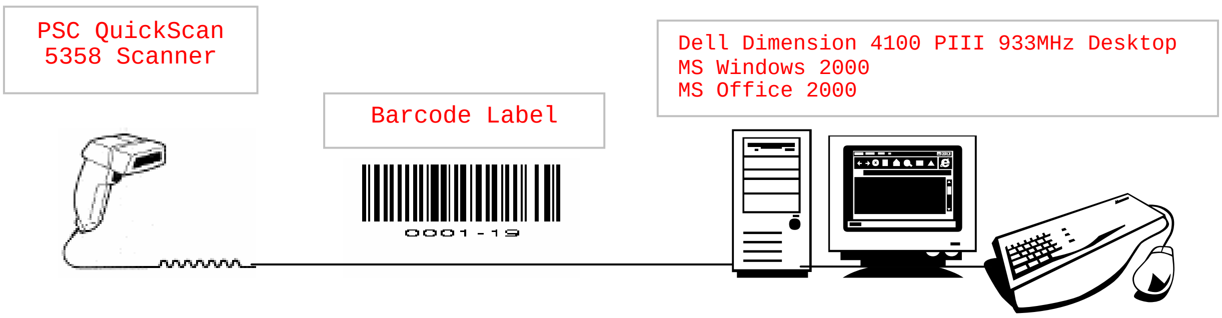


Figure 2. Components of bar-coding hardware system

Software System

The software system for a barcode technology include two essential software: barcode-labeling software and barcode-tracking software. Barcode technology providers such as Loftware LLM-WIN32, BAR-ONE, and BarTender, provide fast and easy to use barcode-labeling software for designing and printing quality labels. Barcode-tracking software, such as IntelliTrack and Inventory Manager, can be used to read and track the barcodes.

The barcode adopted here is the Code 128 symbology (Stukhart 1995). Software named "LLW-Win32 Design" (Version 5.x) from Loftware label printing systems is used to design the identification labels, and all bar-coding labels are printed out through a HP LaserJet printer.

Because bar-coding labels can be easily damaged during transportation and items of construction materials are cumbersome for the storage keeper to scan the barcode labels if they are adhered onto the items/packs, we prepared a handbook of bar-coding labels for all kinds of the construction materials used on different sites. This handbook contains all the barcodes and is maintained and used by the material storage keeper.

Material Identification

For the materials, the bar-coding labels are designed to represent a material and its model. For examples, the code *0001-19* represents “plywood formwork - 19 mm thick - 1 sq m”, the code *0002-525* represents “Cement - Portland, ordinary 525# - 1 bag”, as shown in Figure 2. The "Class No." in Figure 3 is used to represent names of different materials, and the total number of the "Class No." is set as 2,000.

