ADOPTION AND ADAPTATION OF DIGITAL PHOTOGRAMMETRY IN A HONG KONG SURVEY PRACTICE

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ABSTRACT

There are many private land surveying practices existing in Hong Kong. The companies are mainly divided into two groups: concentrating in particular disciplines (cadastral, engineering or fitting out) or in a broad range of types of disciplines. Their competition for business is very high. It is a continuous challenge for the private practices keeping their businesses cost-effective. The manpower, equipment, measurement and data processing techniques applied to tasks are all expenses to the company, which must be offset against income with the aim of making a profit. The management should continually seek ways to achieve this. There are two major arenas that many land surveying companies explore to increase their profitability. First, new markets for providing their services; second, the adoption of new technologies. In the surveying industry, the two arenas do affect each other.

This investigation responds to the above situation. Its aim is to introduce digital photogrammetric technology into a Hong Kong private surveying company to investigate the possibility of advancement in its services. There are two covered areas in the research. First, the technological considerations through an equipment and manpower study, and accuracy standard achievement of photogrammetric techniques compared with traditional surveying methods. Second, the economic considerations involving decision making processes, benefit-cost analysis and sensitivity analysis.

The approaches set in the research can be divided into four areas. Firstly, the evaluation of the current technology, equipment and software. It is necessary to investigate their effect in the company's everyday fieldwork. According to the nature of different projects, conventional surveying methods and photogrammetric techniques have both pros and cons in different areas. Secondly, the establishment of working procedures. Through the practices involving manpower in the company, the crews can have guidance on basic knowledge in the introduced technology. Thus, a spread in learning photogrammetric techniques can form in the private sector. Thirdly, the development of a decision-making algorithm for the industry to investigate the profitability of the adoption of this technology. This analysis is to provide support to users in evaluating their decisions. The different methodologies are treated as different alternatives in the analysis. The well-known Analytical Hierarchy Process is selected as the tool in the benefit-cost analysis. After the development of several photogrammetric techniques both for independent application and in cooperation with conventional surveying methods, the partnering company started investigation on its tasks. Eventually, the exploitation of new opportunities with the aid of the company's photogrammetric field practices is needed.

It is found that for the tasks of 3D visualization model establishment, photographic survey, and terrain modeling, digital photogrammetry show advantages over conventional survey techniques with acceptable costing in equipment and staff training. This conclusion was reached assuming that the photogrammetric systems were already available within the company. However, when their cost is included, only 3D visualization models and photographic survey applications were considered as being feasible.

For the studied company, it was found that projects requiring 3D visualization model establishment could be economically undertaken by digital photogrammetric systems comprising of data acquisition devices such as higher resolution digital cameras (e.g. Fujifilm MX700 in this research) and software such as low-cost photogrammetric/modeling packages (e.g. PhotoModeler).

Chapter 1 Introduction

1.1 Introduction

There are many private land surveying practices in Hong Kong. The companies are divided into main two groups: those concentrating in particular survey disciplines (cadastral, engineering, topographic etc.) and those covering a broad range of disciplines. Both groups essentially employ conventional surveying techniques. Most of them have extensive experience in plane, boundary and topographic surveying, setting out procedures and even deformation monitoring tasks. Their competition for business is very high. It is a continuous challenge for the practices to operate cost-effectively. The manpower, equipment, measurement and data processing techniques applied to tasks are all expenses to the company, which must be offset against income with the aim of making a profit. To achieve this, the management should continuously seek ways to maximize profit. Besides improving the efficiency of manpower or equipment, managers can introduce new business opportunities into everyday operations of the company.

However, the traditional role of the surveying discipline in Hong Kong is to provide accurate and precise information for other disciplines. To be competitive, methodologies that produce measurements according to the clients needs, interests, or even style must be used. Due to the need to cost effectively satisfy client requirements, there are not many opportunities to introduce new techniques or media for presenting the required information. In Hong Kong, this is because of the contracting system that exists in the engineering and construction disciplines. Within the structure of a construction project, a main contractor is responsible to the client for the whole project and acts on behalf of the involved disciplines, such as architecture, construction, and accounting. The different disciplines are arranged in tree-like structure to provide "top-down" supervision. The relationship between the surveying profession and other professions is as "supplier and customer" respectively, which is direct and productive rather than consulting as the supplied information is assessed and evaluated by the other professions (the clients) themselves. The weakness of the surveying profession operating under these conditions is that not enough "customer support with expertise" can be provided. There are few opportunities for creativity.

As technology advances, many newly introduced technologies, such as GPS, GIS, and photogrammetry have become increasingly functional and stable. Companies, no matter what their business, are willing to invest in technological application in an effort to improve their profits. For example, a private land surveying company had generated a series of orthoimages of the North Lantau Highway together with the Tsing Ma Bridge by photogrammetric techniques for the Civil Engineering Department (CED) of the Hong Kong SAR Government. It is believed that such a technology adoption will be considered by other disciplines due to its ability to improve their performance and the quality of their products. There are two major arenas that many land surveying companies explore to increase their profitability. First, new markets for providing their services and second, the adoption of new technologies. In the surveying industry the two arenas are correlative and affect each other.

GPS was the first of the newly adopted technologies (the second arena) to improve the profitability of land surveying companies. GIS was the next to come under wide investigation and application. However, in Hong Kong, photogrammetric techniques have rarely been adopted for use by private land surveying companies' applications.

Photogrammetry was developed over 100 years ago and today there are two main divisions: aerial and close-range. Film-based metric cameras were applied in the past as the data acquisition devices and photogrammetric plotters were necessary for production. They were expensive and their operations were usually very complicated requiring trained operators thus limiting their acceptance by private companies. The general products for clients were line drawings or these in combination with photos.

From the 1970's, mathematical models involving space resection and intersection computation and using collinearity equations took precedence due to the rapid development in computers. The iterative solutions saved time when compared with the past methodologies. The introduction of non-metric film cameras into close-range applications was one of the factors to broaden the application of photogrammetry. This is because of the lower cost of non-metric film cameras compared with aerial and medium format metric cameras. The data acquisition process was then not limited by the necessity to have the above expensive cameras. Another factor for the greater acceptance of close-range photogrammetry was that computers could assist in the processing and computation stage in analytical plotters. However, analytical systems are still expensive compared to traditional surveying equipment.

In the 1980's, the era of digital photogrammetry arrived. The broader adoption of computer technology has enriched the capability of photogrammetric techniques, such as the feature extraction process, multi-convergent network in photography, and CCD cameras vs. traditional film cameras. They are all improving the standard of photogrammetry. In the previous eras, objects were mainly represented as products in point-line form, such as drawn plans or diagrams in analog stage, or CAD computer format through analytical plotters. It is difficult to present more detailed information with these technologies. However, we can collect more information on objects through electronic images taken from digital cameras or scanned images. We can even establish a visual database to virtually represent the actual objects. Moreover, there is rapid development in high-resolution CCD sensors for digital cameras. Commercial digital cameras with one or even two million pixel sensors are very common. These cameras have improved pictorial quality and reduced cost compared to early digital cameras. Together with low-cost photogrammetric software packages such as PhotoModeler™ and 3D Builder™, they can produce the previously described tasks with acceptable accuracy and with other specific requirements, such as photo texturing on the computer-generated models. These photogrammetric software packages provide elementary functions in photogrammetric measurement process, such as image measurements, automatic computation, result analysis and output presentation. The general accuracy and precision is of course lower than other highly precise photogrammetric workstations, like the Intergraph ImageStation™. However, they are more attractive in cost to private survey companies.

In developed countries, like the United States and Germany, there are numerous disciplines applying photogrammetric techniques in fieldwork. Current journals and proceedings report a wide range of applications of both topographic (aerial) and non-topographic (close-range) and analytical and digital photogrammetry. For example Maas and Kersten (1997) discussed cartographic and deformation monitoring by digital CCD cameras, and Renuncio et al. (1998) historic recording with the aid of low-cost photogrammetric software packages. Those surveying companies have more experience in handling photogrammetric tasks from various disciplines. In Hong Kong, government agencies and the large statutory authorities are the major groups applying photogrammetry to their field of work. Moreover, the photogrammetric expertise in Hong Kong is limited because the experienced staff in private surveying companies are familiar with surveying, but not photogrammetry. They have insufficient information to investigate the feasibility of photogrammetric applications into their business. In Hong Kong, there are some investigations into the feasibility of applying close-range photogrammetric techniques to fieldwork. Xu et al. (1998) described the application of digital close-range techniques into the quality control of a Chinese wooden temple construction, and Ho and Chan (1999) investigated the adoption of close-range techniques into engineering practices.

For investigating the transfer of digital photogrammetric technology into a private land surveying company, the Hong Kong Polytechnic University and a local private practice, Mannars Chan and Associates, have jointly undertaken this research under the Teaching Company Scheme. The research will allow the transfer of expertise into the company to broaden the knowledge level of surveyors in accepting photogrammetry as one of the feasible methodologies of fieldwork and the expansion of products and services offered by the company.

1.2 Aims of the research

This research responds to the above situation. There are two areas included in the research. First, the technological considerations through an instrument and manpower study and the accuracy achievement of photogrammetric techniques compared with traditional surveying methods. Second, the economical considerations through assessment of the decision making process, benefit-cost analysis and sensitivity analysis.

In regards to the technological consideration, the study is to conclude the most suitable combination of hardware and software for various applications in different surveying disciplines. It is achieved by a comparison of the existing conventional surveying methods in the company and the adopted photogrammetric techniques. The basis of comparison is the cost of equipment and software, time for processing, and operator's skill. Simultaneously, the working procedures in photogrammetry, which are not familiar to staff of the company, needed to be established.

This project also provided a decision-making algorithm for the partnering company and the selection of suitable technology (traditional surveying or photogrammetry) for different surveying tasks. This algorithm is primarily based on financial judgement, providing a benefit-cost analysis on input resource with output return, and sensitivity analysis on possible alternative techniques. Its significance is that benefit-cost analysis is the core affecting the policy of investment, marketing strategy and daily fieldwork within the company.

1.3 Methodologies

The approaches of the research can be divided into four areas. Firstly, the evaluation of the current digital photogrammetric technology, equipment and software. It is necessary to investigate their possible effect in the company's everyday fieldwork. According to the different projects, conventional surveying methods and photogrammetric techniques will both have pros and cons in different areas. Experiments were carried out in many different types of fieldwork existing within the company. The testing of the involvement of photogrammetric techniques into those field works can see whether they can aid the present works and provide improved products compared with the traditional method or not. The planning, procedures, results and analysis are all considered in feasibility studies from both technological and business viewpoints. It will give a clear understanding as to how digital photogrammetry can aid the business.

Secondly, the establishment of working procedures. There is a problem with wider acceptance of photogrammetry in the surveying industry in Hong Kong. The personnel in surveying companies have little training in photogrammetric techniques. This prevents the companies' investment because there is no guarantee on backup or support from the employees to produce returns. A transfer of expertise to the partnering company can provide more competitive power by application of the technology by the company. Through the practices involving manpower in the company, the staff can have guidance on basic knowledge in the introduced technology. Thus, a spread in the learning of photogrammetric techniques can form in the private sector. At the end of the project, a comprehensive guide of working procedures in the application of photogrammetric techniques is established.

Thirdly, the development of a decision-making algorithm for the land surveying industry to investigate the profitability of digital photogrammetric technology. Through the application of the analytical hierarchy process, the algoritm can guide users in the selection of the appropriate technology for their surveying task.

The techniques investigated are purely conventional surveying method; conventional survey with supplementary imagery low-cost photogrammetric modeling software packages, and precise photogrammetric measurements. All four alternatives were evaluated with the aid of benefit-costs analysis. Various examples are given as evidence to prove the reliability of the decision support system.

Lastly, the investigation of areas of exploitation of photogrammetry's application. After the development of several photogrammetric techniques separately and in cooperation with conventional surveying methods, the partnering company investigated its tasks. Through seeking possibilities for providing new service to other disciplines, like office environment simulation for estate surveying and image re-engineering for film production, it will provide a broader view of the industry and identify areas where there is potential to increase the company's profitability through expanding its product line.

1.4 Dissertation Organization

This dissertation is divided into seven chapters. "Chapter 1 – Introduction" provides an introduction and background to the topic – the adoption and adaptation of digital photogrammetry into a Hong Kong surveying company. "Chapter 2 – Background and Review" reviews the background information and previous investigations relevant to the research. It covers topics of the general concepts of photogrammetry; developments in photogrammetry over the past 100 years, especially digital photogrammetry, digital photogrammetric systems, past investigations in the application of photogrammetry, the uses of photogrammetry in private practices, and a brief description on benefits-costs analysis and decision making process. Previous works of AHP aided decision making in other local and foreign engineering fields were addressed as references.

"Chapter 3 – Conventional and Photogrammetric Survey in Hong Kong" provides the current status of applying conventional and photogrammetric survey in Hong Kong nowadays. The two different methodologies are briefly demonstrated and evaluated under accuracy, capability and economics.

"Chapter 4 – Decision Support System in This Research" concentrates on developing the decision-making algorithm. The construction of hierarchies, weight assignment, computation and resultant weight evaluation are all included.

"Chapter 5 – Cases Studies" is the presentation of results of the testing of different projects and their evaluation. The different projects have the same structure of hierarchies but individual weight differences. It is due to the different specifications and requirements of different tasks.

The final chapter, "Chapter 6 - Summary and Recommendation", first gives a conclusion of the whole dissertation and then provides feedback and recommendations.

Chapter 2 Background and Review

2.1 Introduction

There are two major divisions in photogrammetry: topographic and non-topographic. The former is also known as "aerial photogrammetry" while the latter can also be called "close-range photogrammetry". Aerial photogrammetry has a general flowchart of processing parallel photography, interior and exterior orientation, and bundle adjustment. However, close-range photogrammetry is less standardized by its acceptance of many types of photography and calculation methods, such as the application of the self-calibration bundle adjustment process in calculating results. Thus, there are not as many constraints in close-range photogrammetry as in aerial photogrammetry. Specialists have made investigations into the development of photogrammetric techniques and their exploitation of new opportunities of both divisions for many years. Starting from the last century, the techniques have been applied in architectural recording, biomedical and mapping purposes (Slama, 1980). Following the rapid growth of information technology in the last decade, there has been a digital revolution in photogrammetry. This research concentrated on investigating close-range techniques, which are commonly believed to be of greater capability and flexibility than those of aerial photogrammetry in general application. The adoption of digital close-range photogrammetry by a private land surveying company was chosen to be assessed as a viable alternative to existing conventional surveying methods applied under different requirements and environments.

This chapter provides the background and review of the relevant topics in photogrammetry and looks at, the previous relevant research considering the adoption of photogrammetry into business. A brief definition of photogrammetry and the history of its digital evolution are described in Section 2.2 – " Definition and History of Photogrammetry". The basic concept in formulating close-range photogrammetry with the application of geometry of camera stations and mathematical modeling can be found in Section 2.3 – "Theory of Close-range Photogrammetry". Following is an introduction to "Digital Photogrammetric System (DPS)" in Section 2.4. It will provide the description of important components in establishing a DPS, like data acquisition, enhancement recognition, reduction and extraction process. The

"Application Areas" investigated in previous research, such as engineering and industrial measurements will be shown in Section 2.5. However, there are very few studies in adopting photogrammetry into the private surveying industry, which emphasize the consideration of commercial uses for different disciplines from the point of view of business. The review of those articles can be found in Section 2.6 – "The Use of Photogrammetry in Commercial Markets".

2.2 Definition and History of Photogrammetry

2.2.1 Definition

When compared with other surveying techniques, the unique characteristic of photogrammetry is that *"measurements are carried out indirectly"* (Mikhail, 1989). It is because the coordinates of objects of interest or important features are measured, extracted, and evaluated from a stereopair or even strips, blocks or bundles of overlapping parallel or convergent photographs. Thus, techniques in this measuring science can transfer 2-dimensional information in photographs to 3-dimensional object space information.

The two common divisions in photogrammetry are topographic and non-topographic photogrammetry. The first common technique is topographic (aerial) photogrammetry. Mapmakers recognized the advantages of aerial photogrammetry because the technique provided them with an *"effective, economical and convenient mapping tool"* (Karara, 1989). Non-topographic photogrammetry is widely applied in many disciplines such as engineering and industrial metrology. As described previously, the task of using photogrammetry for measuring relatively smaller format objects led to the term close-range photogrammetry. Most measurements will not exceed 300m in object distance. Another characteristic of close-range photogrammetry different from aerial is that images are often taken from all possible angles around the object. Consequently, the photography is not limited in either parallel or convergent rays.

To support the adoption of technology, it is necessary to have a system of "gain-loss" evaluation to compare the competing technologies. Well-known decision making processes can provide the capability to handle such analysis. In Section 2.7, a brief review of relevant decision analyses and common approaches within will be presented.

2.2.2 History

After 30 years of applying plane table photogrammetric techniques, analog photogrammetry appeared in the 1920s, and the theory of stereoscopy was introduced in this period. Through some refinement in machinery, analogue stereoplotters became the leader in both topographic and non-topographic photogrammetry. Stereometric cameras were later introduced in the 1940s to 50s, and they were applicable in close-range tasks.

However, the expensive costs for such machines prohibited many surveyors from adopting photogrammetry into their businesses. Furthermore, the inflexibility of large format metric cameras also proved to be a limitation to the wider acceptance of photogrammetry in close-range applications. It was not until the development of analytical methodologies in the past three decades that the private sector attention turned towards it.

The analytical stage allowed *"no limitation on model size, plot size, overlap, and base setting, and can be used to plot nearly any types of close-range imagery, including non-metric photography"* (Karara, 1985). This was through the introduction of numerical methods into operations within photogrammetric plotters, and those machines were called "computer-assisted stereoplotters". They had the solving power ability of thousands times better than previous analogue plotters. It was achieved by the involvement of computer calculation in the procedures, like interior and exterior orientations.

The application of smaller format cameras that were metric or non-metric, focusable (compared with non-focusable aerial cameras), and relatively cheap (affordable to the private sector), had allowed the spread of photogrammetry into projects starting from the 1970's. In the 1990's, imaging technology had been recognized as the trend in investigating the improvement in performance of photogrammetric systems. This is because "digital" has become the accepted buzzword in many industries, which is commonly understood that digital imaging techniques can replace the traditional film based imaging in a cost effective manner. The reducing costs in computer platforms, data acquisition devices (especially digital cameras), and the improvement in capability of photogrammetric software will attract more private sector attention for adoption into their businesses.

This analogue to digital imaging transformation is gradual because digital imaging techniques have only become widely applied in recent years. Gruen (1993) stated that the research and development in digital photogrammetric systems, data acquisition devices and processing algorithms grew rapidly starting from the 1980s. For example, the increase in resolution of CCD sensors and advances in techniques of computer systems. Entering the 1990s, two important advancements of digital technology development occurred to notify the private practice surveyors of the feasibility of adopting photogrammetry into their businesses. They were the appearance of low-cost algorithms (PhotoModeler®, 3D Builder® and Rollei CDW®), and various data acquisition routines (Leberl et al., 1992; Peipe, 1995; Sarjakoski, 1992). The first advancement offered surveyors easy handling, quick and lower-cost platforms for lower accuracy projects, while the second advancement broadened the data input for those algorithms, such as digital cameras, film cameras and scanners.

2.3 Theory of Close-range Photogrammetry

To distinguish close-range applications from aerial photogrammetry, their difference from a theoretical point of view is the first important issue to be addressed. In general, photogrammetrists are not limited by the photographic location (camera network). Any configuration or combination of camera stations will be acceptable if the required accuracy can be achieved. Either parallel or convergent photography will be applied in different tasks to fit the requirements of object size, room for photography, and obstruction in the area. Atkinson (1996) stated that mathematical modelling, which can devise object coordinates with the aid of least square estimation, will be very suitable in solving modern close-range tasks because of the above requirements – for example high accuracy and limitation in circumstances.

There are four important issues considered in the conceptual procedures of working close-range tasks. They are all based on coordinate transformations, which is the basic concept for transforming photo-coordinates onto object space coordinates systems. Firstly, the single camera geometry is described (Section 2.3.1). Any objects having their locations projected onto the photo (projection plane) are according to the concept of coordinate transformation. Secondly, camera calibration is described (Section 2.3.2). Lens distortion can be treated as an independent topic in photogrammetry. This is to discuss the problem of image distortion introduced by lenses, which will have great influence on the coordinate transformation. Thirdly, the geometry of two cameras and the object is described in Section 2.3.3. It involves the space intersection calculation to correlate the photo-coordinates from the two photos. Fourthly, the geometrical relationships between all cameras and objects, which are called multi-station convergent networks, are described in Section 2.3.4. Finally, Section 2.3.5 describes the least square adjustment process, which provides a systematic method to achieve unique values of coordinates with the use of redundant measurements.

2.3.1 Single camera geometry

Coordinate transformation is to convert the coordinates of objects from the primary to the secondary coordinate system and vice versa. Photogrammetry is the geometrical description of cameras and objects in photo and object space (primary vs. secondary) coordinates systems. The following is the equation of 3D conformal coordinate transformation. It transforms point A (X_A, Y_A, Z_A) to (x_a, y_a, z_a) in secondary coordinates system with the aid of the primary origin (X_O, Y_O, Z_O) together with the scale μ and any rotations R about the axes:

$$\mathbf{x}_a = \mu^{-1}\mathbf{R}\left(\mathbf{X}_O - \mathbf{X}_A\right) \qquad (2.1)$$

The following equations are the collinearity equations (2.2 & 2.3), which are derived from (2.1) together with the understanding from the geometrical relationship in the following diagram (Fig. 2.1). Atkinson (1996) stated that "*...the collinearity equations are derived from the collinearity of a point such as A, the perspective center O and the perspective projection of A onto the plane of projection at a*".

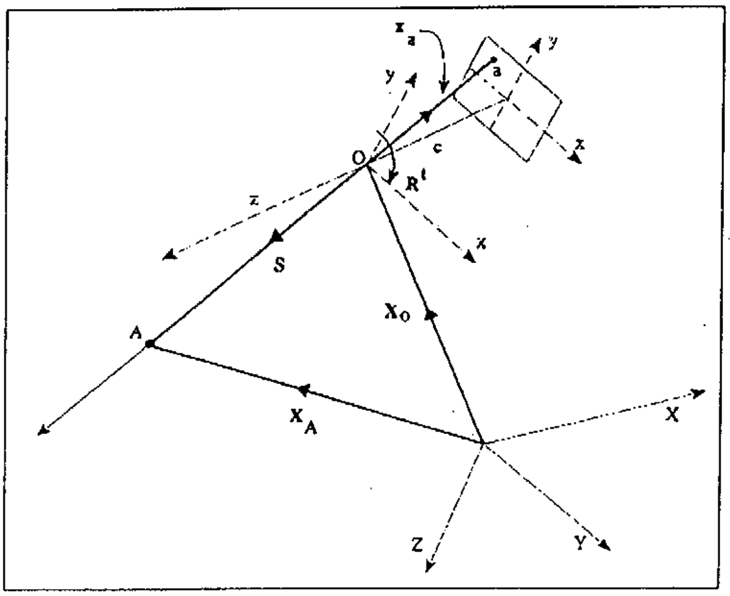

Fig. 2.1 The collinearity condition (Atkinson, 1996)

$$x_a = \frac{-c[r_{11}(X_O - X_A) + r_{12}(Y_O - Y_A) + r_{13}(Z_O - Z_A)]}{[r_{31}(X_O - X_A) + r_{32}(Y_O - Y_A) + r_{33}(Z_O - Z_A)]} \tag{2.2}$$

$$y_a = \frac{-c[r_{21}(X_O - X_A) + r_{22}(Y_O - Y_A) + r_{23}(Z_O - Z_A)]}{[r_{31}(X_O - X_A) + r_{32}(Y_O - Y_A) + r_{33}(Z_O - Z_A)]} \tag{2.3}$$

Measurements of x, y photo-coordinates of points in images give rise to the two above collinearity equations (2.2) and (2.3). If the three elements of interior orientation (c, x_O *and* y_O) given by camera calibration and coordinates (X_A, Y_A, Z_A) of A in the object space coordinate system are known, the two equations will have six unknowns: rotation ω, φ and κ and coordinates (X_O, Y_O, Z_O) of the perspective centre. These six parameters are elements of exterior orientation. Their evaluation is known as space resection. At least three non-linear targets (control points) such as A in the above diagram are necessary for resection of a camera. Zheng and Wang (1992), described a direct evaluation of the above six elements in exterior orientation from photo-coordinates of images of three non-linear control points that does not require any approximate values.

If more statistically rigorous resection is required, the collinearity equations (2.2) and (2.3) can be linearized and an iterative least squares estimation can be used to evaluate the six exterior orientation parameters. In that case, three or more control points are necessary but they can be in different precision levels. In such least square estimation, the estimated parameters can be used in further photogrammetric processing, like space intersection (Section 2.3.3) and multi-station bundle adjustment (Section 2.3.4-5).

2.3.2 Camera calibration

The projection may be affected by some significant discrepancies, and errors will occur. Some of these errors are systematic and can be evaluated through a procedure called "camera calibration".