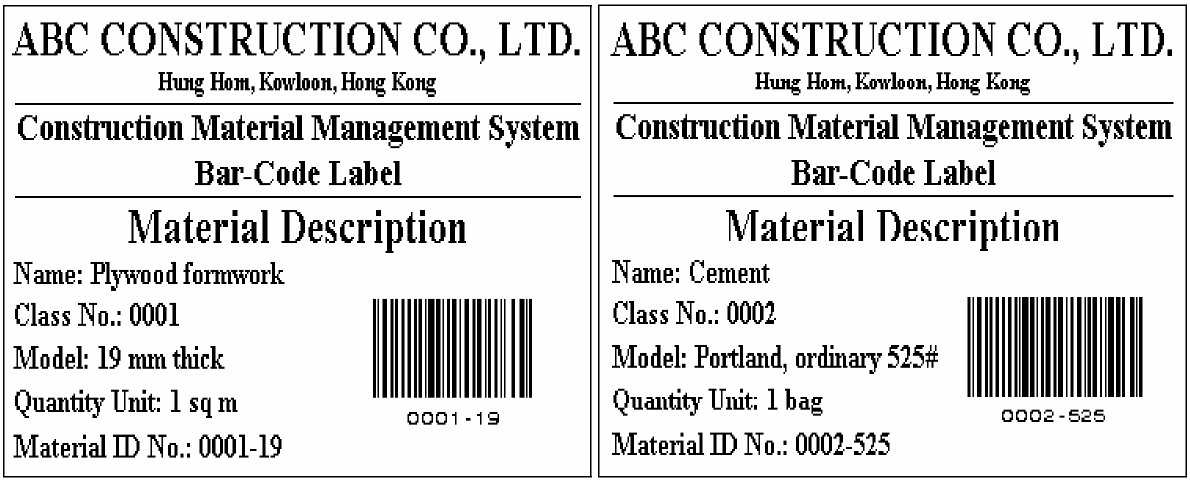
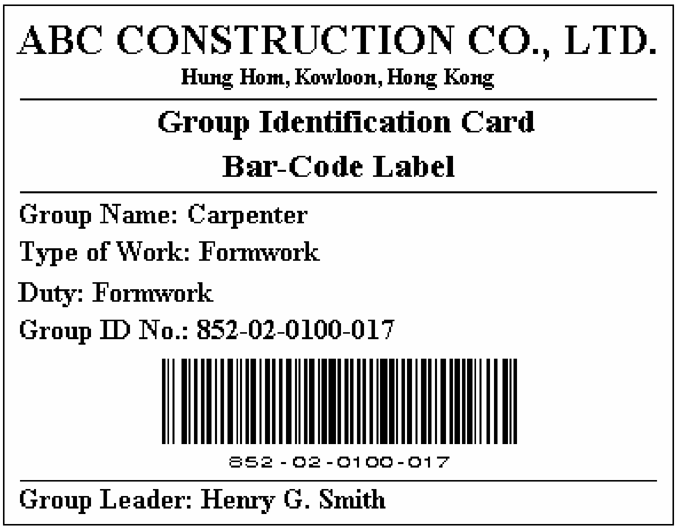


Figure 3. Sample bar-coding labels for construction materials

Working Group Identification

For each working group, an identification label is issued to the group leader, who is responsible for withdrawing and returning construction materials. Figure 4 gives a sample identification label for a working group.


ABC CONSTRUCTION CO., LTD.
Hung Hom, Kowloon, Hong Kong

Group Identification Card
Bar-Code Label

Group Name: Carpenter
Type of Work: Formwork
Duty: Formwork
Group ID No.: 852-02-0100-017

852-02-0100-017

Group Leader: Henry G. Smith

Figure 4. Bar-coding label for a Carpenter group

The barcode of the group represents the group and its leader. For example, coding number *852-02-0100-017* represents "Carpenter group 852 and its leader's staff ID number is 02-0100-017", as shown in Figure 4. By scanning the barcodes for the materials and the group, the computer system keeps records of materials used or returned by the group. These records are then used to calculate the reduction and increase of material wastes generated by the group.

EXPERIMENTAL RESULTS

A public housing project in Hong Kong was selected to experiment the group-based IRP. The project involved constructing two identical 34-storey residential blocks using a 6-day cycle. The 6-day cycle included nine major activities undertaken by nine working groups. The two blocks were constructed simultaneously by two teams of workers, each team having nine working groups with equal numbers of workers to carry out the 6-day cycle construction method. We labeled the two teams as Team A and Team B. For the purpose of comparison, Team A did not adopt the group-based IRP during their operations, while Team B implemented the IRP with our advice and support.

(Insert Table 5 and 6)

The experiment has been conducted over three months. Results from Team A and B during the three months are listed in Table 5 and 6. The first column of the tables is the list of major materials used in the 6-day cycle. The second column is the unit of the materials; the third column contains the group names and their tasks. Columns 4-6 list estimated quantities of materials, quantities of materials delivered to groups, and quantities returned by groups. Column 8 lists the prices of materials, while Column 7 and 9 list results of calculations based on sets 1 and 2. From the experimental results, it can be observed that throughout the three months, Team A consistently wasted more construction materials than Team B, because workers in Team A did not see the benefits of reducing wastes. Therefore, by the end of three months, Team A has wasted additional amounts of construction materials valued at US$95,890.73 (HK$747,947.71). On contrast, Team B has made a substantial saving of US$90,428.83 (HK$705,344.85), indicating that the group-based IRP had effectively motivated workers in Team B in reducing avoidable wastes. The difference between the two projects is US$186,319.56 (HK$1,453,292.5). The cost of the bar-coding system is about HK$150,000. Thus, Team B has about HK$550,000 savings. These results convinced us that the group-based IRP is effective in reducing construction wastes.