A major source of errors considered in camera calibration is from the manufacturing of the lenses, especially the common commercial digital or film cameras (Fig. 2.2). Large metric cameras will also have this problem occurring in their lenses but their manufacturers provide pre-calibrated parameters for reference.

However, laboratory techniques together with self-calibrating bundle adjustments are recommended to be applied before any fieldwork. There are two major considerations in lens distortion, radial distortion (2.4) and tangential distortion (2.5) and (2.6):

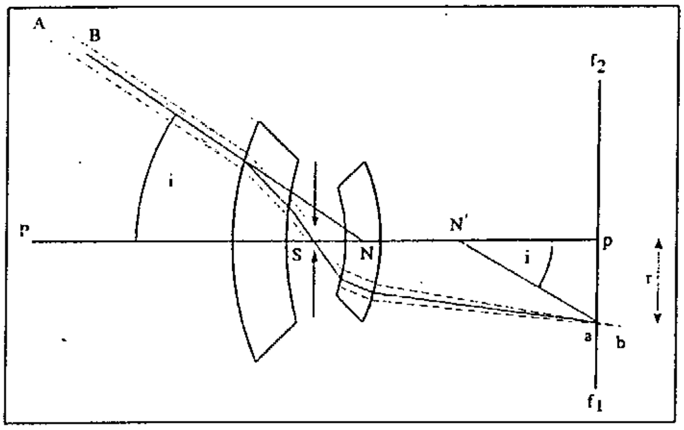

Fig. 2.2 Image formation by a lens (Scott, 1977)

$$\delta r = K_1 r^3 + K_2 r^5 + K_3 r^7 \quad (2.4)$$

$$\delta x = P_1 \left[r^2 + 2(y - y_0)^2 \right] + 2P_2 (x - x_0)(y - y_0) \quad (2.5)$$

$$\delta y = P_2 \left[r^2 + 2(y - y_0)^2 \right] + 2P_1 (x - x_0)(y - y_0) \quad (2.6)$$

The parameters in the above equations are the often referred to additional parameters (APs) in principles of photogrammetry. They are input to strengthen the collinearity equations from various camera stations.

On-the-job or self-calibration is an alternative to laboratory calibration and is a method widely applied in fieldwork and photogrammetric software, especially of the low-cost packages. This is because no object space control is required in self-calibration method, but the camera station network, rays intersection, and numbers of targeted points will greatly influence the precision of the result in such calibration. FEM (Lichti and Chapman, 1996) and analytical plumbline method (Brown, 1971; Fryer and Mason, 1989) are other methods used to calibrate close-range cameras.

2.3.3 Geometry of two cameras

When there are two photos to be determined, the object space coordinates (X_A, Y_A, Z_A) of a target A can be evaluated from measuring the photo-coordinates, such as (x_1, y_1) and (x_2, y_2), together with the exterior orientation parameters resulting from independent resection in each photo. Collinearity equations (2.2) and (2.3) are the basis of the method, but the least square estimation is required because of the three unknowns (X_A, Y_A, Z_A) and four equations. However, the process of combining the resection and intersection is not a cost-effective routine to determine an object in reality. It is because such processes cannot provide as accurate, precise and reliable estimates as multi-station bundle adjustment (Section 2.3.4-5). Moreover, the multi-station bundle adjustment permits the evaluation of camera calibration and interior orientation parameters more easily and reliably than resection and intersection (Fig. 2.3). If the calibration is done in resection, a large number of known control points are needed to provide a reliable result.

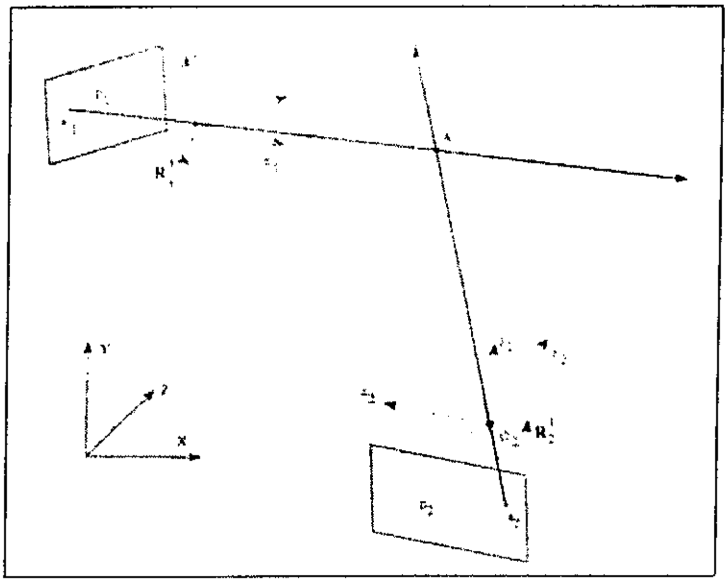

Fig. 2.3 Intersection (Atkinson, 1996)

2.3.4 Multi-station convergent network

In many photogrammetric tasks, there is more than a pair of camera stations for the whole setup. The multi-station convergent network will be established to obtain measurements from different angles (Fig.2.4).

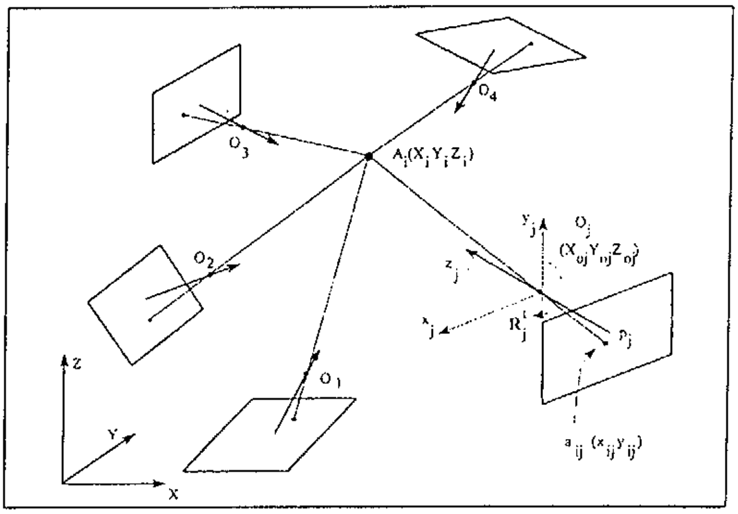

Fig. 2.4 Multi-station convergent configuration (Atkinson, 1996)

The APs (additional parameters), including those described in camera calibration (Section 2.3.2), can be applied in the collinearity equations (2.2) and (2.3) to improve the reliability of the results. Inclusive of the extended collinearity equations, they can be written:

$$\mathbf{F}(\mathbf{x}, \mathbf{b}, \mathbf{a}) = 0 \tag{2.7}$$

Where **x** is a vector representing the *u* elements whose values are required, **b** is a vector representing the *m* measured elements and **a** is a vector representing elements whose values are known constants. The above equation is the functional model of the photogrammetry based on collinearity equations, and is to evaluate **x** (model points on objects), by which **b** and **a** are given. Rather than obtaining the required and supplementing calibration parameters before the fieldwork, there is an alternative procedure to use the least square estimation to evaluate the unknown parameters. It is through the assumption of the parameters remaining unchanged in the observations. It is referred to as "self-calibration".

2.3.5 Least squares estimation

This estimation provides a systematic method for computing unique values of coordinates and other elements based on a large number of redundant measurements of different kinds and weights. It allows any elements to be treated as unknowns, measurements, or even constants depending on circumstances to suit particular tasks. The non-linear nature of functional models used in close-range photogrammetry is its main disadvantage; the estimation process requires approximate values to be inputted for iterating linear solutions.

Traditional photogrammetric software packages will provide least squares estimation for determining all the locations after their first estimation by the user. However, the low-cost packages, which are more popular in non-photogrammetric disciplines, do not have the repetitive estimation process but direct bundle solution because of the need for quickness and simplicity compared with other professional packages. They establish the first camera station through arbitrary assumption and the others are related to the first one. Resection and intersection are the common techniques to calculate the results.

2.4 Digital Photogrammetric Systems

It is now a digital world around us. It provides an environment of continuous development in adopting digital technology to photogrammetric systems. The characteristics of photogrammetry (e.g. data acquisition and geometric relationships between cameras and objects) can now be adapted into the systems in a more intelligent way. At one time, the application of analogue systems was limited and had fixed routines for solving tasks because of the inadequate capability of their mechanical components. However, now there is no restriction on selecting and applying complicated mathematical modeling and least squares estimation for improving the observations and calculations in the computerized environment within the photogrammetric systems. For example, the characteristics of photogrammetric determination like weight and lens distortion parameters enable more observations but have the greater solving power with the aid of quicker computers.

Digital technology can also enhance the presentation; for example, line drawings were the only presentation method of photogrammetry in the past. Conversely, digital data acquisition and feature extraction in modern digital photogrammetric systems can present the enriched details of targeted objects. It is easier to adopt the techniques of photogrammetry into applications of various disciplines which need expertise and accurate measurements for their tasks.

2.4.1 Structure of a digital photogrammetric system (DPS)

For any photogrammetric process, there are two major phases (Atkinson, 1989):

1. Acquiring the data from the object to be measured by taking the necessary photographs, i.e. data acquisition stage; and
2. Transferring the features in photographs (perspective projection) onto maps or in terms of spatial coordinates (orthogonal projection), this is to convert the photograms into analog or digital data, known as the data reduction stage.

There are some digital photogrammetric systems that will generally include both phases. However, the data acquisition devices are generally separated from DPS as individual components because of the need for mobility in fieldwork and adaptability to different systems. The data reduction stage is actually a combination of two procedures: measurement (or recognition) and positioning. They are the fundamental procedures in solving the coordinates of the targeted object. Currently, some extra operations are raised in the digitization of the photogrammetric systems, like data pre-processing before and during the measurement process, and feature extraction to supplement the final output.

There are two major ways of data acquisition for digital photogrammetry systems: image exposure by digital cameras and film image scanning. Both the digital and film based cameras require calibration. Ho and Chan (1999) provided comparisons between digital cameras, film cameras and scanners from the photogrammetric point of view. For the camera calibration methods involving close-range cameras, the common technique applied is the self-calibrating bundle adjustment as outlined in Section 2.3.2. For understanding the structure of a general digital photogrammetric system, Atkinson (1996) gave the following criteria (Fig. 2.5):

- High resolution display,
- Flexible image memory with fast access for real time roaming,
- Interface capability for scanners and cameras,
- Interface with output devices,
- 3D measurement with special control devices,
- Sub-pixel accuracy, and
- Data capture in a geographical information system (GIS) or computer aided design (CAD) environment.

Moreover, there were three more considerations raised by Gruen (1993):

- Capability for self-diagnosis (quality control),
- Potential for high precision and reliability (redundant sensor data), and
- Task flexibility with respect to 3D object reconstruction functions.

Modern computer systems can handle the above requirements easily. The well-known examples of such systems are ImageStation from Intergraph, Helava workstation and PHODIS from Carl Zeiss Ltd. Apart from the acquisition stage, data measurement, reduction and extraction can be processed within the software package installed in the computer. In the data measurement stage, stereoscopic display is not necessary for close-range applications because of the great convergence between images in particular tasks. The three above systems all have the function of stereoscopic display to be compatible with topographic photogrammetric applications.

Next, the data reduction stage. From the model points measured in data measurement stage, the systems can carry out calculation for the object space coordinates. There are two major routines for the data reduction in various digital photogrammetric systems. Simple systems will generally combine all the mathematical solving as the final stage in processing, while other precise systems will solve the required parameters at each stage, such as interior and exterior orientation and bundle adjustment (Section 2.3). The difference between aerial, close-range and simple modelling systems will be described in the next section.

The data reduction operation, which is of most interest to specialists in the area of digital photogrammetry, is image matching and its automation. With the aid of artificial intelligence (AI), computerized images, and palette matching, detection of sub-pixel accuracy can be done through the application of imaging techniques (Shortis et al., 1994). More problems or materials for digital image processing can be found in textbooks such as Burdick (1997).

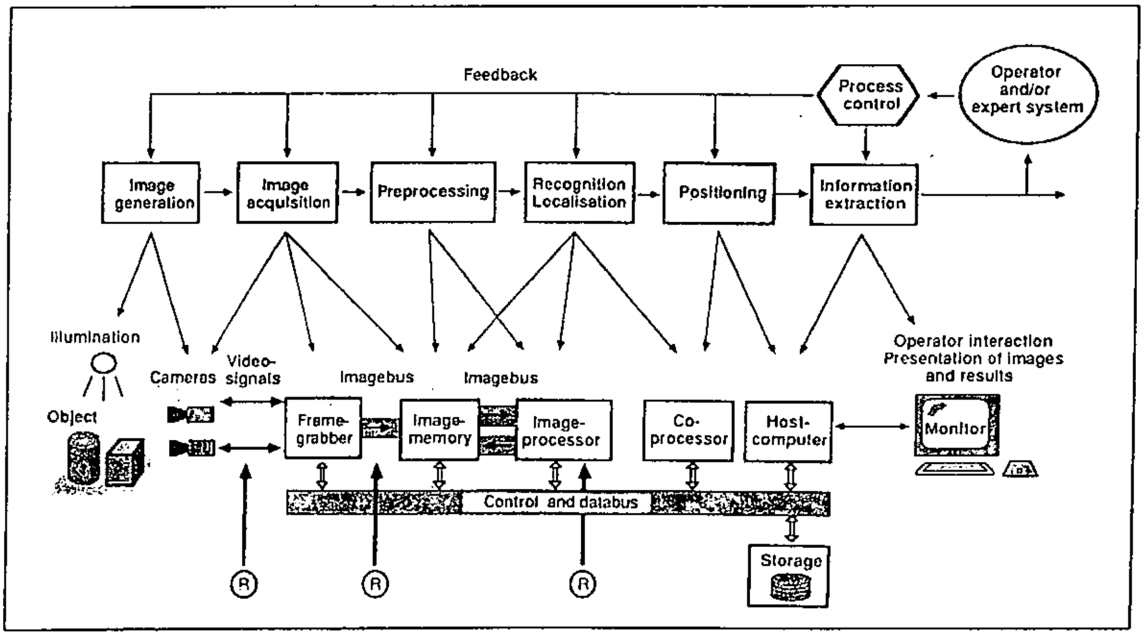

Fig. 2.5 Functional modules of a digital CRP system (Gruen, 1994)

2.4.2 Differences between digital aerial, close-range and modeling systems

With the trend of advancing digital technology, there are an increasing number of digital photogrammetry systems and software packages for customers to apply photogrammetry in their fields. The major categories of such systems are as follows:

- Digital photogrammetric workstations,
- Digital close-range photogrammetric software packages, and
- Simple modeling software packages.

The major difference between the three categories is their prices. Those of precise photogrammetric workstations (over HK$500,000) can cost a hundred times those of modeling software (around HK$5,000). This is because of the difference in requirements, production and procedures between the systems. Firstly, the digital photogrammetric workstations follow the concept of aerial photogrammetry to carry out interior and exterior orientation, and then the bundle adjustment process. If large area coverage is required, the capability of applying aerotriangulation technique is necessary. Therefore, a computer system of huge solving power is recommended to handle thousands of observations at an acceptable speed. Moreover, the image matching and feature extraction procedures also require high solving power to perform the automated matching techniques. On the other hand, precise close-range photogrammetric software packages need the above criteria to fulfill the requirements but not for the same reasons as those of aerial systems. It is because close-range photogrammetry is not limited to parallel photography only; convergent photos are also accepted. However, some close-range photogrammetric systems have the exception of a stereoscopic displaying device to reduce the cost, e.g. FotoG-FMS from Vexcel Company (HK$100,000). There are some modeling packages in the market for non-photogrammetrists to establish quick but lower accuracy 3D model product with a simpler mathematical solver (Section 2.3). Thus, they have lower prices than the previous categories.

Secondly, the difference in input images. Digital aerial and close-range systems are large-format and professional cameras are recommended. The digital CCD sensor cameras with acceptable resolution (over 2,000×2,000 in resolution) are increasingly available/used but expensive in the market. Film images are commonly applied in digital photogrammetric systems with the aid of medium to large format metric cameras. The cameras provide fiducial marks for recognition in the interior orientation stage within the systems. For data conversion, the film images are scanned into digital format for later processing. However, precise photogrammetric scanners are very expensive (above HK$500,000). The commercialized scanners without extra geometrical calibration cannot provide reliable output digital images. It is thus difficult for private surveying practices to select the suitable data acquisition methodology if they lack capital or relevant expertise in photogrammetry.

For simple modeling packages, the digital cameras or scanners in the market have already provided effective results for some low-accuracy close range works.

Although their small image size will limit the measurement accuracy, the ease of input images will provide benefits for the customers without any high precision requirement. The measurement process works in various fields to provide another opportunity, which is in a speedy, cost-effective but accurate way.

2.5 Application Areas

As discussed previously, photogrammetric techniques are divided into two main sections: aerial photogrammetry and non-topographic photogrammetry (Section 2.2). Aerial photogrammetry is primarily for cartographic purpose, like map making, and as a GIS source information provider – image analysis purpose. These require large investment because of the expensive instrumentation, like data acquisition devices (large format cameras and high-precision scanners). However, the latter processing platform is not a problem as the rapid growth of computer workstations are reducing costs. However, investigations have shown that it is feasible to apply high-resolution still-video imagery in aerial applications, like large scale mapping provided by digital camera imagery (Maas & Kersten, 1997).

In non-topographic photogrammetry, various disciplines have applied the relevant measurement techniques in their fieldwork. For example, automatic data extraction and output like orthophotography are adopted as advanced products with the wide spread of using CAD software in architectural and archeological applications. Much research has been done for applications on investigations of historic sites and old buildings (Dallas, 1993 and Jorstad, 1997). The purpose for this is not only limited to the technical side, such as structural deformation monitoring, but recording the historic features is also important (Robson et al, 1994).

Another field adopting photogrammetric techniques is the industrial measurement process. Those industries that require very precise industrial equipment or production methods can make use of photogrammetric techniques. It can provide instant 3D coordinates of objects to be measured with the aid of machine vision; for examples, military aircraft manufacturing, like rockets and the space shuttle, and even commercial aircraft manufacturers (Fraser and Shortis, 1995) and ship-builders (Maas and Kersten, 1994). In textbooks such as Atkinson (1996) and Karara (1989), many examples are also discussed.

Another discipline adopting photogrammetry is the medical field. From Atkinson (1996), we know of many research studies in:

- The detection of medical conditions, by mass screening or examination of individual patients,
- The treatment of a disease or condition,
- Studies into the mechanics, workings and other anatomical aspects of the human body,
- Research in diseases and/or their treatment.

The problem for photogrammetrists practicing in such areas is that the considerations and requirements are not familiar to them. Extra medical knowledge or supervision from specialists in the relevant area is necessary.

Recalling the increase of application of those low-cost photogrammetric software packages, a few researchers have investigated their flexibility and capability on tasks where complicated photogrammetric knowledge was required. In Renuncio et al. (1998), the goal was to document and model a large amount of monuments using low-cost digital technology introducing colored mosaics (PhotoModeler®). While in Patias et al. (1998), another low-cost software package called 3D Builder® was examined in comparison with traditional surveying techniques to record archaeological sites. Furthermore, Xu et al. (1998) had applied close-range photogrammetric techniques through the PhotoModeler® and Vexcel® software for constructing the complete 3D model of the wooden temple buildings of Chi Lin Nunnery in Hong Kong. Together with a few smaller engineering tasks via the above low-cost packages described in Ho and Chan (1999), it is believed that the low-cost systems can also benefit private surveying companies with good planning.

2.6 The Use of Photogrammetry in Commercial Markets

Researches relating to the investigation in applications of close-range photogrammetry have appeared in journals or proceedings in photogrammetry and surveying disciplines for 100 years. However, the study of commercial use of photogrammetry was rare. Wapinski et al. (1980) investigated the technological aspects in photogrammetric applications as well as the viewpoint of economics. The paper considered the technical requirements with the economic aspects as backups of various applications. Another relevant paper is from Mitchell (1986). In his paper, there is more description of various disciplines selecting photogrammetry as a solution in their projects. A guideline in procedures of uses in photogrammetry was provided for other consultant surveyors to follow. In Fryer (1985), it stated that a technological transfer of close-range photogrammetry had occurred from photogrammetrists to industrial users. It explained the two stages in industrial measurements. First, the industry gained acceptance from accurate results by photogrammetrists. Second, the demand increased and software design of applying self-contained turnkey methods became popular. Therefore, a technological transfer to non-photogrammetrists occurred to develop their suitable automated measurement tools for achieving accuracy, flexibility, reliability and productivity.

More up-to-date discussion of the adoption of photogrammetry into private surveying practices focused on the introduction of new photogrammetric software packages. Peters (1997), *Documenta* (1997), Turner (1997) and Zicarelli (1996) all related to the application of their own software packages. The contents provided materials for other land surveyors to determine the cost effectiveness in applying photogrammetry, but based on promoting their packages or services only. Firstly, Peters (1997) introduced the photogrammetric techniques to be applicable in industrial tasks. The advantages of photogrammetry over conventional as-built survey and guidance on requirements for different roles within the project were given. The example site reported had a cost reduction of 50% over conventional survey. Secondly, *Documenta* (1997) was extracted from the homepage of its company on the world-wide-web. It concentrated on architectural photogrammetric tasks and thus relevant comparison with the conventional survey method was its top priority. It emphasized the advantages of photogrammetric techniques over traditional inspection methods, which were cost reduction, precision and accuracy, accessibility, selectivity, and homogeneity. Thirdly, Turner (1997) provided much study on statistics between cost-effectiveness of photogrammetry and conventional survey. There were comparisons in equipment cost, operation cost, and workflow for the two different technologies. Moreover, theory of photogrammetry was also included in the document. It claimed that the saving of cost was also noticeable. Finally, Zicarelli (1996) provided the challenge and benefits of using photogrammetry on precise alignment of machinery projects. A case study of modeling a huge machine was provided with support of a cost-benefit study made. It was found that the total saving of the project was up to ¾ of the original cost of conventional survey.

Although the above articles prove photogrammetric techniques to be very cost-effective in various disciplines, surveying practices should seriously consider their reliability. It is for the purpose of advertising that the articles for promoting the applied photogrammetric systems or software packages were written.

2.7 Decision Making Process

2.7.1 Benefit-cost Analysis

In order to process the tasks within the surveying practices with the most suitable technique, it is not recommended to make decisions based upon past relevant experiences only. Thus, a system for providing clear and analytic decision support is necessary. The whole workflow is called the decision making process, which is supported by evaluation theory and application tool. However, how can the decision-makers (surveyors) find such information and apply the suitable decision analysis for their projects? Both Preece (1989) and Snell (1997) recommended the capability of benefit-cost analysis in determining the evaluation theory. This analysis shows the balance of incomes and expenses in the company, which may have no direct relationships among others. English (1968), Shtub et al. (1994), Nas (1996), and Boardman et al. (1996) outlined some important criteria in handling benefit-cost analysis with various considerations.

Benefit-cost analysis is a traditional tool for allocating resources among a set of activities. From the point of view of the private sector, the firm generally pays all the costs and receives all the benefits, both quantitative and qualitative. The decision making process in investment projects (or new technology adoption projects) involves the calculation of difference in costs and benefits. Benefit-cost ratio (B/C Ratio) is commonly used in evaluations between competing alternatives. Saaty (1995) stated that, it is a practical method for the following uses:

- Deciding whether to undertake specific projects,
- Selecting the most productive activities with the highest benefit-cost ratio,
- Selecting projects whose benefits can be distributed among the population in specific ways,
- Maximizing total benefits within given constraints, such as a budget, and
- Reviewing a set of existing projects for possible elimination or reallocation of resources.

To evaluate if the benefits against the costs, both elements must be in common units of measurement, and the common one is money as monetized items can be found in most benefits and costs. However, the units are not always money in many analyses because some kind of financial description has been used rather than the initial financial or market prices; for example, time saved from faster transportation. When the various costs and benefits are of different kinds, like surveying equipment cost and processing time to reduce fieldwork, there is a process called valuation method. This is to price the tangible elements in a project, such as equipment, labour and training. Therefore, other categories of costs and benefits for which no price information exists can have their values generated. Pricing information of tangible elements can be obtained from competitive markets. The market prices usually represent economic values. However, it is sometimes incorrect because of their differences, or distortionary tax, from a non-competitive market. If market price is used, it is actually an over-estimate of the costs of the project. To avoid this problem, an adjusted price called the shadow price is used to measure the costs and benefits of a project (Snell, 1997).

From Shtub (1994), there are step-by-step approaches for benefit-cost analysis:

1. Identify the problem clearly,
2. Explicitly define the set of objectives to be accomplished,
3. Generate alternatives that satisfy the stated objectives,
4. Identify clearly the constraints (e.g. technological, economic) that exist with the project environment to narrow the choices of alternatives,
5. Determine and list the benefits and costs associated with each alternatives. Specify each in monetary terms, and if unable to, this fact should be stated clearly in the final report,
6. Calculate the benefit/cost ratios and other indicators, if applicable,
7. Prepare the final report.

The B/C ratio comparison method can be subdivided into two streams, which are B/C ratio and marginal B/C ratio (Saaty, 1995). It is useful to give surveyors without much knowledge in economics to compare those combined monetized and non-monetized items via ratio calculation. For the B/C ratio, it is to have the benefit divided by cost of each alternative. For multiple alternative sets, the highest ratio among the group can be said to be producing the best result, where:

$$\textbf{B/C ratio} = \textbf{Benefit (B)} \div \textbf{Cost (C)}$$

For the marginal B/C ratio, it is a relative comparison between the B/C ratios of alternative sets. The procedure is to pick out the one with best B/C ratio first, and then compare it to other sets:

1. For an example, there are four alternatives under a benefit-cost analysis => B_1, C_1, B_2, C_2, B_3, C_3, B_4, C_4;
2. B_1, C_1 (**Alternative 1**) is the one with best ratio. B_1/C_1 is the biggest;
3. The other three sets are to be compared with **Alternative 1** by marginal B/C ratio:

   Marginal B/C ratio $(B_2, C_2) = (B_2 - B_1) \div (C_2 - C_1)$
4. If this marginal B/C ratio (B_2, C_2) is positive, **Alternative 2** has better beneficial returns than **Alternative 1**. The calculation should be started again as **Alternative 2** being the subject to compute the marginal B/C ratio (B_1, C_1):

   Marginal B/C ratio $(B_1, C_1) = (B_1 - B_2) \div (C_1 - C_2)$
5. If the marginal B/C ratio is negative, ignore it and start again using the third set as the object:

   Marginal B/C ratio $(B_3, C_3) = (B_3 - B_1) \div (C_3 - C_1)$
6. Similarly, the third and fourth sets are calculated until the alternative set with the best marginal ratio is found. It can be said that the one with the greatest marginal B/C ratio is the best choice among the alternative sets.

However, there are some shortcomings in benefit-cost analysis. Firstly, the benefit/cost ratio could easily mislead the decision if two sets of ratios were the same but respective costs were in extreme difference. Secondly, the failure in those "unquantifiable" in monetary terms. Such items should then be clearly identifiable from those familiar criteria of economic efficiency, like accuracy, time, and manpower, to be established as social or environmental concerns (Shtub, 1994).

2.7.2 Decision Support System

From the previous Section 2.7.1, the basic considerations in processing a benefit-cost analysis have been discussed. Through its application, the land surveying companies can obtain the cost effectiveness from every alternative. However, it is impossible to evaluate a single task every time. Economists suggest that transferring the concept of benefit-cost analysis into a decision support system is a more effective way to evaluate the analysis. Starting from grouping the essential information for defining the objective to perform the benefit-cost analysis, the whole process can be transferred into the procedures of a decision support system.

From Dyer and Forman (1991), a decision support system was stated as *"supporting managerial decision-makers in "semistructured" decision situations"* with the application of mathematical models, programming process, or even handy manual comparison between selected alternatives. It is mainly determined by its two parts: alternatives and criteria. Alternatives are those methods with possible solutions for the project. They are usually the existing methods together with other recently adopted methods, like new technologies. The purpose of the whole decision support system is to do comparisons between them. A criterion is a rule or principle to evaluate the alternatives. To select a suitable methodology for a project, a group of criteria are often formed to compare the alternatives in various conditions. It is commonly believed that the criteria determine the selection process with their specialities to choose the most attractive method. Thus, the process must access data from a variety of sources. It means that the criteria selected should fulfil the above condition with all possible considerations included. Moreover, the support system should also *"facilitate the development and evaluation of a model of the chosen process. That is, the DSS must allow users to transform the enormous amount of data into information that helps them make a good decision"* (Sauter, 1997).

As tasks involve increasingly complicated decisions, it is necessary to consider a better support tool to make the decisions. It is the aim of decision support tools, to provide the linkage between decisions and the data, information, and analyses pertinent to the decision. Grouping up materials in several references, such as Dyer and Forman (1991) and Snell (1997), most of the decision support tools require the following methods to determine the problems:

- Multi-criteria utility theory,
- Goal programming,
- Expression of multiple goals as constraints, using linear or integer linear programming,
- Pro/con analysis,
- A point scoring or weights and scores system,
- Analytic hierarchy process.

The first three methods have been discussed in various journals or references in the discipline of operational research. The pro/con analysis is for making a choice through listing the pros and cons of each alternative in the decision problem. The choice is based on discussion within the decision group, and thus the result is commonly unstructured and misused in measurement units. A more systematic approach is the weighting or scoring system, which applies matrix calculation in determining weights of different criteria. The method will be of concern if more than a few criteria are required. This is because the method requires the construction of a large matrix in rows and columns for arranging all the criteria into their places. Extra work on programming and calculation will then be needed. The final method described is the analytic hierarchy process, and was developed by Saaty (1980), who applied the eigenvalue computation method to multi-criteria decision making processes.

2.7.3 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is from the concept of the eigenvalue problem in mathematics for converting subjective assessments of relative importance into a set of weight/priorities for selection process (Olson, 1996) (See Appendix A). The methodology of constructing the benefit-cost analysis within the platform and the calculation process were discussed. The two major procedures in the AHP process are firstly, constructing the hierarchy, or brainstorming, for the decision problem. The decision-maker requires a clear understanding of the problem before constructing the hierarchy because the hierarchy will determine the future priorities of various alternatives. Secondly, a comparison process between criteria within the hierarchy helps the prioritization of the alternatives. This is performed with the aid of a weighting system, which requires input of intuitive measurement according to the decision-maker. The measurement unit and scale will be subject to the criteria and alternatives at different natures even on the same study.

Analytic Hierarchy Process has been applied as the tool in decision making processes in many previous studies. On the one hand, Schmoldt et al. (1994) applied the AHP into a participatory decision making process on managing natural resources. Several specialists were invited to take part in group decision making on the relevant topic. The idea of participation of every specialist within the process showed an averaging effect on members' discrimination. In Meziani and Rezvani (1988), the application of group decision making made the process more reliable. On the other hand, Toshtzar (1987) constructed a decision analysis with AHP but without the consultation and score averaging process. He did not use the consultation and score averaging process in order to provide variable capabilities of his hierarchies on future evaluation with different considerations. They were all useful references for author in determining the decision making process and construction of hierarchies of this research.

Unfortunately, there is no relevant investigation tool made in the land surveying discipline in Hong Kong for users to decide whether to adopt any new technology or following the routine with the aid of exiting methods. Surveyors may face difficulties on the decision making process without any specialty knowledge of economics. In fact that the AHP process provides an easy understanding and customizable basis for users to make their decisions. The hierarchy design and application stages are all based upon the background of individual users, i.e. the discipline of the user (Saaty, 1994). It is thus considered to combine this decision-making algorithm with the surveying techniques to have a "cross-discipline" investigation. On the other hand, the liability of the AHP process can be compromised with the application of group decision making during the establishment stage (Saaty, 1994).

As a result, some local researches on the application of AHP into decision making processes relating to other engineering fields in Hong Kong was addressed as further reference. Tam (1996) discussed telecommunication system vendor selection with the aid of AHP. It demonstrated the application of a general hierarchy established for group decision making (geometric mean and normalization), and its evaluation with previous decision using current traditional vendor selection process. Chan (1997) discussed the choosing of the best railway maintenance facility expansion option using the AHP. The technique was found to be useful to convert the decision maker's preference on different decision criteria by capturing how they favour alternatives through pairwise comparison. Fan (1997) studied the critical factors for successful new product development in Hong Kong small and medium-sized household appliances manufacturers. The adoption of various hierarchies in different arenas, like value and investment point of value, widened the capability of the application of AHP process. Each of these studies was useful reference in this research's investigation because the whole workflow of specific local based projects using AHP in decision making process aided the author in the establishing of the hierarchies, and especially in analyzing case studies with the general hierarchies set up.

As the importance of decision analysis increases, there are a few software packages designed under the concept of analytic hierarchy process in the market nowadays. For example, Expert Choice® from Expert Choice Company, and Criterium Decision Plus® from InfoHarvest Inc. The first is an aged DOS product, which has the same scaling as Saaty (1980) developed. Besides its old development history, its limitation in accepting construction of unbalanced hierarchies ("end-node" criteria do not link with alternative levels at the same level) makes users unable to handle that sort of decision making process with it.

The other package, Criterium Decision Plus®, is similar to the previous one in providing AHP solutions for decision making processes but using a Windows environment. The Decision Plus software requires decision-makers to brainstorm the general hierarchy that they need. It is the initial procedure before any actual connection or calculation is made. Its advantage is the quicker processing time in the later analyzing stage when the basic structure of the hierarchy has been completed. Moreover, it is believed that a clear progression is carried out for separating the different stages.

The major difference between Expert Choice and Decision Plus is their different capabilities in solving hierarchies. As formerly described, Expert Choice can only provide parallel levels of criteria (balanced hierarchy). However, Decision Plus does not have such a limitation in constructing hierarchies. It has absolute freedom for decision-makers to design their own styles of component combinations.

Chapter 3 Conventional and Photogrammetric Survey in Hong Kong

3.1 Introduction

The Hong Kong land survey industry has its concentration in conventional surveying methods in applications, but there is increasingly attention on adopting newly advanced technology into the business of the surveying companies. It is to maintain the benefits from fieldwork with the most cost effective survey method. For examples, the application of satellite positioning in control survey and graphic mosaics with the aid of photograph strips.

This chapter concentrates on the consideration of the two selected comparative surveying technologies in this research: conventional and photogrammetric survey. There are separate discussions of the application of the two methodologies in Hong Kong. The first section will address the existing conventional survey applications in private surveying companies in Hong Kong. It is to provide a basic understanding for readers about the benefits and shortcomings of the companies via this routine. The second section will follow the review in Chapter 2, to discuss the different digital photogrammetric systems available in the market and their adoption in Hong Kong applications. Some of the systems were applied in this research for comparison with conventional techniques. Those systems include low-cost photogrammetric software packages, advanced packages and high-end digital photogrammetric systems. Their data acquisition devices were also mentioned, including digital cameras, film cameras and scanners.

3.2 Conventional Survey in Hong Kong

3.2.1 Background

Many private land surveying practices in Hong Kong are contracted to do tasks in civil and construction engineering disciplines. The nature of the tasks can be one of a broad range of techniques, from topographic survey to deformation monitoring purposes. Moreover, the tasks are generally limited in processing time from a few days to one week on average. Therefore, the land surveying companies need the fieldwork done as quickly as possible. The methodology in fieldwork and later processing must have a strong linkage to speed up the processing. Furthermore, the techniques should also be familiar to both survey staff, and clients to ensure accurate communication. As a result, most of the private land surveying companies apply the conventional surveying techniques to their field tasks. The surveying techniques range from simple tape measurements to the application of precise measurement devices, such as electromagnetic distance measurement (EDM) devices and theodolites, digital levelling devices and laser alignment systems (Appendix B.1). The various techniques are widely applied in different disciplines requiring surveying measurements. A paper plot was once the only final product standard but computerised output has gradually replaced its position for survey result presentation to the clients. In addition, most of the procedures from data collection process to product plotting can be automated. The survey staff act in the role of operating the equipment and providing their expertise from their experience within fieldwork or later processing.

Comparing with the photogrammetric techniques of indirect measurements, conventional methods employ relatively higher manpower in the fieldwork stage. A field survey team includes two to three staff members for individual tasks; for example, a surveyor to plan and perform measurements while one or two assistants collect data. This can provide quite high productivity in data collection of various natures, such as topographic survey, setting out, and as-built monitoring purposes.

3.2.2 Procedures

The three major procedures to be completed by private surveying practices to achieve the contract specification are:

1. Fieldwork,
2. Later processing,
3. Presentation.

The fieldwork stage is the period for collecting survey measurements or performing setting-out work from design to existing ground. Surveyors will plan the necessary equipment and manpower to complete the task. There are some general considerations:

- Accuracy requirement,
- Fieldwork time frame,
- Equipment and manpower,
- Operations cost.

Accuracy requirement is generally settled within the contract for the private practice to fulfill. Together with available time frame, and suitable equipment and manpower required, the operations cost can be set up.

The later processing means the modification of measurements made. It has a close relationship with presentation, which provides hard- or soft-copy (CAD file, textual report of measurements, and paper plots) to clients. The manpower required in later processing and presentation should also be included in operations cost.

3.2.3 Application areas

The major application areas for the businesses of Hong Kong private surveying practices are as follow:

- Engineering survey,
- Topographic or detail survey,
- Hydrographic survey,
- Boundary survey,
- Consultant services for other disciplines requiring survey measurements.

3.2.3.1 Engineering survey

Engineering survey projects are the major portion of business in most Hong Kong private surveying practices because any construction sites, from the New Airport construction to the construction of a building on a small lot, need survey measurements for the engineers, project managers and architects for calculation, quality assurance or design. The general requirements include as-built measurements on concrete construction, control point network for general measurements, setting-out work for design, and fitting-out measurements. Most the above measurements require instant, but accurate results (up to millimeter-level in many measurements). Moreover, the presentation is mainly for recording purposes with paper plot still the common media in field communication.

- Pros and Cons of conventional techniques in engineering survey:

The biggest benefit of conventional techniques in engineering survey is of course the quickness of the measurement process. The method of direct measurement provides surveyors with instant data for calculations or even presentation. Furthermore, the traditional practice in fieldwork also allows other professionals, like civil engineers, architects or even project managers, to be familiar with operations and calculations.

However, there is some limitation of conventional techniques when handling complicated tasks. This is because of the massive measurements required and leads to the employment of relatively large amounts of resources, like equipment and manpower, to be involved in the fieldwork stage. For example, underground survey and plant revamp projects. From the experience of the author in practicing in a partnering company, a few relevant projects required extra resources, especially manpower to meet the processing schedules. The operation cost may then be a problem.

3.2.3.2 Topographic survey

Topographic survey is another area of business for private surveying practices. It relates to the rapid development in the New Territories during the past two decades. Before any construction can be performed, the terrain of the development site should be surveyed for design and approval. Together with a detail survey in urban areas, there are a few opportunities for business contracts for the private sector. Similar to engineering survey applications, conventional surveying techniques are applied in private surveying practices to collect land terrain information.

- Pros and Cons of conventional techniques in topographic survey:

The conventional surveying techniques, especially tachometry and radiation measurements, provide great mobility in data collection of topographic survey. Together with the ease of comparison between measurement points within the surveyed area, the accuracy can be maintained to a certain level. Moreover, the massive measurements collected need a relatively small workload to handle the later processing stage. This is because the automatic data logging of instruments helps in calculating and analyzing data (including the application of error adjustment software).

On the other hand, the advance of instruments in conventional techniques cannot overcome a major limitation in topographic survey, i.e. data coverage. Surveyors always face the trouble of missing data within particular areas of the site. It takes additional resources to be involved in "re-filling the missing puzzle pieces" (missed survey areas) of the site. From the experiences of the author in the partnering company, relevant projects often required 30-50% more manpower and equipment than originally planned. Furthermore, the larger the coverage of the surveying area, the more rapid the growth of operations cost is required for the surveying practices.

3.2.3.3 Hydrographic survey

Similar to the New Territories development, the reclamation works in Hong Kong's harbor have rarely stopped in the past two decades. It requires an extra set of instruments (echo sounder) located on a vessel to detect the depth of the seabed. GPS system is the common data acquisition device for controlling the location of the vessel. Some famous relevant projects include: reclamation of Hong Kong New Airport Construction outside Tung Chung, the new Hong Kong Disneyland at Penny's Bay (Lantau Island), and No.8 and 9 Container Terminal (Kwai Chung and Tsing Yi).

- Pros and Cons of conventional techniques in hydrographic survey:

Currently, there are few surveying practices applying common surveying instrument, like theodolites and EDMs (Appendix B.1) in hydrographic surveying projects. This is to maintain the cost-effectiveness of methodology applyication. GPS systems can provide stable results in relevant work for surveyors, and their accuracy has been updated/advanced gradually to improve their competitiveness.

However, there are few private surveying firms that can handle hydrographic survey because of lack of equipment, expertise, and relationship with the maritime engineers. A larger investment than common survey instruments is expected. A practice should own a set of GPS system of accuracy better than 1m (around HK$100,000), an echo sounder (over HK$100,000), and must hire a vessel to mount such a device. Small private surveying practices may not be able to afford the investment.

3.2.3.4 Boundary survey

The boundary survey projects provide quite a large portion of the total surveying tasks in Hong Kong. Any re-allocation or subdivision of land lots requires the owners to apply to the Government for legal approval and record. Together with the development in the New Territories, it is a steady input of business for private surveying practices. The common measurement methodology is the conventional technique, which applies traversing and leveling with theodolites, EDMs and levels in the field survey stage. There are two major purposes for boundary survey; measurement on existing lots, and setting-out on subdivisions or new lots. However, the survey cannot be recognized as a legal reference when submitting to the land registry unless an authorized land surveyor has signed and will be responsible on the legal issues. This created a trend in the survey industry in Hong Kong that there are few private surveying practices without authorized land surveyor background support to link with this sort of boundary survey projects.

- Pros and Cons of conventional techniques in boundary survey:

As described previously, the conventional surveying techniques have been long applied in boundary survey applications. Its major benefit in the fieldwork stage is the instant crosschecking of surveyed results. With sufficiently controlled information collection at the surveying site, different routines of result checking can provide surveyors with enough confidence on measurements for tying the measurements or setting-out coordinates with the adjacent lot to check the consistency.

In contrast, the disadvantage of the application of conventional survey in boundary survey is the reliability of control stations. This is because the local control points may be distorted by means of circumstances; for example, construction work, and previous incorrect survey measurements on surveying or adjacent lots. If surveyors applied the above reference information, the fieldwork would be wrongly projected. To avoid this, most surveyors will apply those approved control stations established by the Government. However, it may require extra fieldwork through traversing to reference to those stations, which may be distant from the surveyed site.

3.2.3.5 Other relevant consultancy works

Besides the above common application areas, many private surveying practices also provide consultant services to other disciplines requiring survey measurements, like:

- Deformation monitoring,
- Archaeological survey measurements and setting-out,
- Detail survey.

Deformation monitoring is not limited to engineering applications, while other disciplines may require the deformation measurements for recording purposes; for example, buildings, landscape, and even landmarks. The private surveying practices apply conventional techniques in those projects. However, there will be an impact on operations cost in the above areas if complexity, presentable detail (imagery), and other requirements are raised.

Occasionally, archaeological surveys are required in Hong Kong, such as old buildings rated as cultural heritage, or archaeological sites. Such applications require prompt measurement to shorten the time of excavation and processing. In general, conventional survey is the common measurement technique in the field. Rather than other application areas, archaeological survey requires relatively low accuracy and simple measurements, which are major benefits from conventional survey. However, the increased demand in detail from archive requires additional input from the survey (e.g. imagery).

Detail survey applications are not limited to government departments or within construction sites only. Some other non-engineering disciplines, like schools, may require detail surveys for their specific purposes. Some private surveying practices also provide such services as part of their business. Depending on different accuracy requirements, like plotting scale (e.g. 1:100, 1:200 and 1:500), surveyors need to plan for different instruments and techniques. This will affect the operations cost of the whole project.

3.3 Adopting Photogrammetry in Hong Kong Private Surveying Practices

3.3.1 Background

Similar to conventional surveying techniques, photogrammetry (or photogrammetric survey) includes fieldwork (data acquisition) and later processing stages in relevant projects. In contrast, photogrammetry is an indirect technique, which generally does not require contact with the surveying surface, to collect measurements. Data acquisition devices (e.g. cameras and scanners) are applied in the fieldwork stage while digital photogrammetric systems are the common media for the later processing stage (Section 3.3.2). Digital photogrammetric systems can be categorized into three classes: low-cost, intermediate, and high-end. Firstly, there are numerous low-cost commercial photogrammetric software packages on the market, for example, PhotoModeler and 3D Builder, which suit low-accuracy modelling purposes, and are run under the common Windows PC platform (see Appendix B.2). Secondly, the intermediate class targets those applications with higher accuracy achievement, for example, FotoG-FMS (see Appendix B.2). There are constraints in the photographic network configuration and control information to generate the desired results. Thirdly, those digital photogrammetric workstations, like Intergraph's ImageStation, and Leica's Helava system are categorized as the high-end class. There is a review of these workstations drawn in Section 2.4 and a description of an investigated model (Helava DPW-770) in Appendix B.2. A comparison between the above packages, which were investigated in this research and selected as representatives from low-cost, intermediate, and high-end digital photogrammetric systems, is shown in Section 3.3.3.

In Hong Kong, there are few but increasing numbers of projects where photogrammetric techniques have been adopted. Both the data acquisition devices and digital photogrammetric systems can be found in particular application areas. Firstly, a gradual increase of the application of digital cameras and scanners is expected in many engineering fields. Secondly, a number of digital photogrammetric workstations have been adopted into the relevant fields of this city; for example, topographic mapping in the New Airport construction project with the aid of an Intergraph ImageStation, another ImageStation in the Planning Department for illegal land use enforcement issues, and a Leica Helava SocetSet in the Lands Department for cartographic purposes. Further description can be found in Section 3.3.4.

3.3.2 Data Acquisition Devices

There are many data acquisition devices available for transferring data into a digital photogrammetric system, including camera and satellite imagery. For the camera imagery, there are two major sub-divisions; digital, and scanned images. The first type is mainly captured by digital cameras, while the second type can be exposed film diapositives, slides, or other media-based images that are scanned into digital formats for later procedures in the digital photogrammetric systems.

3.3.2.1 Digital cameras

Digital cameras can be categorized into three classes: low, medium and high resolution. Firstly, cameras in the low-resolution class can be applied in amateur or simple measurements (640×480 dimensions). Their major advantage is the simplicity and quickness of operation. However, it is commonly believed that those auto-focusing and zoom functions introduce erroneous measurements. Their auto-focusing function will make it more difficult to determine the lens distortion because the focal length is uncontrollable. Camera calibration to the specific focal length is recommended when working on suitable projects. The camera model chosen in this research for representing the low-resolution class was Fujifilm DS-7. It is applied in projects requiring only low-accuracy modelling for the partnering company.

Secondly, the medium resolution digital cameras in markets range from 1K×1K to 2K×2K pixels but their CCD format are still small in dimensions. They have a similar operation when comparing them with the low-resolution class, but have their pixel dimensions advanced by 4 times. Camera calibration is also necessary for them before handling any tasks. Most of the popular models on the market are categorized into this class, like Olympus, Sony, Nikon, and Canon brand. The camera model chosen in this research for representing the medium resolution class was Fujifilm MX-700. It is also applied in low-accuracy modelling projects, as a comparison with low-resolution class, and also existing in some particular engineering applications of the partnering company, and compared with existing conventional techniques.

Thirdly, the high-resolution class is designed for professional measuring sciences or other image processing applications (1.5K×1.5K or above). With a multi-purpose camera body, some particular models can provide lens distortion results during manufacturing. Its cost is much more expensive than the previous two classes and most local private surveying practices cannot afford it as an investment item. The up-to-date models can have pixel resolution of 4K×4K (Rollei Q16, HK$600K). The camera model chosen as a representative of its class in this research is Kodak DCS420, which is an older model but has larger pixel dimensions than those of Fujifilm MX-700. It is applied in engineering applications of the partnering company, as a comparison with the medium resolution camera and conventional surveying techniques.

Table 3.1 shows a short comparison between the three classes of digital cameras applied in this research.

Sample cameras	Fujifilm DS-7 (Low Resolution)	Fujifilm MX-700 (Medium Resolution)	Kodak DCS-420 (High Resolution)
Lens	TV-Fujicon fixed-focus F2.2 to F8	TV-Fujicon auto-focusing	User-defined, i.e. changeable lens
Focal length	f = 5.7mm (38mm for 35mm camera actually)	F = 7.6mm	According to the lens selected
Focal range	Macro: 9 to 13mm Near: 45 to 80mm Distant: 90mm to infinity	Auto-focusing from infinity to close-up at 10mm	According to the lens selected
CCD Format size	4.8mm × 3.5mm	9.92mm × 7.93mm	13.8mm × 9.2mm
Pixels resolution	640 × 480	♦ 640 × 480 ♦ 1280 × 1024	1524 × 1012
Pixel size	~ 7.5 μm	~ 7.75 μm	~ 9 μm
Sensitivity	ISO 100	ISO 100	ISO 100 to 400 (Selectable)
Storage	♦ Memory card (30 images for 1Mb card) ♦ JPEG format	♦ Memory card ♦ (File compression: 1/4, 1/8 & 1/16) ♦ JPEG format	♦ PCMCIA hard disk card (e.g. a 105MB card stores 64 images) ♦ TIFF format

Computer Interface	Serial	◆ Serial ◆ Direct floppy adapter to computer	SCSI II
Possible Application Areas	◆ Low-accuracy 3D modeling	◆ Low-accuracy 3D modeling ◆ Engineering survey applications	◆ Engineering survey applications ◆ 3D modeling ◆ Deformation monitoring

Table 3.1 Comparison between low, medium and high-resolution digital cameras

3.3.2.2 Film cameras

Although there is a rapid growth of the modern digital sensor cameras, film-based cameras are still important parts of data acquisition. With the application of high-resolution scanners, scanned film images are still highly reliable and recommended for precise measurement tasks.