Furthermore, the experiment reinforces that the bar-coding system can achieve cost savings for contractors. Comparing to the total cost of the bar-coding system that is given out in Table 7, the savings obtained from the reduction of material waste are much higher than the initial investment of the bar-coding system.

Table 7. Cost items of the bar-coding hardware system

Item	Price (US$)	Price (HK$)
PSC Quickscan 5358 Scanner	819	6,388.2
Dell Dimension 4100 PIII 933MHz Desktop	870	6,788.0
Loftware LLM-WIN32 Design (Version 5.x)	795	6,200.0
MS Windows 2000	319	2,488.2
MS Office 2000	599	4,672.2
Total cost	3,402	26,536.6

CONCLUSIONS AND DISCUSSIONS

Although experimental results demonstrated the obvious strength of the group-based IRP in reducing wastage of construction materials, there has been a concern from the senior management of the contracting company in using the group-based IRP. The concern was the fear that workers might jerry-build in order to save materials. As the IRP does not directly relate itself to the quality of work, the management felt that there is a need to investigate how to combine the quality and time performances of workers with the IRP when deciding the amounts of rewards to workers. However, the IRP-integrated construction management has been proved to be useful and effective in reducing the amount of available material wastes.

Difficulties have also been identified during implementing the IRP on site. First, because the bar-coding system can only recognize materials that have the standard quantity and does not automatically accept returned bits and pieces, quantities of the returned materials have to be assessed by the storage keeper and be manually entered into the computer system. This can potentially bring inaccuracies into the system. Second, as different groups may withdraw same materials, misunderstanding and conflicts between groups may occur if materials of one group are moved or mistakenly used by members of other groups. This problem will be intensified in situations with congested working spaces. These problems need to be resolved before the group-based IRP can be fully accepted and endorsed by the industry.

This paper presents a group-based IRP, which encourages workers to reducing avoidable wastes of construction materials on site. The IRP is based on the principle of motivating workers through giving them performance-based financial rewards. Because the unique situation in Hong Kong, this study did not consider other factors that may influence the generation of on-site wastes, such as design coordination and site supervision. Therefore, further studies are needed to test the usability of the IRP in other countries. In addition, the paper introduces the use of a bar-coding system to register the flow of materials so that performances of working groups in terms of material wastage can be easily measured. In order to avoid jerrybuilding, further research is needed to integrate the IRP with quality and time management.

Although barcode technology has been proved to be effective and efficiency to information management on construction site, it is also noticed that the bar-coding handbook of materials does not the best solution for tracking materials. First, the life span of a bar-coding handbook is finite due to frequent using. Second, updating of a bar-coding handbook is not easy if we print a new edition set. Third, it can easily produce additional wastage if an old edition or old piece of bar-coding handbook were thrown away, especially in a long-term practice. So a more effective and efficiency approach should be found out in order to avoid these pitfalls.

ACKNOWLEDGEMENTS

The research is supported by a postgraduate studentship provided to the first author by the Hong Kong Polytechnic University.

APPENDIX. REFERENCES

Anderson, M. R. (1993) Barcodes bring savings. *ENR*. November 29. 45.

Anon (1999) Barcode Drives Resin Handling, Shipping. *Packaging Digest*. Vol. 36, No.6. 1.

Baldwin, A. N., Thorpe, A., and Alkaabi, J. A. (1994) Improved Materials Management through Bar-Coding: Results and Implications from a Feasibility Study. *Proceedings of Institute of Civil Engineers: Civil Engineering*. Vol. 102, November.156-162.