Film cameras can be categorized into three formats; small, medium and large, which are defined by their film dimensions. Firstly, the small-format film cameras are generally those of 35mm format, most of which are amateur and non-metric (around HK$2-3000). Previously there were some special models modified with fiducial marks at the corners to work with stereoplotters. However, camera calibration is still necessary when precise photogrammetric applications are required.

Secondly, the medium format film cameras are generally those of 55mm formats, like Rolleimetric, Hasselblad, Zeiss UMK and Wild P32 (HK$150,000 and over). The former two are regarded as semi-metric cameras through the provision of a réseau (Karara, 1989) while the latter two are full-metric terrestrial cameras. These cameras have relatively large focal lengths and wider film formats to provide for high precision non-topographic applications. Comparing with digital cameras, the medium format film cameras provide higher precision at a higher cost.

Thirdly, the large format film cameras are mainly for aerial photogrammetric applications because of their large area coverage. Their camera calibration should be processed within a laboratory and thus general private surveyors cannot afford the expenses. In Hong Kong, the government departments and large statutory authorities apply them in aerial photography for topographic mapping.

3.3.2.3 Film scanners

The film photos could be encoded into digital forms only with the aid of scanners. There are two main types of scanners in the market:

- Drum scanners
- Linear array scanners

The drum scanners provide fast, cheap but unstable measurements. Most errors result from non-uniform movement of the mechanical parts. Therefore, they must be calibrated before usage. An example of drum scanners is Howtek Scanmaster D4000 (Geogiou and Vozikis, 1999).

The linear array scanners are common applied in photogrammetric applications because of their precise construction for high geometric accuracy. The resolution can be up to 7.5μm per pixel. The Zeiss-Intergraph PhotoScan applied in Tuen Mun Project (see Section 6.3.3) is in this category. The film distortion (curving) can be minimized by the flattening process of films during scanning. However, they are expensive and the private sector can hardly afford (around HK$1M). The second choice in linear array scanner is that for desktop publishing. Their resolution can be up to 42.3μm per pixel (600dpi), like Octek Flatbed scanner. Their reliability in precise scanning is much lower than the previous type. It is found that there are usually radiometric differences along the scanning paths inside the flatbed scanners due to the illumination instability and different sensor element response (Georgiu and Vozikis, 1999). Another type is the film scanner for the 35 or 55mm film format (Pomaska, 1998). These can generally produce better output than simple line array scanners. The concern for using them is that the film flattening during scanning is unknown because of the movable cartridge. There is a further type that is specially designed for photogrammetric applications. Their sensors are mounted within comparators or analytical plotters, which can be moved over the image, or the image moved relative to the sensor, e.g. Vexcel VX3000.

Most film scanners or flatbed scanners will be used in tasks of lower accuracy requirement, such as simple modelling purposes and image reengineering tasks. They can provide limited resolution of output digital images up to 20μm by those high-resolution models (e.g. 4000 × 4000).

3.3.3 Digital Photogrammetric Systems

From Chapter 2, there is some discussion between digital photogrammetric workstations, precise close-range photogrammetric packages, and simple modelling packages. This research will investigate their possible application in Hong Kong's private surveying practices through investigating their capabilities and costs. A brief description of their attributes can be found in Appendix B.2.

For simple modelling software packages (low-cost), the accuracy achievement and computation algorithm are not very reliable. Erroneous results can be easily generated even if proper consideration is given in the fieldwork stage. It is not recommended for model re-generation projects, like feature recognition, deformation monitoring, and virtual reality simulation, with accuracy requirements of 1:200 or above. Moreover, its manual modelling process will make the re-construction of a complicated surface too heavy a workload for users. The packages investigated in this research were PhotoModeler and 3D Builder.

The precise close-range photogrammetric packages (medium) are mainly applied in those engineering applications, like plant revamp projects. The computation algorithms of these packages are mostly based on photogrammetric concepts to generate simulated models. However, the photographic network configuration would be a big concern and various packages may have different approaches to fieldwork measurements. Another common feature in these packages is the strong relationship with CAD software, like MicroStation and AutoCAD. Users must have a strong background with CAD software packages in order to facilitate the close-range photogrammetric packages. The package investigated in this research was FotoG-FMS from Vexcel Company.

After the development of the past few decades, the capbilities of digital photogrammetric workstations can be said to have entered the mature stage. Different brands of such photogrammetric workstations can handle massive data measurement processes have, stereoscopic display capability, aerotriangulation, and highly precise digital terrain model and orthoimage generation. Ignoring the expensive cost, digital photogrammetric workstations are capable of numerous tasks, like topographic mapping, cadastral lot identification, deformation monitoring, engineering applications, and virtual reality presentation. Some local government departments and large statutory authorities value these workstations as an important methodology in survey measurement processes (see Section 3.3.4).

3.3.3.1 Comparison between low-cost, medium and high-end packages

After the brief description of the three different photogrammetric software categories, it is found that they are designed for different purposes. The following table (Table 3.2) has a comparison between the three categories, as PhotoModeler and 3D Builder are low-cost packages, FotoG-FMS in the medium, and Helava to be the high-end system.

Name(s) of software	PhotoModeler & 3D Builder (Low-cost)	Vexcel (Medium)	Helava (High-end)
Purpose(s)	3D modelling, visual database establishment	Engineering and industrial photogrammetry	Digital aerial and close-range photogrammetry
Calibrator	Yes	No	No
Palette matching	Visual & manual	Automatic / Manual	Automatic / Manual
Iterating Bundle Adjustment	Yes	Yes	Yes
Stereo-viewing measurement	No	No	Yes
Input image format	Most image formats	TIFF only	TIFF only
Output format	CAD or 3D animation format	CAD format	Cartographic output, e.g. orthophotos, photomaps. Or even CAD format
VR presentation	Yes (with photo-texture, or diffuse colours)	Yes (rendering with diffuse colours)	Yes (cartographic purposes)
Data processing time	Relatively short	Relatively long	Relatively long
Accuracy range	1:200 to 1:8000 (From manufacturer)	1:800 and higher	1:1000 and higher
Price	~HK$6000	~HK$150000	~HK$1000000

Table 3.2 Comparison between three classes of photogrammetric software

3.3.4 Photogrammetric Applications in Hong Kong

Due to the previous stated circumstances and lack of expertise in the Hong Kong surveying industry, there are few surveying tasks applying photogrammetric techniques, especially in the private sector. For the government departments and large statutory authorities, Lands Department is a long-term user applying photogrammetric systems for topographic mapping, but not within specific projects, like engineering surveys. The New Airport Authority (now the Airport Authority) used photogrammetric techniques to perform aerial photogrammetry for checking their excavation work and volume calculation. However, the process stopped after the construction completed in mid 1998. Another recent on-going application of photogrammetry is by the enforcement division of the Planning Department for illegal land use checking. Through the aid of aerial photogrammetry, the department can ensure the proper land use and take legal action against those illegal ones in the New Territories. All the above projects apply expensive digital photogrammetric workstations in the later processing stage.

3.4 Summary

The conventional surveying techniques are the most commonly used approaches in Hong Kong surveying practices. It is understood that those types of equipment are relatively cheaper than newly advanced technologies, like GPS systems and photogrammetric systems. Moreover, the land surveyors in the surveying industry of Hong Kong have most of their experience handling conventional surveying projects. The adoption of advanced technologies in measurement or processing will face great challenge from the traditional partitioners. However, either the low-cost or high-end products in photogrammetry can reduce project cost and be easy for users to operate. The output can enrich the details, which conventional surveying methods cannot achieve. It is necessary to investigate the suitability for surveyors in Hong Kong of combining the updated photogrammetric techniques with conventional survey to achieve the most cost-effective results in projects. This research focuses on this criterion and the further investigation will be described in later chapters. It is necessary for the private surveying practices to have an easy understanding of the technology for then to select the appropriate methodology between conventional survey and photogrammetry in projects. The author established an analytic hierarchy process with the aid of decision support software to help users making decisions from analysis of benefit-cost data (Chapter 4). From the experience in the partnering company, the author checked the reliability and modification of the analytic hierarchy process with the aid of several case studies in Chapter 5.

Chapter 4 Decision Support System in This Research

4.1 Introduction

The decision making process in this research was based upon the benefit-cost analysis (Section 2.7). This is to provide a reliable analysis in deciding the suitable method being applied in the fieldwork of various natures, like engineering surveys, or topographic surveys. Through the comparison between costs and benefits among various alternative techniques, it will be clear and easily interested by surveyors or other users to obtain the resultant earning or loss with the application of cost-benefits ratio (see Section 2.7.1). In order to perform a systematic decision making process for users infamiliar with those complicated mathematical processes, supporting tool or systems were raised in recent years to give various capabilities in computing different processes or even customized approaches (see Section 2.7.2). Regarding to this, the author applied the benefits/costs analysis concept, and there were two respective hierarchies, considering technical and economic issues established, prioritized, and analyzed for the selection of suitable methodology (conventional or photogrammetric survey) in different natures of surveying tasks in this research. The analytic technique to evaluate the hierarchies was the analytic hierarchy process (AHP) developed by Saaty (1980) from the concept of eigenvalue problem (see Section 2.7.3 and Appendx A).

Both the construction of the costs and benefits hierarchies was based on all the expenditure (costs) and income (benefits) in the partnering surveying company together with those previous research stated in Chapter 2. The author determined the criteria to be included from both the quantitative and qualitative considerations (see Section 2.7.2). Those criteria were monetized and categorized into different considerations, such as technical and economic subcriteria. Further details in structuring the hierarchies are included in Section 4.2.1 and 4.3.1.

The weighting process in both hierarchies was done by the author via collecting feedbacks from different voices of the industry in Hong Kong, such as existing land surveying companies, equipment distributors and academic specialists. This was to improve the reliability of the system when solving cases of different natures (Section 2.7.3). However, it is not feasible to construct multiple versions of hierarchies for different natures. It would possibly create an environment of nonsystematic consideration and require excessive investigation on individual natures. Therefore, a version of the costs and benefits hierarchies in general were established for the partnering company to have a clearer understanding in this chapter before going into further details in different surveying natures. In Chapter 5 – Case Studies, the established hierarchies will be evaluated in different natures respectively.

After the weighting process, it is necessary to examine their reliability. Therefore, the sensitivity of individual alternatives among the various criteria is not justified (Section 4.2.3 and 4.3.3). With the aid of the decision support software, individual computations of sensitivity among alternatives with respect to the different criteria can be automatically generated. Any outstanding issues with the change of priorities between alternatives can be easily detected. The decision analysis process is thus easy and clear for users to understand.

Having the approved result through sensitivity analysis for the various alternatives, the final recommendation would be the one with the best rating by using the benefit-cost ratio (Section 4.4). The ratios from all the alternatives were compared between their benefits over costs. The larger the ratio, the better the suitability of applying the methodology in the task.

4.2 Benefits Hierarchy

This hierarchy was designed to evaluate the benefits to be obtained through the various alternatives, which can be categorized into two main areas: conventional and photogrammetric surveying methods. There are three major procedures in establishing the hierarchy. Firstly, the structuring process establishes the decision making tree including criteria for determining the alternatives by the special characteristics of different areas (Section 4.2.1). Secondly, the weighting process inputted the respective weighting into each criterion and alternative. The resulting priorities of alternatives would then be computed and the one with the highest ratio would be the most beneficial method (Section 4.2.2). Thirdly, the calculations should be examined by sensitivity analysis to prevent any low reliability results (Section 4.2.3).

4.2.1 Structuring

In constructing the benefits hierarchy, the author needed to categorize both the quantitative and qualitative considerations because the important criteria were not only those technological considerations, but also the economic considerations without significant quantitative measurement units. As a result, it required extra effort to standardize to a common unit of measurement, like monetization, before configuring the components of the hierarchy. However, it was considered that quantitative and qualitative components should be categorized into two different groups to prevent any conflicts.

The former group included the benefits during the measurement and achievement stage, such as improvement in measurement accuracy and advance in output presentation, while the latter group determined credits collected after the company applied the procedures in various methods. The technological benefits would be the instant or short-term benefits from the methods that would affect the income relating to that specific project. On the other hand, the economic benefits would be in the long-term, and affect the running or marketing strategy of the company in future. Moreover, the feedback from the specialists showed that the settings in the "Technological benefits" stream would be variable, due to the different natures in individual projects. This is reflected in this research in that a general condition set up was established for both the benefits and costs hierarchies, but their particular elements would vary according to the special characteristics of projects of different natures shown in the examples in the next chapter.

The above configurations of dividing technological and economic considerations can help users who are not familiar with benefit-cost analysis to establish the critical issues in an easier way. An owner or manager of a land surverying company will have a certain level of business knowledge. The style of the hierachy can sort the extreme of considerations group by group, but with a common unit of measurement. The following are the further details of the constituent elements in the benefits hierarchy (Fig. 4.1).

- Goal: The goal of the benefits hierarchy is to prioritize the alternatives taking into consideration the different criteria in a beneficial study. It is to obtain the maximum benefits of each alternative from the criteria. The final result (weight) will be compared to the one deduced in the costs hierarchy.
- Technological benefits: One of the two important issues in determining the effects of different technologies applyed in fieldwork in a beneficial study. It considers the stages of measurement and achievement, which are the two stages that would most the benefit production of individual fieldwork.

- Economic benefits: this is the other issue in determining benefits in fieldwork. It examines any improvement in efficiency for the users and even the companies themselves through specific surveying methods (alternatives). These sub-criteria are mostly qualitative and thus monetization is needed to transform the elements into the common measurement unit with technological benefits.
- Effort, Productivity, and Opportunities: These are the sub-criteria in "Economic benefits". They are to evaluate the alternatives under the manner of prospective benefit. This means how the alternatives improve the motivation of employees (Effort), speed up the procedures in fieldwork (Productivity), and the opportunities forecasted after the application of the alternatives (Opportunities).
- Measurements: This is one of the "Technological benefits", and considers the benefits of alternatives for the measurement stage in most fieldwork. It ranges from "Measurement accuracy", "Complexity", "Non-reaching", to "Repetition", all of which are common indicators for evaluating application methods in various surveying natures. The four elements are from the consultation group described previously. "Measurement accuracy" is always the first item to be considered in the measurement stage of every project. Most clients will use the resultant accuracy to determine folfillment of the contract. It is thus necessary to examine the application methods according to this criterion. Complicated, repeahing or inaccessible measurements in fieldwork can affect the resultant accuacy, and so have to be taken into account. It is also critical for the alternatives to provide improvement on the existing procedures.
- Achievements: This is the other issue in "Technological benefits". The criteria underneath are the most common indicators for evaluating surveying methods: "Resultant accuracy", "Time progress", and "Output presentation".

These three elements are actually the essentials in any surveying natures, such as engineering and industrial applications.

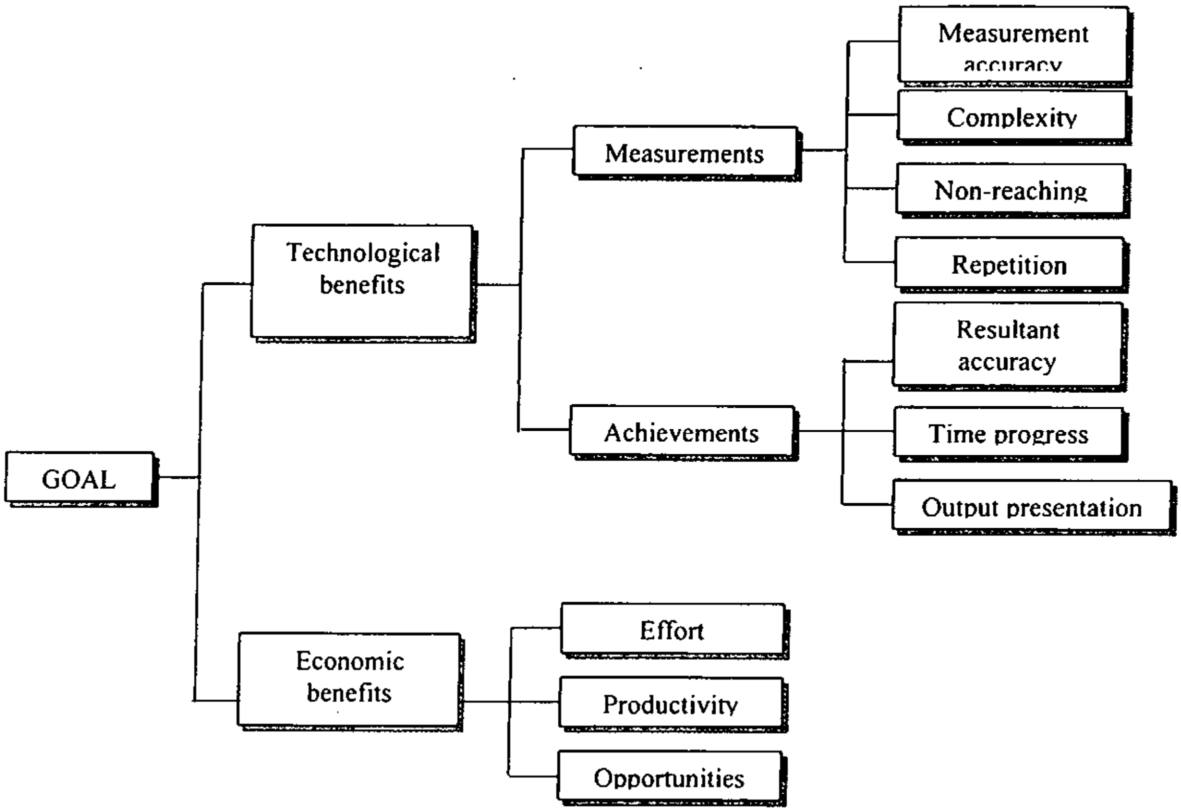

Fig. 4.1 The benefits hierarchy in this research, excluding the alternative level.

There is an alternative level for every hierarchy. The alternatives included are to be determined by the surveying practices. They are connected to each node of the upper levels in the hierarchies in this research are the same. This is to provide the common alternatives in comparing benefit-cost ratio. As this research is concentrating in the comparison between conventional and photogrammetric survey methods, the testing alternatives were designed for these methods. They are as follow

- Pure conventional survey methods,
- Conventional survey with imagery,
- Low-cost photogrammetric packages,
- Precise photogrammetric measurements.

Firstly, the pure conventional survey methods are those applied by in the land surveying compaies, like pure theodolite application for angle and distance measurements. It is actually the cheapest and traditional method for the land surveying industies in Hong Kong. Secondly, conventional survey with imagery means that some kind of imagery is also involved in the project, such as photographs for recording purposes. This is used to supplement the information collected from the conventional methods only due to its limitation of vector data collection. Its purpose is similar to that of photographic surveys, which add photographs onto survey measurements for enriching the product. Unlike photogrammetric surveys, the images cannot be reconized as effective measurement tools due to the lack of orientations before applying them. Thirdly, there are a few low-cost photogrammetric software packages in the market, such as PhotoModeler and 3D Builder. They are effective tools for low precision or accuracy purpose, like simple 3D modeling for web use. The major advantage of these software packages is their relatively low cost compared to those highly precise photogrammetric workstations. This type of measurement can provide as highly accurate measurements as the conventional methods do. The benefit over the conventional methods is that inaccessible or hazardous features can also be recorded. However, it is more expensive to invest in such highly precise photogrammetric measurements than other methods, such as the data acquisition devices.

4.2.2 Weighting

The weighting process is to prioritize the alternatives when different importance of the criteria is considered. For the benefits hierarchy in this research, there are two groups with two constituent elements involved (Figure 4.1). The author applied the pairwise comparison method in weighting for the whole hierarchy originally. This method assigns different scale factor to each pair one-by-one in the group (Table 4.1). For an example, if A is "weakly better (or Moderate Importance)" than B, the weight of A to B is 3 (third times of more importance). The scales were based on the following table (Saaty, 1995):

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to describe it

Table 4.1 The fundamental scale for pairwise comparisons (Saaty, 1995)

However, it was found that the result had too extreme difference from the realistic situation from the feedback of the consulting specialists. The criteria in both groups (Technological benefits v. Economic benefits, and Measurement v. Achievements) in the benefits hierarchy have their differences lower than double from the advice of the specialists. As a result, the direct comparison method was considered between "Technological Benefits" and "Economic Benefits". From the assignment of independent weights for each criterion in this method, it is feasible to determine slight difference between criteria.

During the assignment process, the weight was considered independently under the scale system of 100, and the results were 60 for "technological benefits" and 40 for "economic benefits". The relative weights are shown as 0.6 and 0.4 respectively.

When determining the lower level of criteria, it was found that more than three criteria were to be considered. The pairwise comparison method was then applied to maintain the consistency. It is commonly believed that the higher the number of elements involved, the harder it is to check of outlying residuals (inconsistent data). It is necessary to have a routine to take into account any inconsistent data within the comparison matrix in each group.

The following tables (Table 4.2 & 4.3) show the respective weight assignment, consistency, and resultant local weights of each group of criteria in Benefits hierarchy:

Goal	Weight	Priority
Technological Benefits	60	0.600
Economic Benefits	40	0.400
		C.R =0.000

Technological Benefits	Weight	Priority
Measurement	40	0.400
Achievement	60	0.600
		C.R =0.000

Economic Benefits	P	O	E	Priority
Productivity	1	1	3	0.144
Opportunities	1	1	3	0.428
Effort	0.3	0.3	1	0.428
				C.R =0.000

Measurement	M A	C	N R	R	Priority
Measurement Accuracy	1	4	4	3	0.54
Complexity	1/4	1	1	1/2	0.12
Non-reaching	1/4	1	1	1/2	0.12
Repetition	1/3	2	2	1	0.22
					C.R =0.003

Achievement	RA	PT	OP	Priority
Resultant Accuracy	1	1	3	0.444
Progress Time	1	1	2	0.386
Output Presentation	1/3	1/2	1	0.170
				C.R =0.016

Measurement Accuracy	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	2	4	1	0.374
Conventional Survey with Imagery	1/2	1	3	1	0.245
Low-cost Photogrammetric Package	1/4	1/3	1	1/3	0.089
Precise Photogrammetric Measurements	1	1	3	1	0.291
					C.R =0.017

Complexity	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	2	1/5	1/4	0.121
Conventional Survey with Imagery	1/2	1	1/3	1/2	0.113
Low-cost Photogrammetric Package	5	3	1	2	0.473
Precise Photogrammetric Measurements	4	2	1/2	1	0.293
					C.R =0.088

Non-reaching	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	1/5	1/5	0.083
Conventional Survey with Imagery	1	1	1/5	1/4	0.087
Low-cost Photogrammetric Package	5	5	1	2	0.497
Precise Photogrammetric Measurements	5	4	1/2	1	0.332
					C.R =0.018

Repetition	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	1/2	1/2	0.163
Conventional Survey with Imagery	1	1	1/2	1/2	0.163
Low-cost Photogrammetric Package	2	2	1	2	0.395
Precise Photogrammetric Measurements	2	2	1/2	1	0.278
					C.R =0.022

Resultant Accuracy	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	4	2	0.365
Conventional Survey with Imagery	1	1	4	1	0.302
Low-cost Photogrammetric Package	1/4	1/4	1	1/4	0.076
Precise Photogrammetric Measurements	1/2	1	4	1	0.257
					C.R =0.022

Progress Time	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	2	1/5	1/4	0.107
Conventional Survey with Imagery	1/2	1	1/5	1/4	0.075
Low-cost Photogrammetric Package	5	5	1	2	0.501
Precise Photogrammetric Measurements	4	4	1/2	1	0.317
					C.R =0.033

Output Presentation	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/4	1/4	1/5	0.068
Conventional Survey with Imagery	4	1	1/2	1/3	0.183
Low-cost Photogrammetric Package	4	2	1	1/2	0.281
Precise Photogrammetric Measurements	5	3	2	1	0.468
					C.R =0.036

Effort	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/4	1/5	1/4	0.068
Conventional Survey with Imagery	4	1	1/2	1/2	0.206
Low-cost Photogrammetric Package	5	2	1	2	0.433
Precise Photogrammetric Measurements	4	2	1/2	1	0.292
					C.R =0.033

Productivity	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	2	2	4	0.435
Conventional Survey with Imagery	1	1	2	3	0.286
Low-cost Photogrammetric Package	1/2	1/2	1	2	0.182
Precise Photogrammetric Measurements	1/4	1/3	1/2	1	0.097
					C.R =0.017

Opportunities	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/2	3	3	0.312
Conventional Survey with Imagery	2	1	3	3	0.444
Low-cost Photogrammetric Package	1/3	1/3	1	1	0.122
Precise Photogrammetric Measurements	1/3	1/3	1	1	0.122
					C.R =0.022

Table 4.2 Local weights of various criteria/alternative groups in Benefits hierarchy

Level 1 Criteria	Local Weight	Level 2 Criteria	Local Weight	Level 3 Criteria	Local Weight	Global Weight
Technical benefits	0.6	Measurement	0.4	Measurement Accuracy	0.54	0.1296
				Complexity Non-reaching	0.12	0.0288
				Repetition	0.12	0.0288
					0.22	0.0528
		Achievement	0.6	Resultant Accuracy	0.444	0.15984
				Progress Time	0.386	0.13896
				Output Presentation	0.170	0.0612
Economic benefits	0.4	Productivity	0.144			0.0576
		Opportunities	0.428			0.1712
		Effort	0.428			0.1712
					Total	1.000

Table 4.3 Global weights of various criteria in Benefits hierarchy

Although the benefits hierarchy is a combined one including 2-criteria and 3 or more criteria groups, it is recommended that the assignment of weights is done with the aid of the "top-bottom" approach, rather than the "bottom-top" approach. It is because the former approach can provide users the greater understanding of distribution of weights in the whole decision tree. The latter approach is better to perform independent check of each level with examining the groups of criteria one-by-one through this "bottom-top" approach after the assignment of the whole tree. The same arrangement was also included in the costs hierarchy construction.