Bell, L. C., and McCullouch, B. G. (1988) Barcode Application in Construction. *Journal of Construction Engineering and Management*. ASCE. Vol. 114, No. 2. 263-278.

Bernold, L. E. (1990) Testing Barcode Technology in Construction Environment. *Journal of Construction Engineering and Management*. ASCE. Vol. 116, No. 4. 643-655.

Bernold, L. E. (1990) Barcode- Driven Equipment and Materials Tracking for Construction. *Journal of Computing in Civil Engineering*. ASCE. Vol. 4, No. 4. 381-395.

Blakey, L. H. (1990) Barcode: Prescription for Precision, Performance, and Productivity. *Journal of Construction Engineering and Management*. ASCE. Vol. 116, No. 3. 468-479.

Brandon, T. L., and Stadler, R. A. (1991) Use of Barcode Technology to Simplify Sieve Analysis Data Acquisition. *Geotechnical Engineering Congress 1991 (Volume 1): Proceedings of the Congress sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers*. (Edited by McLean, F. G., Campbell, D. A. and Harris, D. W.) (Geotechnical Special Publication No. 27) ASCE. 556-561.

Carberry, E. (1996) Assessing ESOPs. *Journal of Management in Engineering*. ASCE. Vol. 12, No. 5. 17-19.

Cheung, C. M., Wong, K. W., Poon, C. S., Fan, C. N., and Cheung, A. C. (1993) *Reduction of Construction Waste: Final Report*. Department of BRE and CSE of the Hong Kong Polytechnic University and The Hong Kong Construction Association Ltd..

CIOB (1997). *Code of Estimating Practice (6th edition)*. The Chartered Institute of Building. Longman. England.

Coventry, S., Woolveridge, C., and Patel, V. (1999) *Waste Minimisation and Recycling in Construction - Boardroom Handbook*. Special Publication 135. CIRIA. London.

Echeverry, D., Guerra, C. A. and Beltran, A. (1998). A Regional Attempt to Implement Barcode Control in Construction Project. *Computing in Civil Engineering: Proceedings of*

International Computing Congress in Civil Engineering (5th) (Editor-in-chief: Wang, K. C. P.; Associate editors: Adams, T., Maher, M. L., and Songer, A.). ASCE. 450-453.

Echeverry, D., and Beltran, A. (1997). Barcode Control of Construction Field Personnel and Construction Materials. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering (4th)* (Editor-in-chief: Adams, T. M.). ASCE. 341-347.

Echeverry, D. (1996). Adaptetion of Barcode Technology for Construction Project Control. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering (3th)* (Editor-in-chief: Vanegas, J and Chinowsky, P.). ASCE. 1034-1040.

EPA (2000) *EPA Region 9 Solid Waste Program: Construction and Demolition (C&D) Debris*. Available at http://www.epa.gov/region09/waste/solid/debris.htm.

EPD (Environmental Protection Department, Hong Kong) (2000). *Environmental Impact Assessment Ordinance*. Chapter 499, Section 10.

EPD (Environmental Protection Department, Hong Kong) (2000). *Environment Hong Kong 2000*.

EPD (Environmental Protection Department, Hong Kong) (1999). *Environmental Protection in Hong Kong*. < http://www.info.gov.hk/epd/ehk99/>.

EPD (Environmental Protection Department, Hong Kong) (1999). *Monitoring of Solid Waste in Hong Kong 1998*. <http://www.info.gov.hk/epd/waste/msw98/TEXT/TOC.HTM>.

EPD (Environmental Protection Department, Hong Kong) (1999) *Monitoring of Solid Waste in Hong Kong 1997*. <http://www.info.gov.hk/epd/E/pub/sw-rep/Toc.htm>.

EPD (Environmental Protection Department, Hong Kong) (1999) *Solid Waste Statistics 1998 Updates*. <http://www.info.gov.hk/epd/E/pub/sw-rep/98update/Index.htm>.

Fishbein, B. K. (1998) Building for the Future: Strategies to Reduce Construction and Demolition Waste in Municipal Projects. <http://www.informinc.org/cdreport.html>.

HB, Government of the HKSAR (2000). *Hong Kong Fact Sheet - Housing (1999)*. Available at *http://www.info.gov.hk/hkfacts/housing.pdf*.

Ho, L. (1997) *Human resources planning strategies of the Hong Kong construction industry*. Thesis of MBA. Department of Management, Hong Kong Polytechnic University.

Kemme, M. R. (1998) Barcode Tracking System for Hazardous Waste (HW). Construction Engineering Research Laboratory, US Army Corps of Engineers. Available at *http://www.cecer.army.mil*.

Laufer, A., and Jenkins, G. D. (1982) Motivating Construction Workers. *Journal of the Construction Division*, ASCE. Vol. 108, No. 4. 531-545.

Liska, R. W., and Snell, B. (1993) Financial Incentive Programs for Average-Size Construction Firm. *Journal of Construction Engineering and Management*. ASCE. Vol. 118, No. 4. 667-676.

Love, P.E.D., and Li, H. (2000). Quantifying the Causes and Cost of Rework. *Construction Management and Economics*. **18** (4), pp.479-490.

Lundberg, E. J., and Beliveau, Y. J. (1989) Automated Lay-down Yard Control System-ALYC. *Journal of Construction Engineering and Management*. ASCE. Vol. 115, No. 4. 535-544.

Merchant, K. A. (1997) *Modern Management Control Systems: Text and Cases*. Prentice-Hall, Inc. New Jersey.

McCullouch, B. G., and Lueprasert, K. (1994) 2D Barcode Applications in Construction. *Journal of Construction Engineering and Management*. ASCE. Vol. 120, No. 4. 739-753.

MWA (Metro Waste Authority) (2000) *Commercial Programs - Construction & Demolition*. <http://www.metro-waste.com/commercial/construction.htm>.

Nelson, B. (1994) *1001 Ways to Reward Employees*. Workman. New York.

Olomolaiye, P. O., Jayawardane, A. K. W., and Harris, F. C. (1998) *Construction Productivity Management*. The Chartered Institute of Building. Addison Wesley Longman Limited.

Pilcher, R. (1992) *Principles of Construction Management*. 3rd edition, McGraw-Hill.

PIPS (2001) Scanners and Data Collection Terminals. <*http://www.pips.com/scanners.html*>

Poon, C. S., Xu, Y., and Cheung, C.M. (1996) Building Waste Minimization in Hong Kong Construction Industry. *Journal of Solid Waste Technology and Management*. Vol. 23, No. 2. 111-117.

Poon, C. S., and Ng, L. H. (1999) The Use of Modern Building Technologies for Waste Minimization in Hong Kong. *Proceeding of International Conference on Urban Pollution Control Technology (eds.* Poon, C. S., and Li, X. Z.*)*. The Hong Kong Polytechnic University. Hong Kong. 413-419.

Proverbs, D. G., Holt, G. D., and Olomolaiye, P. O. (1998) A comparative evaluation of reinforcement fixing productivity rates amongst French, German and UK construction contractors. *Engineering, Construction and Architectural Management.* Vol. 5, No. 4, 350-358.

Rasdorf, W. J. and Herbert, M. J. (1990). Automated Identification Systems- Focus on Bar Coding. *Journal of Computing in Civil Engineering*. Vol. 4, No. 3. 279-296.

Rasdorf, W. J. and Herbert, M. J. (1990). Bar Coding in Construction Engineering. *Journal of Construction Engineering and Management*. Vol. 116, No. 2. 261-280.

Rasdorf, W. J. and Herbert, M. J. (1989). Barcodes on the Job Site. *ID Systems*. Vol. 9, No. 3. 32-36.

Schuette, S. D., and Liska, R. W. (1994) *Building Construction Estimating*. McGraw-Hill, Inc. New York.

Skibniewski, M. J., and Wooldridge, S. C. (1992) Robotic Materials Handling for Automated Building Construction Technology. *Automation in Construction*. Vol. 1, No. 3. 251-266.