To conclude the whole benefits hierarchy, refer to Fig. 4.2 showing hoe weight has been assigned.

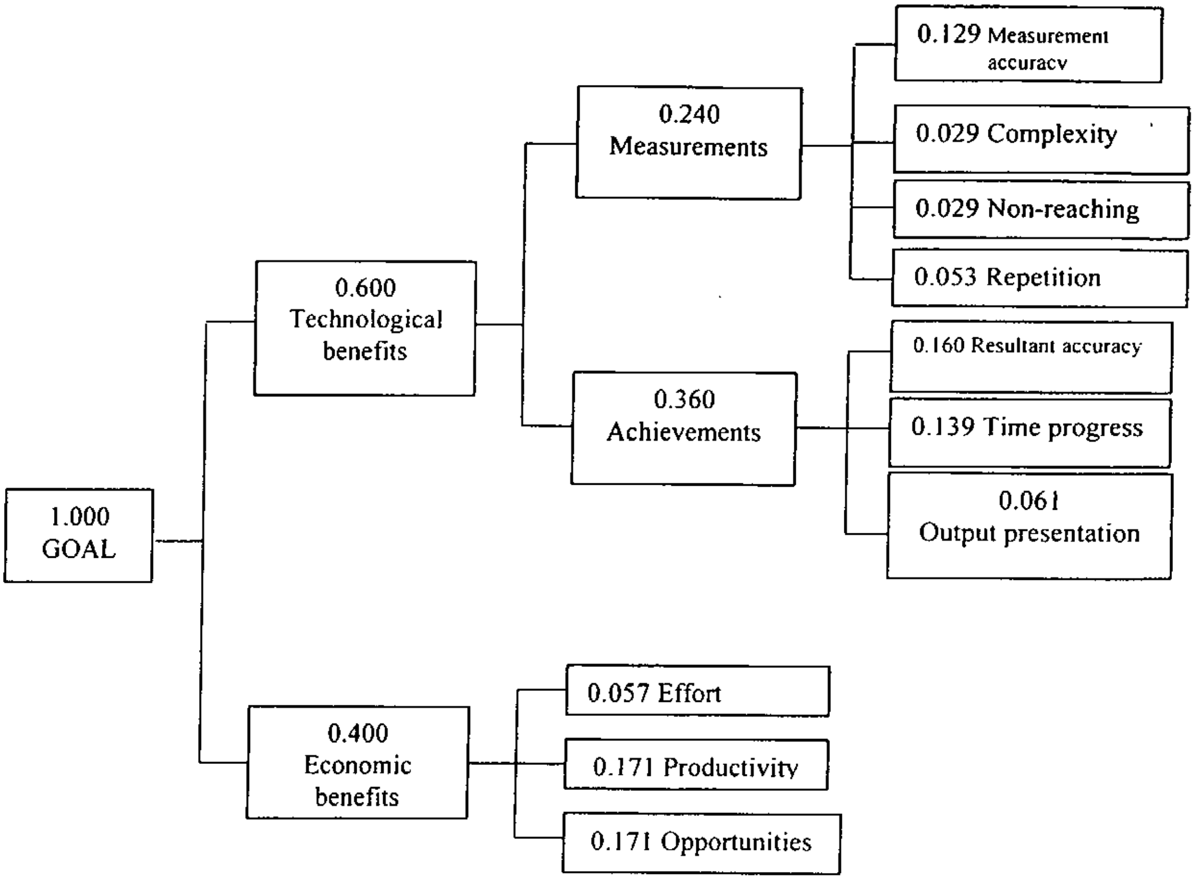

Fig. 4.2 The resultant benefits hierarchy in this research, excluding the alternative level

The resultant priorities of the selected technologies are:

Pure conventional survey methods	⇒	0.270
Conventional survey with imagery	⇒	0.255
Low-cost photogrammetric packages	⇒	0.236
Precise photogrammetric measurements	⇒	0.238

The alternative "Pure conventional survey methods" was selected as the most suitable technology in this hierarchy, which means it provided the most benefits from the existing settings of criteria within. However, it would not be the final selected method until the result from the costs hierarchy (Section 4.3) also proved this with the application of benefit-cost ratio. Reviewing all the groups of criteria, they reflected the existing situation in most land surveying companies in Hong Kong. The suitable measurement process applied for achieving the required level of accuracy, time schedule and output presentation can earn its maximum benefits (income); for example, weight of resultant accuracy (0.160), and time (0.139) were nearly equal to the motivation of staff (Effort-0.057) and forecasting productivity (0.171). As a result, the experiences in applying the same method into more projects would strengthen the benefits productivity of opportunities in future.

4.2.3 Analysis

The determination of the benefits hierarchy would not be complete before the resultant priorities examination through sensitivity analysis. This is actually testing *"how sensitive are the alternative priorities to change we may contemplate in the weights of the criteria"* (Dyer and Forman, 1991). With this analysis, any unusual top prioritizy alternatives can be detected and corrected. This is needed because if the leading option was too sensitive with regards to the second choice under the influence of a particular criterion, the assignment of weights between them could problems. The common minimum acceptable magnitude in changing the weight of a particular criterion to affect the final priorities of alternatives, or in other words - its criticality, is 5%, which is even smaller than the 10% consistency ratio in examining a pairwise comparison matrix.

However, the criticality is meaningless because italics hierarchies are applied to compute for their ratio. One single hierarchy is not selected as the best alternative. The major consideration in sensitivity analysis for both hierarchies in this research is the trend of priorities distribution. As a criterion increases in percentage of the overall weight in the hierarchy, the alternatives will be biased in their result of local relative priorities under the criterion. This means that it gains more importance in the equation. For example, the following diagram (Fig. 4.3) shows the sensitivity analysis in "Time progress":

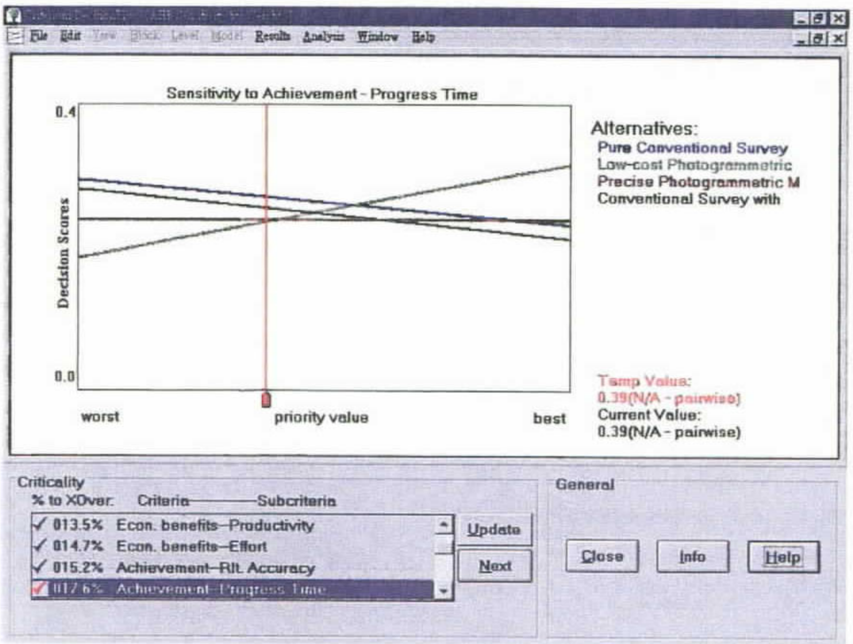

Fig. 4.3 A screenshot from a decision analysis tool applied to check the sensitivity analysis of criteria in the benefits hierarchy

As the priority of the specific criterion increases, the priorities of alternatives may alter and become new situations, like the above diagram: "Pure conventional survey" has the top priority initially but "Low-cost photogrammetric software" will become the first choice if "Time progress" is more and more a concern (time period shortening). This has to be considered in the hierarchies' construction for them to be stable.

4.3 Costs Hierarchy

This hierarchy is to evaluate the costs/expenditures within the surveying company for assigning the priorities among the alternatives. Similarly to the previous benefits hierarchy, existing situations in other surveying companies and opinions from some academic specialists were considered in the establishment and weighting process of the hierarchy. In the following sub-sections (Section 4.3.1 to 4.3.3), the procedures starting from the hierarchy structuring, weight assignment, to the eventual sensitivity analysis are discussed in detail.

4.3.1 Structuring

The structure of the cost hierarchy (Fig.4.4) is based upon items of major expenses within the teaching company. The balance sheet was considered as the proof of the existing situation in its expenditures. Five major influencing elements were selected from the list of expenses of the company as the basic criteria. They are:

- Capital cost: The capital kept as required for the running of the company. It is always a large sum of money kept ready for investment. The reason for introducing it into the algorithm is that the preparation for investment in various alternatives is different, but in a fixed ratio after initialization.
- Development cost: This cost is similar to, capital cost. The capital cost is to maintain the running of the company, and to support the investments. The development in technology of various alternatives is rapid. Development cost is designed for keeping up with the steps of technology for various alternatives, like cameras in photogrammetry, new total stations in conventional survey, or GPS. However, it does not consider the investment in equipment only. The selection of practicing methods is also controlled by various other criteria, such as manpower. The development cost is also a fixed cost relative to the various alternatives.

- Educational cost: In the past, new staff in a surveying company could gain their experience from operation of the methodology, and experienced / senior staff in the company. However, the newly developed technologies are actually unfamiliars to most of the employees. The expense of training staff should be seriously considered. In the cost hierarchy, the educational cost ranked at the same level as capital cost and operational cost. It has two streams, which are company staff training and client training. Why do we consider it in this way? It is because support should be provided for the clients, in case thehy experienced difficulties when they evaluate the products. The simplest way is to provide training for them, for example an introduction to photogrammetry, or basics in visual database.
- Equipment cost: In the surveying industry, every single methodology requires the application of equipment. The expense in purchasing equipment can be at either extreme; for example, a tape measure (a few tens of dollars) vs. a total station (a few hundred-thousand dollars). The difference between the alternatives must be compared in this important issue. Unlike the development cost, which considers the methodologies as well as the manpower study to investigate the suitable alternatives, the equipment cost concentrates in equipment only.
- Operation cost: This criterion is actually the greatest expense for a surveying company. Unlike the capital or development costs, which preserve a sums money in the company balance, the everyday fieldwork will produce a large cumulative sum of expenses every month. The attached balance sheet of the teaching company shows that the total expense relating to technological aspects is one of the greatest costs. Inside the operation cost, there are four major influencing factors: accuracy, time, output and complexity. The "accuracy" is the cost needed to handle the accuracy requirements of the client. The different alternatives have different accuracy achievements. The proper methodology for production must then be considered. Similarly, the three others use the same concept. All four elements consider the difference in performance between the various alternatives. The input of "complexity" is to raise the major difficulties in common field practices. Comparing with the other difficulties, complicated measurements occur more than hazardous or

inaccessibile ones. Every field practice can have its own method to handle the complicate measurements. However, the latter two instances will lead to a biased result in determining the performance of handling of individual alternatives. This is then a factor in the cost study.

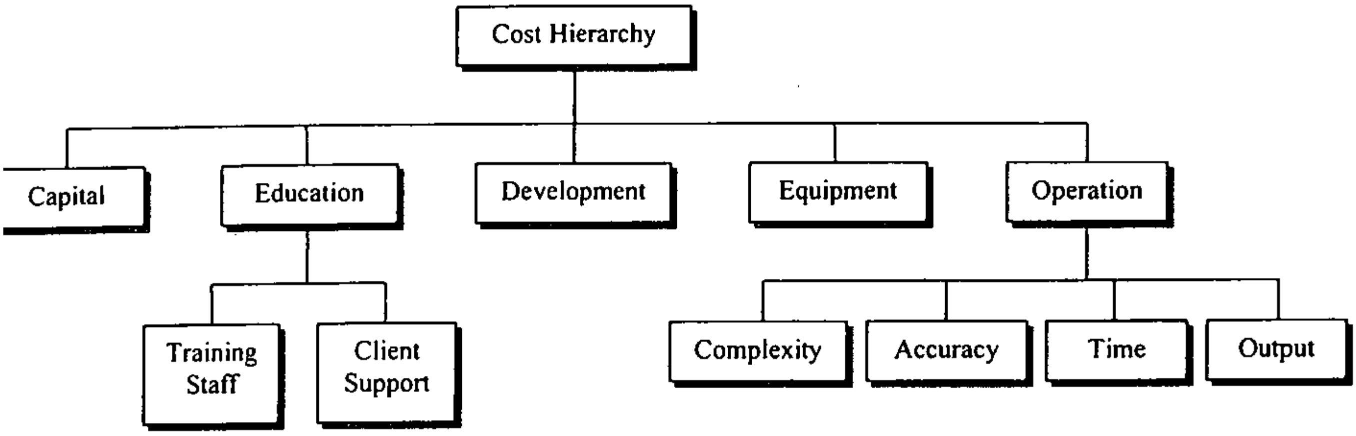

Fig. 4.4 The Cost Hierarchy structure, excluding the four alternatives

All the end nodes in various routines of the hierarchy were connected to the four alternatives respectively. As described previously in Section 4.2.1, both the cost and benefit hierarchies determine all of them to produce the cost-benefits ratio. The alternatives are of course the same as in the benefit hierarchy (Section 4.2.1), and thus will not be discussed in here.

4.3.2 Weighting

After the structuring of the hierarchy, relative priorities of every single criterion must be assigned. Pairwise comparison method was gone through comparing each criterion with others in the same group (Table 4.4).

Subjective criterion	Weight assignment	Objective criterion
Capital	2 – Barely Better than	Development
Capital	2 – Barely Better than	Education
Equipment	2 – Barely Better than	Capital
Operations	4 – Moderately Better than	Capital
Education	3 – Weakly Better than	Development
Equipment	4 – Moderately Better than	Development
Operations	5 – Strongly Better than	Development
Equipment	3 – Weakly Better than	Education
Operations	4 – Moderately Better than	Education
Operations	2 – Barely Better than	Equipment

Table 4.4 Comparison evaluation table of Level 1 Criteria of Costs hierarchy

The group was then a comparison matrix formed in the AHP software package and other groups comparison matrices are as follow (Table 4.5):

Goal	Capital	Equipment	Development	Education	Operations	Priority
Capital	1	1/2	2	2	1/4	0.128
Equipment	2	1	4	3	1/2	0.277
Development	1/2	1/4	1	1/3	1/5	0.061
Education	1/2	1/3	3	1	1/4	0.106
Operations	4	2	5	4	1	0.428

C.R =0.041

Education	TS	C	Priority
Training Staffs	1	4	0.8
Clients	1/4	1	0.2

C.R =0.000

Operations	C	A	T	O	Priority
Complexity	1	1/3	1/2	1/2	0.1234
Accuracy	3	1	2	2	0.424
Time	2	1/2	1	1	0.226
Output	2	1/2	1	1	0.226

C.R =0.004

Capital	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/2	1/3	1/4	0.094
Conventional Survey with Image	2	1	1/2	1/4	0.146
Low-cost Photogrammetic Package	3	2	1	1/2	0.269
Precise Photogrammetic Measurements	4	4	2	1	0.491

C.R =0.017

Development	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	1/2	1/2	0.163
Conventional Survey with Image	1	1	1/2	1/2	0.163
Low-cost Photogrammetic Package	2	2	1	1/2	0.278
Precise Photogrammetic Measurements	2	2	2	1	0.395

C.R =0.022

Training Staffs	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/2	1/3	1/4	0.091
Conventional Survey with Image	2	1	1/2	1/4	0.141
Low-cost Photogrammetic Package	3	2	1	1/4	0.237
Precise Photogrammetic Measurements	4	4	4	1	0.531

C.R =0.032

Equipment	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/2	1/2	1/4	0.106
Conventional Survey with Image	2	1	1/2	1/4	0.150
Low-cost Photogrammetic Package	2	2	1	1/2	0.248
Precise Photogrammetic Measurements	4	4	2	1	0.496

C.R =0.022

Accuracy	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	1/4	1/2	0.127
Conventional Survey with Image	1	1	1/3	1	0.162

Low-cost Photogrammetic Package	4	3	1	3	0.517
Precise Photogrammetic Measurements	2	1	1/3	1	0.193
					C.R =0.017

Output	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	3	6	5	0.564
Conventional Survey with Image	1/3	1	4	3	0.258
Low-cost Photogrammetic Package	1/6	1/4	1	1/2	0.069
Precise Photogrammetic Measurements	1/5	1/3	2	1	0.109
					C.R =0.029

Clients	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	1/2	1/3	0.141
Conventional Survey with Image	1	1	1/2	1/3	0.141
Low-cost Photogrammetic Package	2	2	1	1/2	0.263
Precise Photogrammetic Measurements	3	3	2	1	0.455
					C.R =0.004

Complexity	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1	5	3	0.395
Conventional Survey with Image	1	1	4	3	0.377
Low-cost Photogrammetic Package	1/5	1/7	1	1/3	0.073
Precise Photogrammetic Measurements	1/3	1/3	3	1	0.156
					C.R =0.025

Time	PCS	CSI	LPP	PPM	Priority
Pure Conventional Survey	1	1/2	4	3	0.320
Conventional Survey with Image	2	1	4	3	0.455
Low-cost Photogrammetic Package	1/4	1/4	1	1/2	0.086
Precise Photogrammetic Measurements	1/3	1/3	2	1	0.139
					C.R =0.030

Table 4.5 Local weights of various criteria/alternative groups in Costs hierarchy

Cost or expense is divided into two streams: fixed and variable. According to the information of the teaching company and other sources, "Capital", "Development" and "Education" in the cost hierarchy come under the heading of fixed cost. This indicates the three criteria were set at the initial stage and would not have many significant change in their priorities compared with other variable costs.

"Equipment" and "Operation" come under the heading of variable cost, as they vary by the change of importance of their different sub-criteria in different conditions. For examples, quick access with low accuracy achievement would decrease the weight of "Accuracy" but increase that of "Time", or moderate time with high precision and accuracy required would lead to an increase in weight of "Accuracy" and that of "Time" would decrease. Every single decision of change in distribution of weight would alter the final priorities of the alternative.

Level 1 Criteria	Local Weight	Level 2 Criteria	Local Weight	Global Weight
Capital	0.128			0.128
Equipment	0.277			0.277
Development	0.061			0.061
Education	0.106	Training Staff	0.8	0.08489
		Client Support	0.2	0.0212
Operation	0.428	Complexity	0.1234	0.0528
		Accuracy	0.424	0.1815
		Time	0.226	0.0968
		Output	0.226	0.0968
			Total	1.000

Table 4.6 Global weights of various criteria in Costs hierarchy

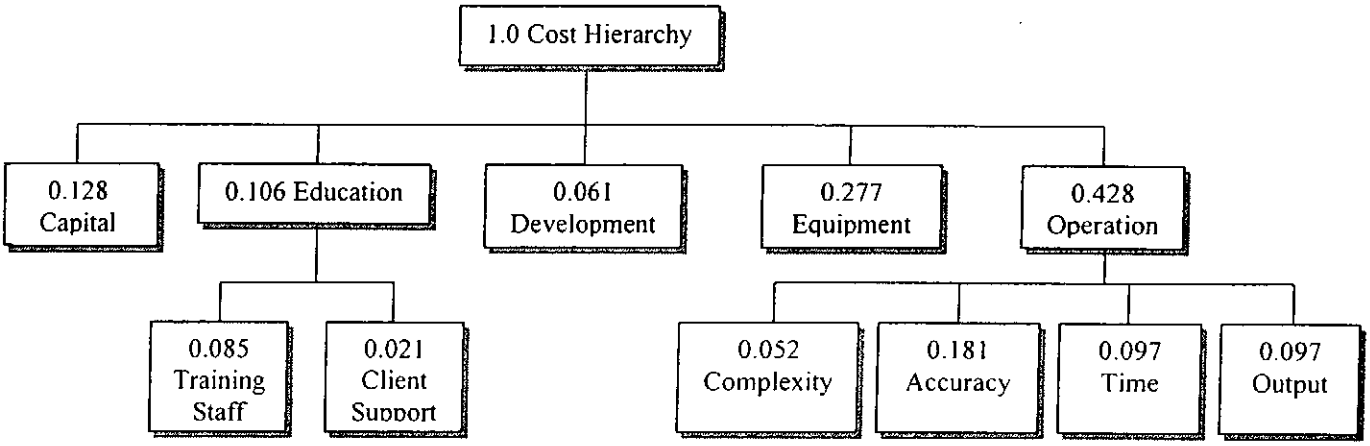

Fig. 4.5 The Cost Hierarchy after weighting process, excluding the four alternatives

The above is the finalized weightings among the different levels of criteria in Costs Hierarchy (Fig. 4.5). For the final priorities of the four alternatives calculated from Table 4.6 are as follow:

Pure conventional survey methods	⇒	0.199
Conventional survey with imagery	⇒	0.221
Low-cost photogrammetric packages	⇒	0.255
Precise photogrammetric measurements	⇒	0.325

Different from the former benefits hierarchy, the selected alternative is the one with lowest priority in this costs hierarchy. It is because the unit for determining the alternatives in each criterion is money, or cost. As the priorities increase in scale, it is the alternatives involving more costs. Thus, the alternative with the lowest scale is the method saving most costs than others.

Reviewing the resultant hierarchy, it is found that the "Accuracy" involved the greatest weight in "Operations". It is from the experience in partnering company and advice from the specialists within the industry. The operation costs have already involved more than half of the general expenditures in the company, such as staffs' salary, equipment operations and travelling. To maintain the accuracy requirement from clients, there are always extra procedures required to achieve. The weight "Accuracy" was even greater than "Capital", "Development" and "Education"!

4.3.3 Analysis

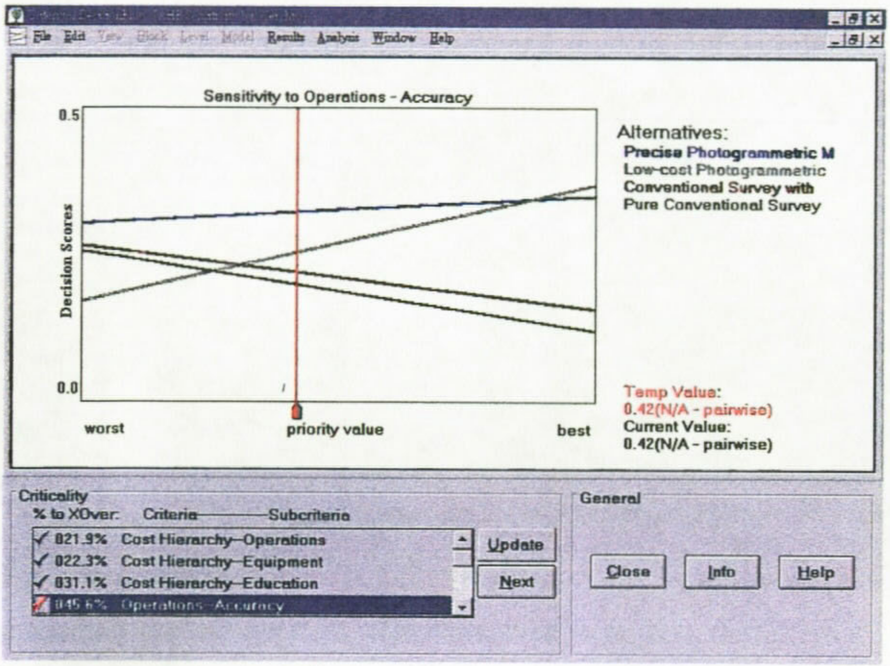

Fig. 4.6 A screenshot from decision analysis tool applied to check the sensitivity analysis of criteria in the costs hierarchy

As for the construction of the benefits hierarchy, the sensitivity analysis is the last important process to ensure the reliability of the costs hierarchy. With the aid of the decision analysis software package, the analysis provided the criticality of the alternatives in each criterion. The degree of the criticality was not the major concern in alternatives, but the trend of changing in their priorities affecting by difference in weight of individual criterion was more considerable. For example, the "Low-cost photogrammetric packages" would be the least expensive if the "Accuracy" requirement was lower. However, this alternative would have the greatest cost if higher "Accuracy" requirement was needed.

4.4 Benefit-cost Ratio

Under the common measurement unit, the benefits and costs can be calculated to find the ratio. If the ratio is greater than 1, it means that the method can produce benefits and overcome the cost. Otherwise, the method will be proved costly when the ratio is lower than 1.

In this research, the four alternatives, which are Pure conventional survey, Conventional survey with imagery, Low-cost photogrammetric packages, and Precise photogrammetric measurements, were run through the benefit-cost analysis. The priorities in benefits and costs considerations were done in Section 4.2 and 4.3 respectively. Their ratings are in the following table (Table 4.7) which shows that the greatest ratio is still pure conventional surveying methods. This may result because this is the existing method used for this surveying company, and most capital, equipment and training costs are minimized.

Method / Alternative	Rating in Benefits Hierarchy	Rating in Costs Hierarchy	Benefit-cost Ratio
Pure conventional survey	0.270	0.199	1.357
Conventional survey with imagery	0.255	0.221	1.154
Low-cost photogrammetric packages	0.236	0.255	0.925
Precise photogrammetric measurements	0.238	0.325	0.732

Table 4.7 The ratings of alternatives in benefits and costs hierarchies respectively

For a more advanced computation method of the benefit-cost (B/C) ratio, the marginal method can be applied. This involves arranging the alternatives starting with the lowest costs. In this research, the Pure conventional survey has the lowest costs (from Section 2.7.1):

B/C ratio of Pure conventional survey

= 1.357

Marginal B/C ratio of Conventional survey with imagery

= (0.255 - 0.270)÷(0.221 - 0.199)

= -0.682

- This alternative (Conventional survey with imagery) will be ignored because of the negative marginal B/C ratio, which shows negative return compared to the first alternative (Pure conventional survey). The next one (Low-cost photogrammetric packages) will then be compared with the first again due to the rejection of the second alternative (Section 2.7.1).

Marginal B/C ratio of Low-cost photogrammetric packages:

= (0.236 - 0.270) ÷ (0.255 - 0.199)

= -0.607

- The third alternative (Low-cost photogrammetric packages) will also be ignored because of its negative marginal B/C ratio with the first one (Pure conventional survey).

  Marginal B/C ratio of Precise photogrammetric measurements:

  = (0.238 - 0.270) ÷ (0.325 - 0.199)

  = -0.254

- The forth alternative (Precise photogrammetric measurements) will also be rejected because of its negative B/C ratio with the first one.

Eventually, the "Pure conventional survey" was determined as the most beneficial method in handling general surveying projects within a Hong Kong private sector surveying practice. This is because the expenses on capital investment (especially equipment, like cameras), and staff re-education for the other methods are great. Moreover, the achievable accuracy via conventional survey is still higher than that of photogrammetric survey.

However, it is necessary to investigate the great difference in beneficial achievement between the four alternatives because the enriched details did not receive much consideration by the benefits hierarchy. More testing in Chapter 5 will investigate the reliability of both hierarchies together with the weighting process in true tasks.

4.5 Summary

In this chapter, the general benefit-cost hierarchies of decision making processes for this research have been discussed in detail. There are four important areas covered in the relevant fields of studies. Firstly, there was a background description of how the AHP process is suitable for selecting methodology in the Hong Kong private surveying sector. This allows for simplicity and quickness in handling the relevant commercialized software packages rather than designing their own algorithms.

Secondly, the construction of benefits hierarchy in this research was shown in Section 4.2. Starting with the research in suitable criteria and alternatives, structuring the whole hierarchy, and the weight assignment in each component were discussed in detail. The important issue for determining the effect of benefits in the hierarchy is to decide whether the design topics offer elements that are more suitable to the project or not. The benefits hierarchy in this research involve both technological and economic benefits to determine the common concerning criteria like time progress and resultant accuracy. For the final priorities, "Pure conventional survey methods" (0.270) leads the three other alternatives, which are "Conventional survey with imagery" (0.255), "Low-cost photogrammetric packages" (0.236) and "Precise photogrammetric measurements" (0.238).

Thirdly, the details of costs hierarchy in this research were discussed. Unlike the former benefits study, the costs hierarchy was applied to determine the expenses relevant to the methodologies from many issues; for example, capital cost, educational cost, equipment cost and operation cost. In fact, both hierarchies were applied to determine the common group of alternatives (the same in benefits hierarchy). The important issue in constructing the costs hierarchy is to separate the fixed and variable types of costs (Section 4.3.2). Afterwards, the final top priority (or highest cost) went to "Precise photogrammetric measurements" (0.325), and then "Low-cost photogrammetric packages" (0.255), "Conventional survey with imagery" (0.221), and "Pure conventional survey methods" (0.199).

Eventually, the benefit-cost ratio provided a reliable result through comparison between the four sets of ratios (1.357 of "Pure conventional survey" – best). To analyze in a higher accuracy, the marginal B/C ratio was applied. "Pure conventional survey" still lead other alternatives to be the most beneficial methodology in a general situation. More project-orientated results follow in Chapter 5 – Case Studies.

Chapter 5 Case Studies

5.1 Introduction

From the previous chapter, a set of benefits and costs hierarchies under initial considerations was established. Although there are many different natures of surveying tasks, it is an essential step for the author to establish a basic decision support tool at the beginning. To fit the environment of various application areas, it is easier to modify the existing hierarchies rather than re-construct different sets of new hierarchies for individual areas. The important issue in the former case is that there be flexibility when the general hierarchy is adapted to particular cases (Section 4.2 and 4.3). The essential elements determining the varying criteria, such as operation, and equipment costs, could be adjustable in weight assignment for requirements in different natures.

In this chapter, investigation was made in specific projects of different natures under both conventional and photogrammetric surveying methods. With the application of designed benefits and costs hierarchies, the suitable method for the specific project's characteristics can be computed by adjusting the constituent elements of the hierarchies. Experiences of the author at different sites in the following case studies were used as a basis for the decision analysis processes. The previously established benefits and costs hierarchies were analyzed and modified to fit the special characteristics of the individual application areas of the teaching company. The areas include 3D visualization model establishment (Section 5.2), terrain modelling purpose (Section 5.3), and monitoring building structures (Section 5.4).

Firstly, Section 5.2 describes the wide range of feasible application areas of 3D visualization models. Such models can be applied into numerous disciplines, such as as-built or initial survey, and photographic survey for recording purpose. With the wide spread of 3D CAD software packages and virtual reality presentation software programs on market, the establishment of 3D visualization models providing the richer details is recommended. The discussion in this section concentrates on the above application areas, which are part of the major markets for private surveying companies in Hong Kong. By providing the details in the preparation stage, fieldwork stage and data processing stage in various examples, the reliability of the relevant decision trees (benefits/costs hierarchies) will have a strong support.

Secondly, the cooperation between conventional and photogrammetric survey in tasks relating to terrain modelling is described in Section 5.3. This is one of the potential application areas for involving photogrammetric techniques in private surveying practices. Unlike the traditional conventional techniques, photogrammetry can provide terrain models and orthoimagery for users. The experiences of the author in two cases were selected for describing the necessities in the decision process for handling relevant studies in the future. Those two cases are the Tuen Mun Highway widening project and a topographic survey project on Lamma Island. The testing hierarchies were adopted and analyses were drawn for both cases.

Thirdly, Section 5.4 investigates the monitoring of building structures through the relevant work done for the Chi Lin Nunnery timber temple establishment project and a Tsim Sha Tsui old building deformation monitoring project. These were selected to support the modified hierarchies for future monitoring tasks. The major consideration was the fulfillments of the high accuracy requirement of the photogrammetric techniques in major. Moreover, comparisons between various data acquisition methods, like traditional, high-end and low-cost equipment in photogrammetric survey were investigated and will be described in the section to support the decision analysis in this research.

In all the three categories of projects, the author compared the designed hierarchies of AHP process with the existing situations in fieldwork and later processing stages. As the situations vary from time to time and specifications would be different in projects, the benefits-costs hierarchies need to be evaluated every time before performing the survey fieldwork. The author tried to figure out any common issues appearing in similar natures at the end of each case study, and modified the general hierarchies and Benefits/Costs ratio computation by assigning different weights at the alternative level again to fit the circumstances of specific fieldwork natures. Such weightings were done in the direct comparison method to provide simplified but still accurate solutions rather than the pairwise comparison done in the original hierarchies. Moreover, the updated B/C ratios were recalculated once again to be evaluated with the experiences in the partnering company.

5.2 3D Visualization Model Establishment

5.2.1 Introduction

The 3D visualization models are generally applied in projects involving as-built or initial survey works, like plant revamp, construction, and site inspection works. There are always high-accuracy achievements required and complicated measurements are expected. The visual databases or final 3D models established for such projects can assist engineers and designers with inspection of different stages of their projects. Their ease with as-built or initial survey works is due to the modification and update of the product. This will reduce the repeated checking on site, which costs great sums of money, needed to update the models for engineers.

Besides those applications requiring complicated 3D models, there are some simpler, low-accuracy applications, which also exist in the business of the common Hong Kong private surveying practices. The photographic survey applications may not be purely photogrammetrical, but also photographic, image rendering and 3D modeling techniques included.

5.2.2 As-built/Initial survey

The common purpose of all as-built or initial survey works is to record the different stages in the construction for checking or quality assurance. The survey works are periodically updated for comparison between different stages. 3D visualization models can aid users to compare different stages in project works.

The investigated projects in this area were a construction site on the Peak, Kwai Hung warehouse redevelopment, and Sai Kung Swimming Pool revamp project. The three above projects were similar in nature as all were as-built checking surveys.

5.2.2.1 Construction site on Peak

- Background:

  This is a project of the partnering company on the Peak. The adjacent construction site of a client was suspected to have its relevant structure stepping into his lot and needed to be examined. For the boundary structure, it includes a gate with a 10m long fence. The requirement is to investigate any overlapping of those structures into the client's lot. The acceptable accuracy requirement from the client is ±5mm for the overall measurements. Both the conventional technique and photogrammetry were applied to investigate their differences in benefit-cost analysis.

- Methodologies:

Conventional survey

The fieldwork was simple and quick for this project, which required one working day to complete all the measurements (two half-days of work). The general procedures included establishing three control points, and radiating measurements to specific locations distributed along the suspected boundary (around 20 measurements towards the fence and gate). Afterwards, it was necessary to compare the existing boundary with the initial record from information received from the government. Subsequently, a team of two survey crews completed the fieldwork effectively (two man-days of work). The in-field surveyor or another draftsman in the office completed the data processing and mapping within 1 man-day of work. It was around 3 man-days of work using the conventional surveying technique in total.

Photogrammetry

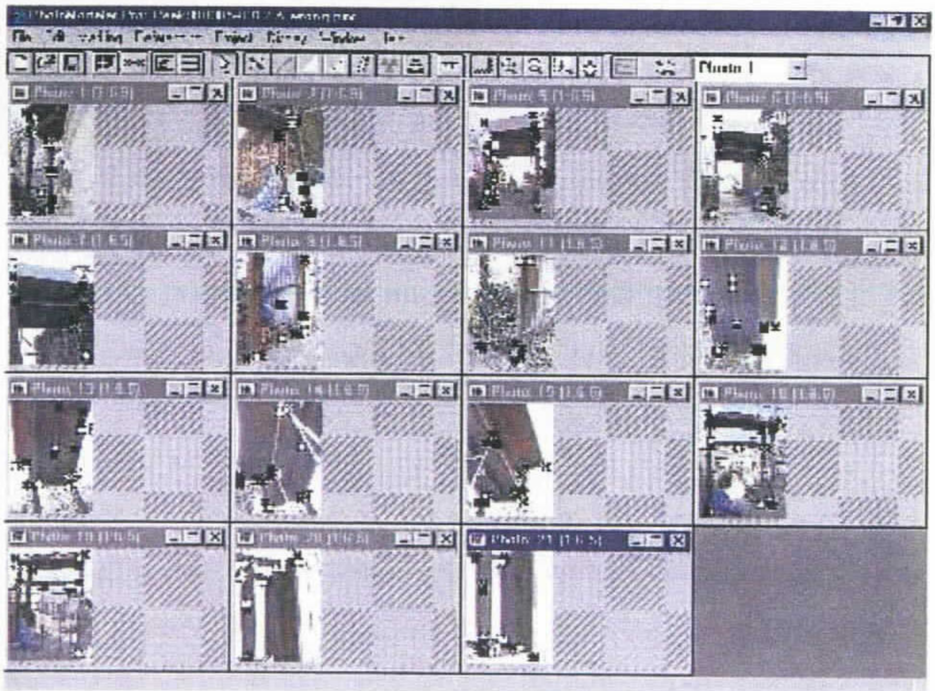

Fig. 5.2.1 The set-up in PhotoModeler for this project

The fieldwork required was one visit to the site for checking the boundary to simulate one of the periodic visits to those real-case construction works.

The application of digital photogrammetry in this project built up a visual database for the boundary area (Fig. 5.2.1). It could then have been easily compared with another visit to the site. On the other hand, the accuracy requirement was not very high (~20mm). The low-cost digital camera (Fujifilm DS-7) and 3D modeling package (PhotoModeler) were applied (Section 3.3). As well, a control survey was needed during fieldwork. For achieving a higher accuracy, a conventional survey technique was applied for spatial referencing. The survey crews in future can be reduced down to one surveyor with photogrammetric knowledge together with his/her assistant.

The photography was finished in half a man-day of work with more than 30 photos for the fence together with the gate taken. The control information collection process for this project requires a team of two survey crews working one half-day to complete, i.e. 1 man-day of work. The later data processing of this photogrammetric technique is the biggest portion of working hours – 2 man-days to complete the modeling. As a result, it required three and a half man-days of work to complete this project with the aid of photogrammetry.

- Discussion:

The conventional technique applied in this project showed quick and accurate results. The overall precision in the measurements was 5mm and completed in 2 man-days for fieldwork. Moreover, no extra specific equipment was needed which kept the operation cost low. The total operation costs for manpower was \$500 × 2 = \$1000, in which the daily operation cost per head was \$500 average. Together with costs of equipment and travelling, it was \$1000 + \$100 (equipment) + \$100 (fuel for travelling) = \$1200 in total. It is believed that the project is an example of how the conventional technique can be superior.

The photogrammetric technique needed more time than conventional survey to establish the resultant 3D model. The time consumed in photography together with achieving control information was more or less the same as the previous technique. It required a half-day of fieldwork for the author to photograph all possible shots for the features and another half-day for the control information to be collected. In contrast, the survey which included the required measurements for the control points in the photogrammetric method, was completed in a similar time period to the conventional method. However, the project is not a complicated one in measurements and it is believed that the time consumed in photography together with control survey will greatly increase as the complexity of the targeted object increases.

Considering the operation costs of the photogrammetric technique in this project, $500 × 3.5 = $1750 was the total manpower expense. However, the equipment cost was cheaper than conventional surveying equipment because of the low-resolution digital camera applied in this project. It was around $1-2000 for purchasing an acceptable model with 640 × 480 resolution. Additionally, the software package was newly purchased (PhotoModeler), and cost around $6000. Therefore, the total cost for this project was: $1750 + $2000 (price of digital camera) + $6000 (software) + $100 (travelling) = $9850.

The only advantage of digital photogrammetry over conventional survey in this project was the flexibility in presentation of result. The surveyed data was mainly point-line format for the conventional technique. However, a realistic 3D model was established by photogrammetry for users to examine the details (Fig.5.2.2a). Furthermore, there were different display formats to choose from (Fig.5.2.2b). The advance presentation platform provided the detail that conventional technique can hardly achieve.

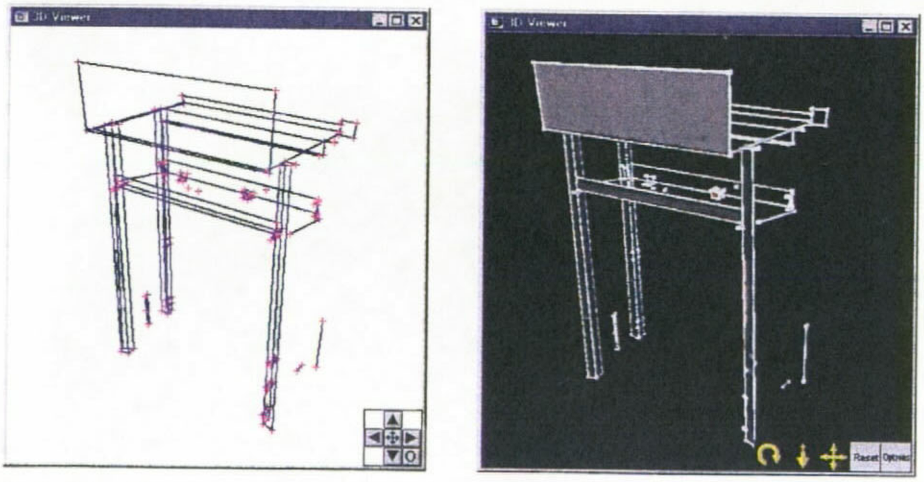

Fig. 5.2.2a&b The resultant 3D model of the gate of the construction site on the Peak (left), and the VRML enhanced model (right)

5.2.2.2 Kwai Hing warehouse

- Background:

This project was to perform an in-house building survey of a warehouse area inside a Kwai Hing industrial building of area over 2000m^2. The warehouse was a closed area with concrete beams and columns hanging on the walls and ceiling (Fig.5.2.3). The required precision should reach ±15mm. It was suitable to make a comparison between the two methodologies in fieldwork and data processing.

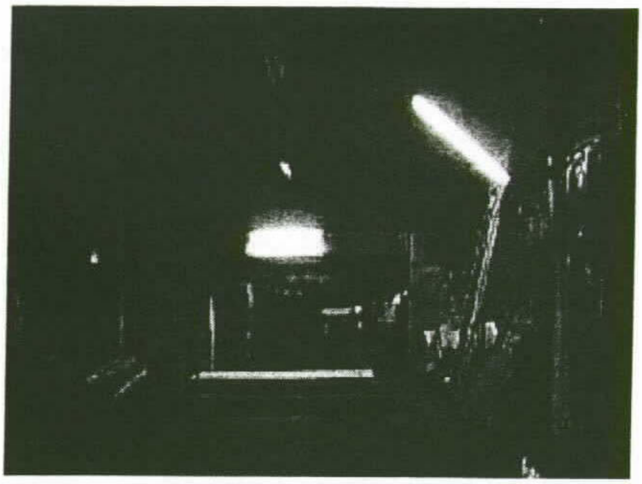

Fig. 5.2.3 Dark environment within the Kwai Hung warehouse area

- Methodologies:

<u>Conventional survey</u>

There were 15 control points in total and the whole fieldwork was thus sub-divided into two stages: a control stage and a measurement stage. It required 2 man-days to establish the whole control network, while the measurements were completed in 20 man-days. The slow progress was caused by the great number of beams and columns, slow mobility and the dark environment. The point-by-point measurement technique consumed great manpower to collect almost one thousand points in total. It was recommended that any reduction in measurements for the features within the warehouse area would reduce the operation costs.

The later data processing time was slow and complicated. To handle the hundreds of points of measurement, it required 5 man-days for the draftsman to complete the final plot of the warehouse area. Data input, modification and checking were time consuming processes needed to guarantee the warehouse area was correctly mapped. In conclusion, it was 27 man-days of work to accomplish this project with the aid of conventional surveying techniques.

<u>Photogrammetry</u>

The author applied photogrammetric technique in the partial modeling of the warehouse area only because of limited resources. The photographed area covered around $500m^2$ with a total of 200 images taken. There were two cameras applied, a high-resolution one (Kodak DCS420) and a low-resolution one (Fujifilm DS-7) (Section 3.3.2.1). The low-resolution camera was initially applied but was replaced by the higher-resolution one to improve the quality. In general, a single corner has already had at least 3 images overlapping from stations at different angles. The modeling platforms were the low-cost modeling packages, which were PhotoModeler and 3D Builder (Section 3.3.3.1, and Appendix B.2).

There were 3 man-days of photography. If the whole warehouse were to be photographed, it would consume at least 4 times that manpower for completion. For the later processing, it was completed in 7 man-days with the aid of the photogrammetric software packages. However, not all the photographed area ($500m^2$) was modelled because of the shortcomings of image quality, limitation of time, and experimental purpose in applying the commercial packages. Further detail will be discussed in the following section.

- Discussion:

The manpower consumed by the two methodologies has shown a relatively large difference: 27 man-days of conventional survey vs. 10 man-days of photogrammetry. In addition, the previous method involved more actual survey crews than the latter one. In this project, it was only the author himself who complete all the fieldwork in the photogrammetric method. The application of a control survey was neglected because of simplification of workload to generate a relatively low accuracy product with the aid of low-cost commercial packages.

The reduction of fieldwork is related to the different resultant accuracy achievements of the two methodologies. The conventional technique provided a highly precise measurement process for the whole area. The average achievement can reach ±20mm, which was reduced because of the tight schedule of the fieldwork. The whole area was measured within 2 weeks with later visits for checking initial measurements included. In contrast, the author generated the 3D model of the warehouse area in 7 man-days. The average precision of the model is ±50mm, which resulted from the lack of precise control information, and the low measurement accuracy during later processing (the generation of the 3D model within the photogrammetric packages).

However, the automatic extraction and calculation of surveyed data from the electronic total station was instantly processed by the draftsman. After 5 days of work in modifying and drafting, the final elevation plan can be submitted to the client. On the other hand, the author faced many problems in generating the 3D models in particular areas. As a result, another package was employed to complete the modeling process. The following figure (Fig. 5.2.4) shows the setup within the software package and 3D model generated:

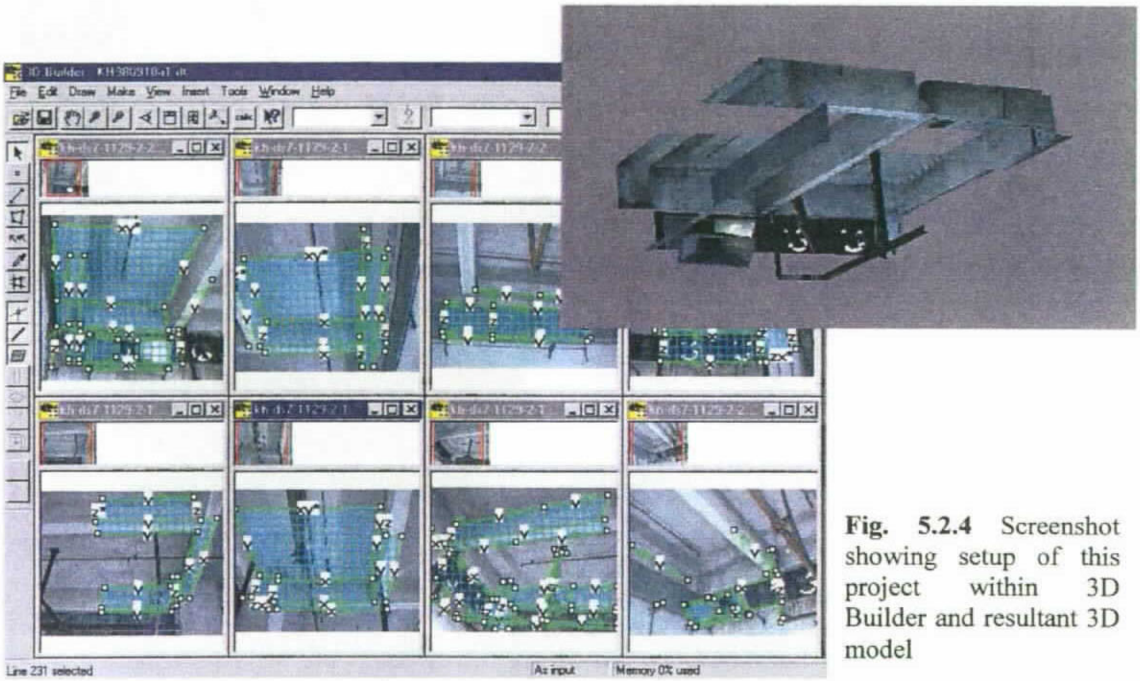

Fig. 5.2.4 Screenshot showing setup of this project within 3D Builder and resultant 3D model

For the comparison in costs, the total operation costs of the conventional technique were:

	$500 × 27 =	$13500	(manpower)
	$100 × 15 =	$1500	(equipment)
+	$100 × 10 =	$1000	(travelling)
	Total:	$16000	

The total operation costs of the photogrammetric technique were:

	$500 × 10 =	$5000	(manpower)
		$0	(digital cameras)
		$6000	(software)
+	$100 × 10 =	$1000	(travelling)
	Total:	$12000	

However, the mapped area of photogrammetric technique was less than 1/4 of that of conventional survey, i.e. the whole warehouse area. For the $0 expense on digital cameras, the low-resolution camera was previously purchased and should be considered differently from the conventional surveying equipment. Moreover, the high-resolution digital camera (Kodak DCS420) was borrowed from the university.

5.2.2.3 Plant revamp in Sai Kung swimming pool

- Background:

  The public swimming pool in Sai Kung was under an extension scheme to construct more facilities. Meanwhile, the existing pools were having their maintenance and redecoration. The plant area underneath was expected to be affected because there are huge pumps, and water tanks in the plant used for backing up the pools. Any settling or deformation affected by the construction should be determined as soon as possible to prevent any hazards in future. The partnering company was contracted to provide measurements and to monitor any sudden changes in any particular areas within the plant. Because of the monitoring purpose, it required a high accuracy achievement of better than ±10mm for the measurement points.