Stone, P. A. (1983) *Building Economy (3rd Ed.)*. Pergamon Press. England.

Stukhart, G. (1995) *Construction Materials Management*. Marcel Dekker, Inc., New York.

Stukhart, G., and Nomani, A. (1992) *Barcode System Standardization*. Source Document 70. Construction Industry Institute.

Stukhart, G., and Cook, E. L. (1990) Barcode Standardization in Industrial Construction. *Journal of Construction Engineering and Management*, ASCE. Vol. 116, No. 3, 416-431.

Stukhart, G., and Cook, E. L. (1989) *Barcode System Standardization in Industrial Construction*. Source Document 47. Construction Industry Institute.

Stukhart, G. and Pearce, S. L. (1989) Construction Barcode Standards. *Cost Engineering*. Vol. 31, No. 6. 1989. 19-26.

Stukhart, G. and Pearce, S. L. (1988) Construction Barcode Standards. *Proceedings of 5th International Symposium in Robotics in Construction*. Japanese Society of Civil Engineers. 361-370.

SunMax Corp. (2001) Barcode Basics. Available at *http://www.barcodesystems.com*.

Thomas, H. R., Sanvido, V. E., and Sanders, S. R. (1990) Impact of Material Management on Productivity - A Case Study. *Journal of Construction Engineering and Management*, ASCE. Vol. 115, No. 3, 370-384.

Thomas, H. R., Sanders, S. R., and Bilal, S. (1992) Comparison of Labor Productivity. *Journal of Construction Engineering and Management*, ASCE. Vol. 118, No. 4, 635-650.

Warren, R. H. (1989) *Motivation and Productivity in the Construction Industry*. Van Nostrand Reinhold. New York.

Wirt, D., Showalter, W. E., and Crouch, G. (1999) Integrating Permanent Equipment Tracking with Electronic Operations and Maintenance Manuals. *Durability of Building Materials and Components 8 (Volume Four): Information Technology in Construction*. (Edited by Lacasse, M. A., and Vanier, D. J.) (CIB W78 Workshop) NRC Research Press. 2716-2723.

Table 5. Experimental Result without Group-based IRP (Team A)

Materials	Unit	Group		$Q^i_{estimated}(j)$	$Q^i_{delivered}(j)$	$Q^i_{returned}(j)$	$\Delta Q^i(j)$	P_i	$C(j)$
		Name	Duty						
Rebar	ton	Steel bender	Fix wall rebar	1760.00	1795.20	0.00	-35.20	2271.31	-79950.11
			Fix slab rebar	1408.00	1425.60	0.00	-17.60	2271.31	-39975.06
Precast facade	set	Rigger	Place precast façade	1760.00	1760.00	0.00	0.00	3000.00	0.00
Precast slab	set		Place precast slab	9856.00	9856.00	0.00	0.00	1500.00	0.00
Cement	ton	Concretor	Concrete wall	31680.00	31715.20	0.00	-35.20	640.80	-22556.16
			Concrete slab	10560.00	10630.40	0.00	-70.40	640.80	-45112.32
		Plasterer	Fit up wall, ceiling & floor	15400.00	15554.00	0.00	-154.00	640.80	-98683.20
Sand	cubic meter	Concretor	Concrete wall	26928.00	27280.00	0.00	-352.00	57.04	-20078.08
			Concrete slab	10560.00	11264.00	0.00	-704.00	57.04	-40156.16
		Plasterer	Fit up wall, ceiling & floor	24024.00	24670.80	0.00	-646.80	57.04	-36893.47
Cobblestone	cubic meter	Concretor	Concrete wall	26752.00	27456.00	0.00	-704.00	58.30	-41043.20
			Concrete slab	10560.00	11264.00	0.00	-704.00	58.30	-41043.20
Hydrated lime	ton	Plasterer	Fit up wall, ceiling & floor	9394.00	9424.80	0.00	-30.80	464.00	-14291.20
Plywood formwork	square meter	Carpenter	Fix timber slab form	26400.00	27280.00	0.00	-880.00	57.20	-50336.00
Nail	bag		Fix timber slab form	1760.00	2640.00	0.00	-880.00	50.10	-44088.00
Drywall board	square meter	Rigger	Install wall board	9460.00	9900.00	0.00	-440.00	164.00	-72160.00
Block	10000 blocks	Bricklayer	Bond masonry wall	2.20	2.75	0.00	-0.55	7296.12	-4012.87
Embedded plastic conduit	meter	Electrician	Concel conduit installation	18480.00	22000.00	0.00	-3520.00	1.05	-3696.00
Glass	square meter	Glazier	Install window glass	8078.40	8448.00	0.00	-369.60	27.80	-10274.88
Paint	square meter	Painter	Fit up minor works	468.60	484.00	0.00	-15.40	25.00	-385.00
Wall tail	square meter	Plasterer	Fit up wall	22704.00	23760.00	0.00	-1056.00	34.00	-35904.00
Mosaic	square meter		Fit up wall and floor	10824.00	11352.00	0.00	-528.00	89.60	-47308.80
			Total(HK$)						-747947.71