- Methodologies:

  Conventional survey

  There were four control points established, which took a team of four survey crews a half-day work to complete (GPS together with theodolites were applied) – which is 2 man-days of work. Afterwards, all the features within the area were surveyed but it was a complicated and heavy workload process because of the irregular shapes of different tanks, pipes and pumps. The whole measurement process was completed in 4 working days by a team of 3 survey crews, i.e. 12 man-days of work. The later processing was completed in 1 man-day by the draftsman at the office. Therefore, it was a total of 16 man-days of work for the as-built modeling of the plant area through conventional techniques.

  Photogrammetry

  Firstly, there were originally 45 control points established within the area. However, half of the controls were badly calculated with over ±0.5m precision. It is still a mystery as all the measurements and calculation procedures were checked and re-measured but nothing was found to be wrong. The actual size of each control target was 20mm in diameter, which was calculated for providing clarification on its center from the digital images. The remaining control points with relatively good precision were around ±0.2m. The control survey was done in 6 man-days because the control points were surveyed twice by two teams at different days for checking.

Secondly, there were around 50 images taken to cover as many features within the area as possible. However, there were still minor parts obstructed by other features, like pipes and gauges. Convergent network configuration was selected to suit the requirement of the photogrammetric software package (PhotoModeler). The camera used for this application was the Fujifilm MX-700, which is a medium-resolution digital camera (1280×1024) (Fig. 5.2.5).

Thirdly, the modeling process was under the platform of PhotoModeler, which can allow users to model cylinders as well as rectangular shapes (Appendix B.2). According to the photography of those features from various angles, the author examined their 3D model generation, like complex shapes, and cylinders (pipes). The author spent 5 man-days attempting to construct the 3D model but failed.

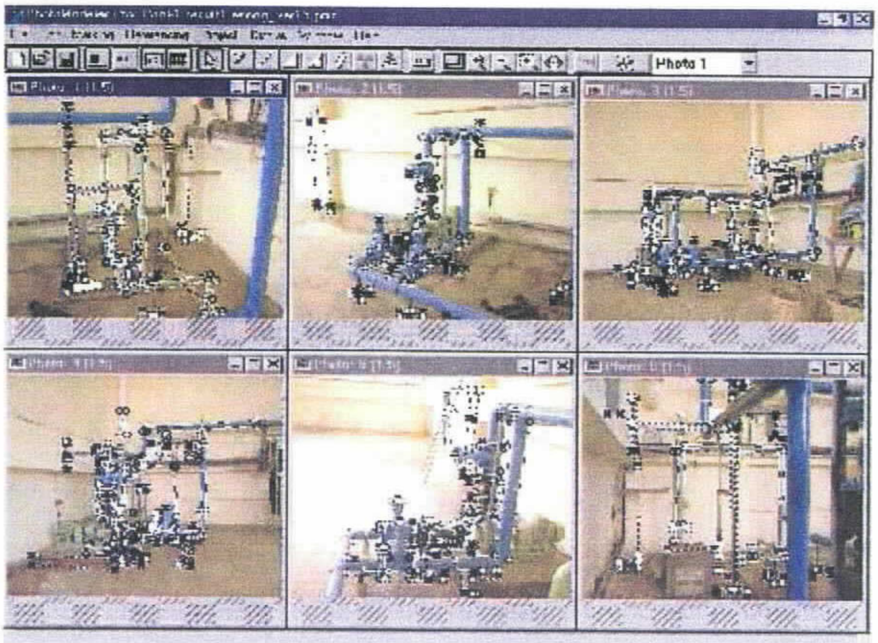

Fig. 5.2.5 Screenshot showing a setup in PhotoModeler for constructing the 3D model in Sai Kung swimming pool plant area

- Discussion:

As opposed to the previous two projects with features of mainly regular shapes, the features (pipes, gauges, and tanks) to be mapped here were more complicated. Both of the methodologies needed special consideration in handling the survey measurements and modeling processes.

For the conventional surveying technique, it was 16 man-days of work in total with the aid of total stations and GPS equipment. The application of GPS receivers had reduced the time needed to transfer distant government control points to the local site. The savings in manpower and equipment was up to 1-2 man-days of work. Furthermore, the average achieved precision in survey measurements in this project reached ±10mm, which fulfilled the accuracy requirement considered. Together with the total fieldwork working days being within a week, it shows that the conventional technique can handle this kind of project well.

However, the involved manpower and survey data collection was a problem because large manpower was used in this project (4 crews in one day's work). Moreover, there were some difficulties for the survey crews in measuring particular features, like tanks.

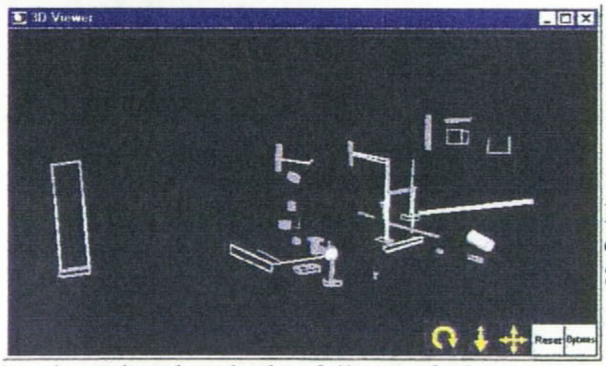

Fig. 5.2.6 3D model generated containing cylinderical objects in Sai Kung swimming pool plant area

On the other hand, the failure of photogrammetric technique in this project was mainly from the following factors. Firstly, the control survey was done twice but the results were still unacceptable. The average resultant precision was more than ±0.5m, which was mainly caused by particular points. Rejection of those points made the precision ±0.2m but it was still below standard.

Secondly, the author designed a convergent photographic network for capturing most of the features in the area. Under the circumstance of limited area, most rays towards the same features were intersected within 90°. It led to problems for the 3D model generation in the software package (Fig. 5.2.6).

Thirdly, the function of generating cylinders in PhotoModeler was not 100% successful. For testing this function of the software package, different pipelines, gauges and tanks in the area were captured into digital imagery. The features were in different orientations and combinations for investigating its capabilities. However, the generation of those cylinderical objects was not successful.

To compare the differences in costs between the two methdologies, the operation cost for manpower by conventional survey is $500×16 = $8000. The expense on equipment is ~$300 per day (1 total station and 2 GPS receivers), and the cost of fuel for travelling was ~$100 per trip. The total cost was: $8000 + $300×4.5 days + $100×5 (trips) = $9850.

For the photogrammetric technique, the expense on manpower was $500×13 = $6500. The equipment cost had been covered by previous projects for the software package but the medium format digital camera cost $4000. Together with the travelling cost, the total cost by photogrammetric technique was: $6500 + $4000 + $100×4 (trips) = $10900.

5.2.2.4 Decision support process for as-built/initial survey projects

To conclude the differences in benefits-costs study between the selected methodologies, the reassignment of weightings of alternatives with four grades (0.4 – Great, 0.3 – OK, 0.2 – Fair, and 0.1 – Poor) was established (see Table 5.2.1 and Table 5.2.2). An update in decision support processes can be previewed for future relevant projects. An important issue in assigning the weight is that their total should be equal to 1 as the total local weight to prevent any errors in calculation.

Level 1 Criteria	Level 2	Level 3	Global Weight	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
	Criteria	Criteria	(G.W.)	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Technological benefits	Measurement	Measurement Accuracy	0.1296	0.4	0.05184	0.3	0.03888	0.1	0.01296	0.2	0.02592
		Complexity	0.0288	0.1	0.00288	0.2	0.00576	0.4	0.01152	0.3	0.00864
		Non-reaching	0.0288	0.1	0.00288	0.2	0.00576	0.4	0.01152	0.3	0.00864
		Repetition	0.0528	0.2	0.01056	0.2	0.01056	0.3	0.01584	0.3	0.01584
	Achievement	Resultant Accuracy	0.15984	0.4	0.06394	0.3	0.047952	0.1	0.015984	0.2	0.031968
		Progress Time	0.13896	0.2	0.02779	0.2	0.027792	0.4	0.055584	0.2	0.027792
		Output Presentation	0.0612	0.1	0.00612	0.2	0.01224	0.3	0.01836	0.4	0.02448

Economic benefits	Productivity		0.0576	0.3	0.01728	0.3	0.01728	0.2	0.01152	0.2	0.01152
	Opportunities		0.1712	0.3	0.05136	0.1	0.01712	0.3	0.05136	0.3	0.05136
	Effort		0.1712	0.2	0.03424	0.2	0.03424	0.3	0.05136	0.3	0.05136
				Total:	0.26889	Total:	0.217584	Total:	0.256008	Total:	0.25752

Table 5.2.1 Application of Benefits hierarchy into decision making process of selecting methodology in as-built/initial survey purposes

Level 1 Criteria	Level 2 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
			Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Capital		0.128	0.094	0.012	0.146	0.0187	0.269	0.0344	0.491	0.0628
Equipment		0.277	0.106	0.0294	0.15	0.0416	0.248	0.0687	0.496	0.1374
Development		0.061	0.163	0.0099	0.163	0.0099	0.278	0.017	0.395	0.0241
Education	Training Staff	0.08489	0.091	0.0077	0.141	0.012	0.237	0.0201	0.531	0.0451
	Client Support	0.0212	0.141	0.003	0.141	0.003	0.263	0.0056	0.455	0.0096
Operation	Complexity	0.0528	0.3	0.0158	0.4	0.0211	0.1	0.0053	0.2	0.0106
	Accuracy	0.1815	0.2	0.0363	0.2	0.0363	0.3	0.0545	0.3	0.0545
	Time	0.0968	0.3	0.029	0.3	0.029	0.1	0.0097	0.3	0.029
	Output	0.0968	0.3	0.029	0.3	0.029	0.2	0.0194	0.2	0.0194
			Total:	0.1723	Total:	0.2006	Total:	0.2346	Total:	0.3925

Table 5.2.2 Application of Costs hierarchy into decision making process in as-built/initial survey purposes

For the updated benefits/costs ratio:

Alternative	Benefits/costs ratio
Pure Conventional Survey	0.26889 / 0.1723 = 1.561
Conventional Survey with Imagery	0.217584 / 0.2006 = 1.080
Low-cost Photogrammetric Packages	0.256008 / 0.2346 = 1.091
Precise Photogrammetric Measurements	0.25752 / 0.3925 = 0.656

Table 5.2.3 Resultant benefits/costs ratios among alternatives

Table 5.2.3 shows the updated decision process with specific settings to the nature of as-built/initial survey purposes. The "Pure Conventional Survey" still shows advantages over the other methodologies (alternatives in AHP), which seems reasonable from the experiences in the previous example projects. However, it was mainly the conflict with the hierarchies designed at the initial stage for the private surveying practices to adopt photogrammetric techniques in their businesses, especially the investment and capital costs. The costs criteria remained at the beginning of the adoption process, and investment in photogrammetric equipment greatly consumed the weightings.

Reflecting the changes in costs hierarchy, the concentration was on the sub-criteria of "Operation" and "Equipment". The various sub-criteria under "Operation" helped to determine how to minimize the expense on manpower and equipment by applying the suitable methodology.

The consideration for "Equipment" was due to the popularity of photogrammetric techniques, like digital cameras and software packages. The investment costs on these hardware and software products could be turnover by more applications on fieldwork. The difference between conventional and photogrammetric equipment may become smaller in future and users should consider it before their decision is made.

5.2.3 Photographic Survey

The original photographic survey has been applied in the industry for many years. It is to take photographs of features of interest in the site with documentation attached for recording details. The process is documented quickly but without geometric description within. Any project requiring simple, speedy, but precise dimensions can make use of the application of low-cost photogrammetric packages and digital cameras with 3D visualization models.

The two sample projects in this section are feature modeling in Chi Lin Nunnery, and seawall monitoring outside Sai Kung swimming pool. The former involved photogrammetric techniques to produce 3D models of the various features. However, the latter presented more realistic output through the application of photogrammetric software packages rather than traditional snapshots.

5.2.3.1 Features modeling in Chi Lin Nunnery

- Background:

  The wooden temple construction at Chi Lin Nunnery, which is sited at Diamond Hill in Hong Kong, is in the ancient Chinese "Tang" Dynasty architectural style (around 800 AD). It required monitoring during the assembly of timber blocks which were to become the various wooden buildings. Both conventional surveying and photogrammetric techniques were applied at this site to establish the computer based 3D model for examination by engineers and designers (Section 5.4.2).

Another purpose of applying photogrammetry at the Chi Lin site was for recording purpose. Different irregular features created difficulty for conventional techniques, like sculpture and decorating features (Fig.5.2.7). In this section, there are a few examples of photogrammetric techniques employed in generating the 3D models of particular features in the project.

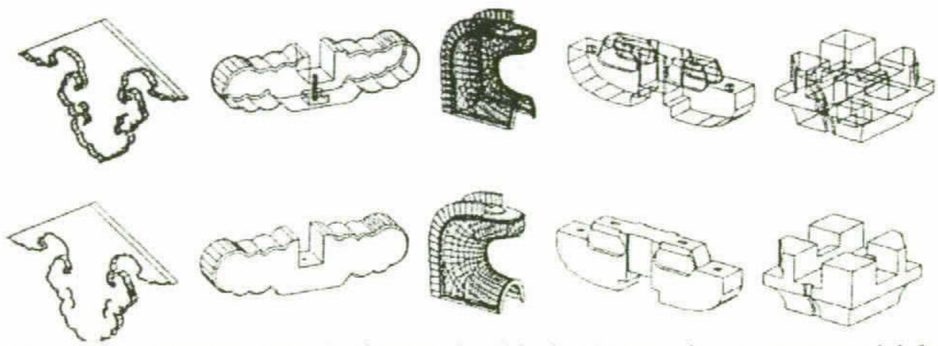

Fig. 5.2.7 Different irregular features in Chi Lin Nunnery in computer model format (Xu et al., 1998)

- Methodology:

Generation of these 3D models concentrated on techniques of photogrammetry. It is because all the models generated could only be created via the photogrammetric routine, and not by conventional methods.

Lotus-shaped tower cap

This is a decorating feature called "Lin Fa" (lotus-shaped tower cap) on the top of the roof of one of the buildings. The original dimensions are: 756.9mm (bottom diameter), 1080mm (upper diameter) and 288mm (height).

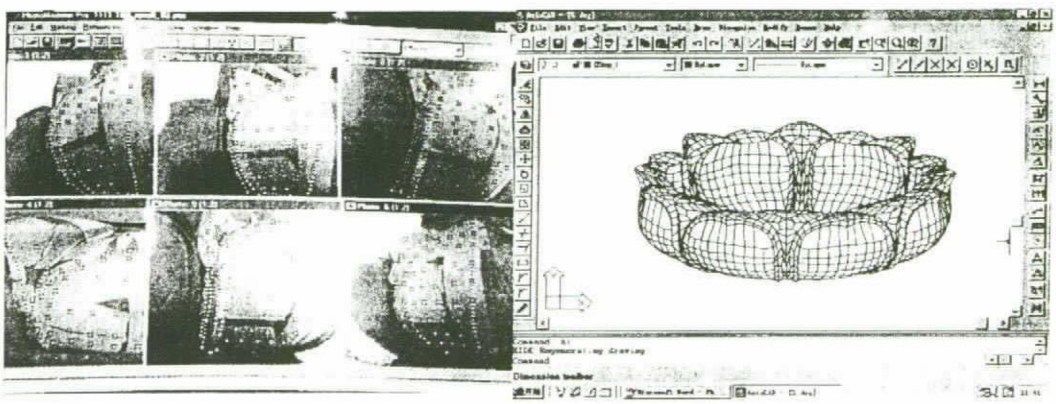

Fig. 5.2.8 "Lin Fa" – steps to generate its 3D model via PhotoModeler (Zhu et al., 1999)

It took only 2 hours for the photography, including the distance measurement and there were 2 man-days to build up the 3D model (Fig.5.2.8). The resultant precisions on model points were generally 2mm, and thus 1: 400 precision was achieved. The resultant 3D model was imported to CAD tool for modification.

<u>Owl's mouth</u>

This decorating feature is called a "Chih Wei" (Owl's mouth) on the top of the tile roof of the Main Hall. It is 1200mm long, 700mm wide, and 1660mm high. No pre-marked points were permitted to be marked on the original pieces during photography (Fig.5.2.9). Therefore, the re-generation was with the aid of its model at around 1/23 size (around 72mm high).

For the resultant model, a 1mm shift was found at the top region, i.e.precision of 1:70. If the error were projected to the actual size (1.6m high), there would be a 2.3cm shift on the top. After some checking and re-calculation, the error was reduced to a 0.5mm shift at the top region.

Fig. 5.2.9 Chih-Wei – a decorating feature on top of tile roof of the Main Hall (model of it) – Left; The 3D computer model of "Chih-wei" – Right

The whole modeling of "Owl's mouth" required 15 images to cover all its faces. There were 14 man-days consumed starting from the photography to the modeling process. The low-resolution digital camera (Fujifilm DS-7) was the data acquisition device in this and the previous task.

<u>"Xuanyu"</u>

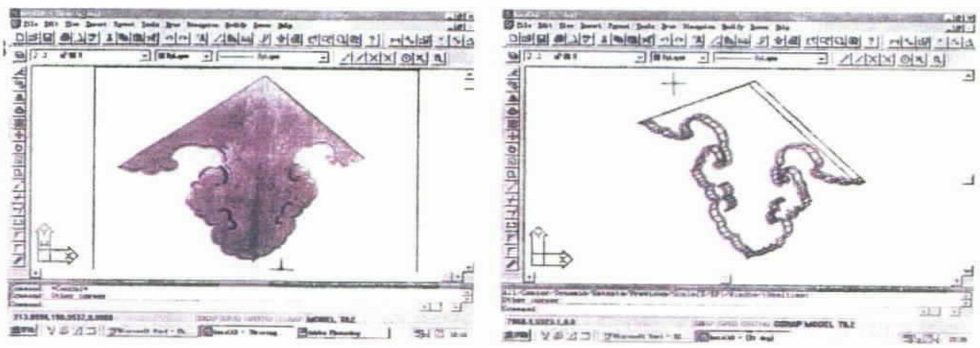

Fig. 5.2.10 Xuanyu – image acquired in CAD tools (left), and 3D model built up (right)

"Xuanyu", which can protect ridge purlins from damage, is a piece of decoration on the gable of the suspended ancient structure (Zhu et al., 1999).

Its flat surface made it difficult to model with formal photogrammetric technique. However, a 3D model of this feature could still be generated with the use of "near" rectified image together with direct import into CAD environment (Fig.5.2.10).

The whole task was completed in a single man-day. However, the operator has had experience in both photogrammetry and CAD operation to handle the above tasks.

- Discussion:

All the above tasks showed quick and simple operation with the aid of photogrammetric technique to generate the 3D models. Except for the "Owl's mouth" which required a longer processing time (14 man-days) to produce the resultant 3D model, the "Lin-Fa" tower cap and "Xuanyu" were both completed in a speedy manner.

On the other hand, the operation costs were lower than the as-built projects. Without any control survey required, the costing can be cut significantly by reducing the manpower and equipment. The general tasks can be completed within a few working days including fieldwork and later processing. Conventional surveying techniques cannot provide good results in this area because the irregular features are time consuming in data collection and also in the modelling process.

5.2.3.2 Seawall outside Sai Kung swimming pool

- Background:

The seawall outside Sai Kung swimming pool required an initial inspection report to monitor effects on stability of the construction on the swimming pool (relevant study in Section 5.2.2.3).

As the seawall faces the sea, the conventional surveying techniques cannot provide any measurements on its surface. Photography taken towards the wall from a vessel on the sea was used to construct a series of 3D models. The client did not set any accuracy requirement but it was recommended that a precision of ±50mm be used in determining any serious displacement.

- Methodology:

As the seawall is 100m in length but less than 10m in height, the whole length must then be cut into different sections for photography. To obtain the

10m×10m coverage, a Kodak DCS420 camera was applied to take the photography from the vessel. The resultant pixel size represented around 6.6mm on ground to enable recognition of any cracks on the seawall.

There were 24 photos taken for covering the adjacent areas beyond the boundary of the relevant seawall area and 100% overlapping was planned of adjacent photos. The level rods (Fig.5.2.11) provided limited control information to scale the resultant 3D model properly.

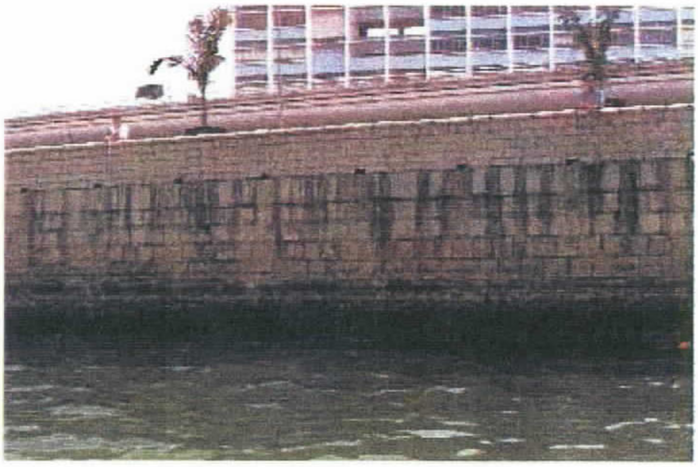

Fig. 5.2.11 A Photo showing the configuration of the sewall project

The whole fieldwork was completed in 2 hours by 3 survey crews (1 photographer with 2 assistants). There was around 1 man-day spent and the later processing was completed in 3 man-days. The total 4 man-days of work completed the project with a 3D visualization model provided for the client.

- Discussion:

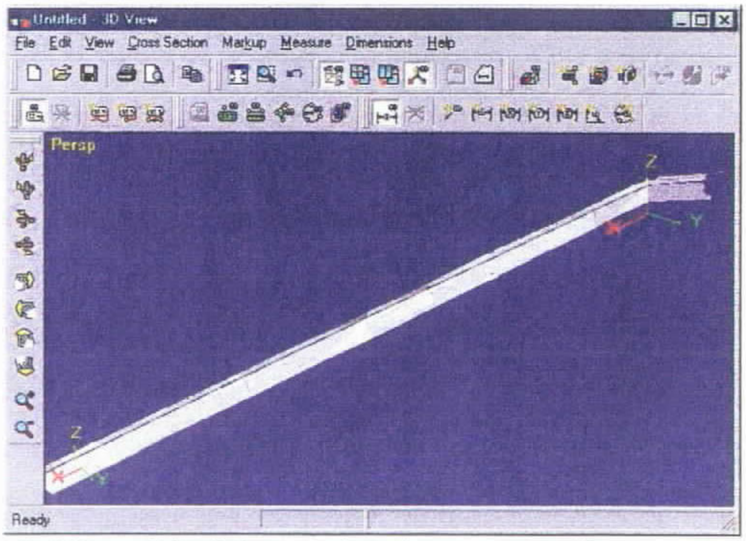

Fig. 5.2.12 Screenshot showing VRML frame model of Seawall project

A 3D model of the whole relevant seawall area was built up in this project (Fig. 5.2.12). All the procedures within it showed quick and simple access.

Moreover, the initial investment for the photogrammetric technique can be said as acceptable for:

Camera employed (Kodak DCS420): HK$100,000 (selective)

Low-cost photogrammetric package: HK$6,000

The choice of camera employed is flexible because the commercial models in the market (HK$3-4000) can also provide acceptable results.

The resultant precision of the generated 3D model was around ±40mm in most measurement points. The white colour model (Fig.5.2.12) in VRML format, which is without texture mapping on the surface. The VRML browser requires users to link the frame model with the respective texture through customized algorithm (Fig.5.2.13). This would require extra manpower in post-processing.

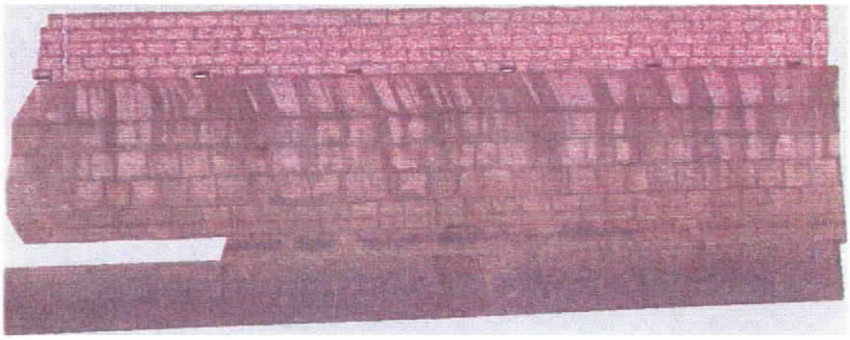

Fig. 5.2.13 3D View in PhotoModeler showing image texture mapped on the 3D model

However, there was a concern in presenting the output to the clients because they may not be familiar with photogrammetric survey and its products. Extra effort would be need to be considered. This will definitely increase the cost of the survey.

5.2.3.3 Decision support process for photographic survey projects

To conclude the differences in benefits-costs study between the selected methodologies, the reassignment of weightings of alternatives with four grades (0.4 – Great, 0.3 – OK, 0.2 – Fair, and 0.1 – Poor) was established (Table 5.2.4 & 5.2.5). An update in decision support processes can be previewed for future relevant projects. An important issue in assigning the weights is that their total should be equal to 1 as the total local weight to prevent any errors in calculation.