Table 6. Experimental Result with Group-based IRP (Team B)

Materials	Unit	Group name	Duty	$Q^i_{estimated}(j)$	$Q^i_{delivered}(j)$	$Q^i_{returned}(j)$	$\Delta Q^i(j)$	P_i	$C(j)$
Rebar	ton	Steel bender	Fix wall rebar	1760.00	1724.80	17.60	52.80	2271.31	119925.17
			Fix slab rebar	1408.00	1372.80	17.60	52.80	2271.31	119925.17
Precast facade	set	Rigger	Place precast façade	1760.00	1760.00	0.00	0.00	3000.00	0.00
Precast slab	set		Place precast slab	9856.00	9856.00	0.00	0.00	1500.00	0.00
Cement	ton	Concretor	Concrete wall	31680.00	31609.60	17.60	88.00	640.80	56390.40
			Concrete slab	10560.00	10454.40	17.60	123.20	640.80	78946.56
		Plasterer	Fit up wall, ceiling and floor	15400.00	15276.80	15.40	138.60	640.80	88814.88
Sand	cubic meter	Concretor	Concrete wall	26928.00	26576.00	105.60	457.60	57.04	26101.50
			Concrete slab	10560.00	10384.00	211.20	387.20	57.04	22085.89
		Plasterer	Fit up wall, ceiling and floor	24024.00	23870.00	123.20	277.20	57.04	15811.49
Cobblestone	cubic meter	Concretor	Concrete wall	26752.00	26576.00	246.40	422.40	58.30	24625.92
			Concrete slab	10560.00	10384.00	211.20	387.20	58.30	22573.76
Hydrated lime	ton	Plasterer	Fit up wall, ceiling and floor	9394.00	9332.40	3.08	64.68	464.00	30011.52
Plywood formwork	square meter	Carpenter	Fix timber slab form	26400.00	26048.00	140.80	492.80	57.20	28188.16
Nail	bag		Fix timber slab form	1760.00	1584.00	88.00	264.00	50.10	13226.40
Drywall board	square meter	Rigger	Install wall board	9460.00	9350.00	0.00	110.00	164.00	18040.00
Block	10000 blocks	Bricklayer	Bond masonry wall	2.20	2.15	0.22	0.28	7296.12	2006.43
Embedded plastic conduit	meter	Electrician	Concel conduit installation	18480.00	18004.80	176.00	651.20	1.05	683.76
Glass	square meter	Glazier	Install window glass	8078.40	7867.20	26.40	237.60	27.80	6605.28
Paint	square meter	Painter	Fit up minor works	468.60	462.00	2.20	8.80	25.00	220.00
Wall tail	square meter	Plasterer	Fit up wall	22704.00	22545.60	132.00	290.40	34.00	9873.60
Mosaic	square meter		Fit up wall and floor	10824.00	10718.40	132.00	237.60	89.60	21288.96
			Total(HK$)						705344.85