Level 1 Criteria	Level 2 Criteria	Level 3 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
				Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Technological benefits	Measurement	Measurement Accuracy	0.1296	0.3	0.03888	0.2	0.02592	0.2	0.02592	0.3	0.0388
		Complexity	0.0288	0.1	0.00288	0.1	0.00288	0.4	0.01152	0.4	0.0115
		Non-reaching	0.0288	0.1	0.00288	0.1	0.00288	0.4	0.01152	0.4	0.0115
		Repetition	0.0528	0.2	0.01056	0.2	0.01056	0.3	0.01584	0.3	0.0158
	Achievement	Resultant Accuracy	0.15984	0.3	0.04795	0.2	0.031968	0.2	0.031968	0.3	0.04795
		Progress Time	0.13896	0.1	0.0139	0.1	0.013896	0.4	0.055584	0.4	0.05558
		Output Presentation	0.0612	0.1	0.00612	0.2	0.01224	0.3	0.01836	0.4	0.0244
Economic benefits	Productivity		0.0576	0.2	0.01152	0.2	0.01152	0.3	0.01728	0.3	0.0172
	Opportunities		0.1712	0.2	0.03424	0.2	0.03424	0.3	0.05136	0.3	0.0513
	Effort		0.1712	0.1	0.01712	0.1	0.01712	0.4	0.06848	0.4	0.0684
				Total:	0.18605	Total:	0.163224	Total:	0.307832	Total:	0.34289

Table 5.2.4 Application of the Benefits hierarchy of decision making process in photographic survey

Table 5.2.5 shows the Costs hierarchy for photographic survey purposes:

Level 1 Criteria	Level 2 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
			Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Capital		0.128	0.094	0.012	0.146	0.0187	0.269	0.0344	0.491	0.0628
Equipment		0.277	0.106	0.0294	0.15	0.0416	0.248	0.0687	0.496	0.1374
Development		0.061	0.163	0.0099	0.163	0.0099	0.278	0.017	0.395	0.0241
Education	Training Staff	0.08489	0.091	0.0077	0.141	0.012	0.237	0.0201	0.531	0.0451
	Client Support	0.0212	0.141	0.003	0.141	0.003	0.263	0.0056	0.455	0.0096
Operation	Complexity	0.0528	0.4	0.0211	0.4	0.0211	0.1	0.0053	0.1	0.0053
	Accuracy	0.1815	0.2	0.0363	0.3	0.0545	0.3	0.0545	0.2	0.0363
	Time	0.0968	0.4	0.0387	0.4	0.0387	0.1	0.0097	0.1	0.0097
	Output	0.0968	0.4	0.0387	0.4	0.0387	0.1	0.0097	0.1	0.0097
			Total:	0.1969	Total:	0.2381	Total:	0.2249	Total:	0.34

Table 5.2.5 Application of the Costs hierarchy of decision making process in photographic survey

For the updated benefits/costs ratio:

Alternative	Benefits/costs ratio
Pure Conventional Survey	0.18605 / 0.1969 = 0.945
Conventional Survey with Imagery	0.163224 / 0.2381 = 0.686
Low-cost Photogrammetric Packages	0.307832 / 0.2249 = 1.369
Precise Photogrammetric Measurements	0.342896 / 0.34 = 1.009

Table 5.2.6 Resultant benefits/costs ratios among alternatives

Due to special circumstances in both investigated projects, the photogrammetric techniques (either low-cost or highly precise solutions) showed great benefits over the traditional conventional techniques (Table 5.2.6). It was believed that in any similar projects that conventional techniques are hardly applicable. Indirect measurement techniques, photogrammetry is preferred for these cases.

5.3 Terrain Modelling

5.3.1 Introduction

This section discusses two examples of terrain modeling of slopes. First, the Lamma Island topographic survey project. Second, the terrain modeling of Tuen Mun Highway widening project. The existing methodology, conventional survey, requires survey crews to collect measurements of the slopes. In comparison, the indirect photogrammetric measurement technique can provide competitive results (quickness, accuracy and resource expenditure) with that of conventional ones. Investigation is needed to see whether the introduction of photogrammetry can help in future relevant projects.

5.3.2 Topographic survey on Lamma Island

5.3.2.1 Background

In this project, a large area of landscape near So Kwu Wan on Lamma Island was to be surveyed for landslide prevention purposes. Most are general slopes, except a boulder, which is at least 10m high by 15m wide, located at the centre of the area. To locate it with the aid of conventional techniques only, the approximate boundary around its bottom together with 1 to 2 spot heights on the top can be said as accessible only. To project this on a topographic map, there is not enough information to describe the detail of the boulder. With a low-accuracy requirement (±500mm), it is recommended to evaluate the feasibility of the application of photogrammetric data acquisition and processing.

5.3.2.2 Discussion

The following table (Table 5.3.1) shows the differences in applying the two different methodologies in the Lamma topographic survey project:

Criteria consideried	Conventional surveying techniques	Photogrammetric techniques
Resultant accuracy	50 mm in average	400 mm in average
Equipment applied	Electronic total station	1. Medium-resolution digital camera, and low-cost modelling software (Photogrammetry); 2. Electronic total station (Control).
Measurement points	1 (boulder) 50 (topographic data posts)	25 points (on boulder surfaces)
Working period	1 working day	1/2 working day
Resultant manpower	6 man-days (fieldwork) 1 man-day (post-processing)	1 man-day (fieldwork) 2 man-days (post-processing)

Table 5.3.1 Comparison between the two methodologies in Lamma Island project

The comparison between the two methodologies in this project is not too relevant because they work for different purposes. The conventional technique helps the topographic survey on the general slope areas. However, photogrammetry cooperates with the conventional technique to collect the survey measurements around the boulder.

- Conventional survey:

  Similar to the general topographic survey purposes, the bearing-distance technique (radiation) with the aid of total station was applied in this project. The precision level of the applied total station is ±5" in angular measurement. There were two survey teams (2 surveyors with 4 assistants) assigned to complete the whole project. For the density of collected points, 2m-interval was set to maintain the reliability of data collected.

- Photogrammetry:

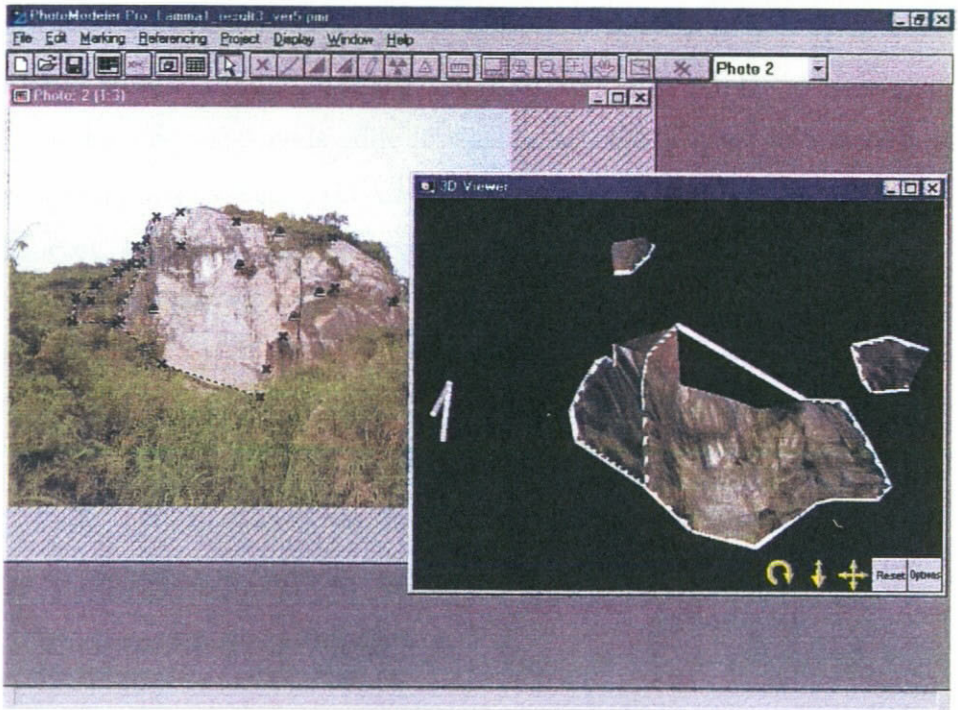

Fig. 5.3.1 Low-accuracy terrain modelling with PhotoModeler in Lamma Island project

With the low accuracy requirement in this project, a medium-resolution digital camera (Fujifilm MX-700) together with a low-cost 3D modelling package (PhotoModeler) was applied (Appendix B.2). A control survey, which is used for establishing control points, is done with the aid of total station and a non-reflective EDM – "Disto" mounted above the theodolite without the use of any reflective prism. A 3D intersection technique was applied to compute for the respective control point coordinates. There were three initial observation stations to increase redundancy measurements, however, most measurements from the third station were rejected due to the effect of heavy rain during observation. It resulted in a decrease of resultant precision of control points to ±50mm in average. There are 16 control points established in total to configure the terrain model (Fig. 5.3.1).

The major difference between the two methodologies was the resultant accuracy. The photogrammetric technique had 8 times the error of the conventional technique. However, the manpower involved in the latter technique was more than twice of the former one. For a private surveying practice to start using photogrammetric technique, an extra that cost needs to be considered a data acquisition device and processing software (Appendix B2).

The above example was barely achieved using the conventional survey techniques in a cost-effective way because of the difficulty in handling the boulder area. There were always extra manpower and resources required to complete the task, but the result was not much improved. On the other hand, low-cost photogrammetric or modeling techniques provide quite low accuracy achievement of measurements but with great manpower saved. The only concern would be the difficulties in doing a control survey, especially for the slope area in this project.

To analyze the general benefits-costs hierarchies previously designed, it was understood that the weightings among the alternatives in "Technical Benefits" should be varied, for example differences of weightings of alternatives in "Measurement Accuracy" became smaller (accuracy less concerned). "Progress Time" could have the weighting of "Low-cost Photogrammetric Packages" double that of "Pure Conventional Survey Methods" (as half of the manpower was saved).

5.3.3 Tuen Mun Highway Expansion

5.3.3.1 Background

The project, which determined the status of the slopes before the construction of the widening of the road, was located at the Tai Lam Section of the Tuen Mun Highway. The integrity artificial slopes formed in its construction was evaluated (Fig. 5.3.2). This project combined both conventional and photogrammetric techniques to perform the terrain modeling. The conventional survey established a control network for the series of photography along the slopes. The photogrammetric survey involved control target placing, on-flight and field photography, 3D visual database establishment (stereomodels of photo strips), and terrain model generation.

Fig. 5.3.2 An image of Tuen Mun Highway Side Slope in the project

5.3.3.2 Discussion

The following are some details of the whole workflow planned and processed in this project:

- Photography and control survey:

  The total length of the slope area is about 1.4km and has an average height of 60m and was subdivided into 4 photo strips for photography. The image exposure platform was from a helicopter with a loaned Rolleiflex 6006 film camera. The above average height of the slopes limited the photo coverage for stereopairs with 80% overlap only. For the manpower consumed in photography, one half of a man-day was used to complete the whole area with over 200 exposures taken for the strips along the slopes.

  More than 40 control marks had been targeted on the slopes for use of reference control of photography. Traverse method was used to establish several intermediate stations for locating the coordinates of the control targets. The misclosure of the traverse survey was 20mm in total measurements and an average of 5mm between adjacent stations. For the fieldwork of the control survey, 3 survey teams (1 surveyor with 2 assistants) completed it in 3 days, i.e. 27 man-days were involved in total.

- Scanning:

  As the original photography was in film format, all the photos had to be scanned into digital for use in digital photogrammetric systems. This was achieved with a precise photogrammetric scanner, Intergraph PhotoScan™, with a resultant pixel resolution up to 7μm (different at different strips). 2 man-days were required to process the whole scanning.

- Data reduction:

  The data reduction stage was accomplished within the Helava system (Appendix B.2) for the computation of orientations and formation of stereomodels of Section 1. The photo strips along Section 1 were stereoscopically linked together. The original plan was to configure the models with respect to the 4 controls pairs at the start and end of the strip. However, the two pairs contained 2 and 3 control points instead. It did not provided enough relevant measurements in orientation and stereomodel generation.

The results via Helava system were shown at a certain level of failure and unreliability, especially on the terrain model generation. RMS errors were high in both horizontal and vertical directions (~0.7m and ~0.6m) in absolute orientation process. There were at least 15 man-days consumed in this data reduction process.

According to the lack of referencing from control points in the section, the bundle adjustment was not the best. In the Digital Elevation Model (DEM) generation, the model formed did not fit the terrain relief at the boundary area. It was because of the involvement of errors in the models. The later processing stages like ortho-imaging and mosaicing could not be continued. Afterwards, the project was sub-contracted to a company called Hong Kong Geomatics, to apply another photogrammetric software program – Virtuoso. Their plan was to produce many sections profiles (contour) and fit these into the planar presentation of the photos through an image processing software - Adobe Photoshop. Unfortunately, the terrain models generated also could not convince the client that it was a reliable product until some of the procedures were corrected long agfter the submission date. As a result, both the above works were considered unsuccessful with regards to the result.

5.3.3.3 Difficulties and recommendations

From the experiences involved in the project, it is a huge sum of investment money for the equipment and workstations. The camera employed was the Rolleiflex 6006 metric film camera. Together with the lenses used, the sum can reach $150,000. The film scanning required $4,000 per day, and the hire fee of the helicopter was $20,000 per hour. The company provided the survey crews. These are all acceptable for the budget. The later processing by the digital photogrammetric system can be in the terms of "on loan" from Hong Kong Polytechnic University (the above costs will be re-paid by the main contractor except for the camera).

As a result, this kind of project may not be very suitable for the private sector in Hong Kong due to the large investment and expertise required. However, the procedures within, like the data acquisition stage or the reduction stage may be suitable for the private surveying practice to be involved. First, the project can be sub-contracted to other companies with relevant expertise. The equipment, expertise and operation costs would not be the same large concern as before. Second, the investment costs of updated photogrammetric-related equipment like high-resolution cameras, workstation and software could be overcome in future with other contracts. If so, will it provide enough work? Otherwise, is it worth it for the sub-contract with equipment on loan?

5.3.4 Decision support process for terrain modelling projects

To conclude the differences in benefits and costs between the two methodologies in terrain modelling projects, the aerial photogrammetric techniques show some benefits over the conventional techniques when a large area is required for topographic mapping. With the re-assignment of different weightings for alternatives in this specific project type - terrain modeling using four grade (0.4 – Great, 0.3 – OK, 0.2 – Fair, and 0.1 – Poor). The following (Table 5.3.2 and 5.3.3) are some updates in decision making hierarchies for future relevant projects.

Level 1 Criteria	Level 2 Criteria	Level 3 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
				Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Technological benefits	Measurement	Measurement Accuracy	0.1296	0.3	0.03888	0.3	0.03888	0.2	0.02592	0.2	0.02592
		Complexity	0.0288	0.1	0.00288	0.2	0.00576	0.3	0.00864	0.4	0.01152
		Non-reaching	0.0288	0.1	0.00288	0.2	0.00576	0.4	0.01152	0.3	0.00864
		Repetition	0.0528	0.2	0.01056	0.2	0.01056	0.3	0.01584	0.3	0.01584
	Achievement	Resultant Accuracy	0.15984	0.3	0.047952	0.3	0.047952	0.1	0.015984	0.3	0.047952
		Progress Time	0.13896	0.2	0.027792	0.1	0.013896	0.4	0.055584	0.3	0.041688
		Output Presentation	0.0612	0.1	0.00612	0.2	0.01224	0.3	0.01836	0.4	0.02448
Economic benefits	Productivity		0.0576	0.3	0.01728	0.3	0.01728	0.2	0.01152	0.2	0.01152
	Opportunities		0.1712	0.3	0.05136	0.1	0.01712	0.3	0.05136	0.3	0.05136
	Effort		0.1712	0.2	0.03424	0.2	0.03424	0.3	0.05136	0.3	0.05136
				Total:	0.239944	Total:	0.203688	Total:	0.266088	Total:	0.29028

Table 5.3.2 Application of Benefits hierarchy into decision making process of selecting methodology in terrain modelling projects

Level 1 Criteria	Level 2 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conv.. tional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
			Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Capital		0.128	0.094	0.012	0.146	0.0187	0.269	0.0344	0.491	0.0628
Equipment		0.277	0.106	0.0294	0.15	0.0416	0.248	0.0687	0.496	0.1374
Development		0.061	0.163	0.0099	0.163	0.0099	0.278	0.017	0.395	0.0241
Education	Training Staff	0.08489	0.091	0.0077	0.141	0.012	0.237	0.0201	0.531	0.0451
	Client Support	0.0212	0.141	0.003	0.141	0.003	0.263	0.0056	0.455	0.0096
Operation	Complexity	0.0528	0.3	0.0158	0.4	0.0211	0.1	0.0053	0.2	0.0106
	Accuracy	0.1815	0.2	0.0363	0.2	0.0363	0.3	0.0545	0.3	0.0545
	Time	0.0968	0.2	0.0194	0.4	0.0387	0.1	0.0097	0.3	0.029
	Output	0.0968	0.2	0.0194	0.2	0.0194	0.2	0.0194	0.4	0.0387
			Total:	0.1529	Total:	0.2006	Total:	0.2346	Total:	0.4118

Table 5.3.3 Application of the Costs hierarchy of decision making process in terrain modelling purposes

For the updated benefits/costs ratio:

Alternative	Benefits/costs ratio
Pure Conventional Survey	0.239944 / 0.1529 = 1.569
Conventional Survey with Imagery	0.203688 / 0.2006 = 1.015
Low-cost Photogrammetric Packages	0.266088 / 0.2346 = 1.134
Precise Photogrammetric Measurements	0.29028 / 0.4118 = 0.705

Table 5.3.4 Resultant benefits/costs ratios among alternatives

The above table (Table 5.3.4) shows the updated decision process with specific settings to the nature of terrain modeling purposes. The "Pure Conventional Survey" still shows advantages over the other methodologies (alternatives in AHP). This was mainly due to the conflict with the hierarchies designed as the initial stage for the private surveying practices to adopt photogrammetric techniques in their businesses. The costs criteria remained at the beginning of the adoption process, and investment in photogrammetric equipment greatly consumed the weightings.

However, the "Low-cost Photogrammetric Packages" showed increasing benefits from the general hierarchies. After the surveying practice had started the adoption and adaptation of photogrammetric techniques, the costs required would be greatly reduced.

Furthermore, the "Precise Photogrammetric Measurements" was limited by initial costs in investing in those data acquisition devices (like metric cameras, and digital photogrammetric workstation). In fact that large area topographic mapping can hardly be cost effective using conventional technique. From the above Tuen Mun expansion project, the data reduction process was evaluated with the aid of the digital photogrammetric workstation within Hong Kong Polytechnic University. For any future similar tasks, it is also recommended to review the criteria levels to fit the circumstances.

5.4 Monitoring Building Structures

5.4.1 Introduction

Conventional surveying methods require survey crews to reach the objects to be measured to collect data. The complexity of measurements in deformation monitoring involves too many resources for conventional surveying. This section compares these conventional methods with photogrammetry, specifically architectural which photogrammetry, which is defined as the handling of tasks relating to architecture using the application of photogrammetric techniques.

Two example sites, a wooden temple construction in Chi Lin Nunnery (Section 5.4.2) and an old building in Tsim Sha Tsui (Section 5.4.3), were investigated in this section.

5.4.2 Chi Lin Nunnery

5.4.2.1 Background

The Chi Lin Nunnery wooden temple construction project had undertaken a survey to provide the documentation for all the components during and after the construction. Besides the recording purpose (Section 5.2.3.1), the prevention of deformation in timber components is another important issue. However, the complexity of the buildings may limit the ability of conventional surveying techniques in determining the degree of movements in separate elementary blocks (Fig. 5.4.1). Furthermore, the applied technique should also have cost-effective procedures and results for checking the buildings periodically.

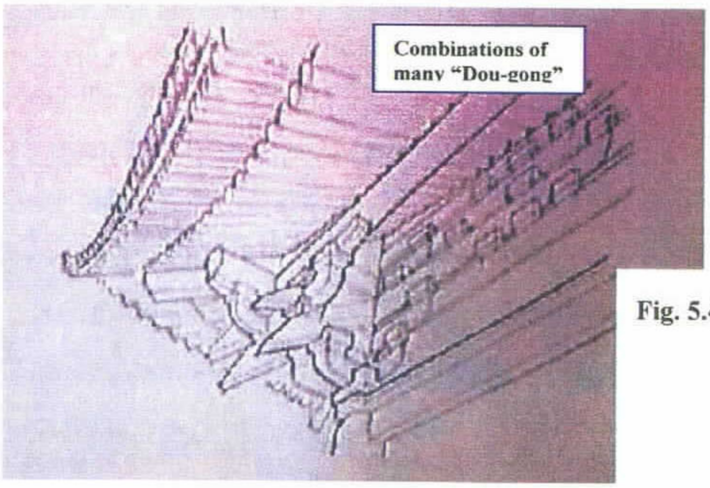

Fig. 5.4.1 The structure of part of a bldg. showing Dou-gong ("Historic Chinese Architectures", 1985)

The author thus investigated the application of photogrammetric techniques into the construction work of wooden temples in Chi Lin to compare with those existing conventional survey methods.

5.4.2.2 Discussion

The author established the following testing sets for investigating the differences between the conventional and photogrammetric surveying techniques in measurement, and later processing in this project:

1. Single timber components,
2. Group of blocks forming a set of "dou-gong", and
3. Monitoring of wooden and concrete roofs on different buildings.

Firstly, comparing the measurement processes of single blocks by the two methods was to obtain their difference in time processing and accuracy studies. Secondly, the forming of a set of "dou-gong" with the two methods can also provide an analysis on various criteria, like time, and accuracy achievement. Thirdly, two more testing areas were selected for the comparison – a wooden roof on the Main Hall and a concrete roof on the Tower of Millions of Buddhas. This was to examine the performance of the two methods in another context-monitoring relatively flat surfaces.

The following table (Table 5.4.1) is some discussion in comparison between the techniques with reference to their fieldwork and later processing issues:

- Single components:

Criteria considered	Conventional surveying techniques	Photogrammetric techniques
Resultant accuracy	< 1mm (regular only)	3-5 mm (regular) 10 mm (irregular)
Equipment applied	Rule measure	Low-resolution digital camera, and low-cost modeling software
Working period	Minutes	At least 1/2 hour for simple regular blocks

Table 5.4.1 Comparison between the two methodologies in the testing set of single components

This shows the conventional surveying techniques as having more benefits in the first testing set (single component modeling). The average error was lower than 1mm via repetitive measurements for conventional techniques. On the other hand, the use of photogrammetric technique also showed acceptable accuracy in results: 3-5mm for regular blocks, but 10mm for irregular blocks. The conventional surveying technique simply required a rule measure but speedy and accurate results were obtained. Although a low-resolution digital camera (640×480) together with commercial modeling software (PhotoModeler) was applied, the photogrammetric technique showed much less strength in resource and cost issue. Furthermore, the difference in working periods between the two methodologies was also great because of the ease of use of rule measures when comparing with data acquisition, image measurement and processing within photogrammetric survey. Most photogrammetric measurements in this category still required half a man-day to complete while the conventional technique needed minutes only.

However, there was one type that the rule measures could not provide measurements for easily. The irregular wooden blocks were too complicated to use rule measures to perform their measurements, and it showed the advantage of applying photogrammetric techniques to measure those components.

- Groups of blocks:

Criteria considering	**Conventional surveying techniques**	**Photogrammetric techniques**
Resultant accuracy	3-5 mm	5-10 mm (regular) >10 mm (irregular)
Equipment applied	Electronic theodolites, and rule measures	Low-resolution digital camera, and low-cost modeling software
Working period	1-2 hours in average	At least 1/2 day for small group of blocks

Table 5.4.2 Comparison between the two methodologies in the testing set of group components

Unlike measuring the single components, the groups of blocks required more complicated measurements. Both methodologies required more resources and manpower to complete the task (Table 5.4.2). The difference of accuracy achievement was reduced among the selected techniques. This was mainly because of the increase in complexity of measurements. The involvement of equipment became more advanced and also resulted from the increase in complexity. However, the photogrammetric equipment is still additional investment for the private surveying practice as a newcomer. The author compared the differences in their time progress. It was found that both methodologies require a large increase in processing time to provide the final 3D models of the group of blocks. For the conventional technique, it generally required half to one man-day to complete the measurement and later processing. The photogrammetric technique required more expertise for photograping and processing the object as the complexity of the group increased (Fig.5.4.3a and b). This resulted in those very complicated sets having poor results (Table 5.4.3), and required more manpower (at least 1 man-day) to complete a similar task.

Fig. 5.4.2a & b Two photos showing the increase in complexity between different groups of blocks

Set name	**Corner Blocks on Main Hall (Fig. 5.4.3a)**	**Group of blocks underneath ceiling of Main Hall (Fig. 5.4.3b)**
Photo(s) used	3 photos	6 photos
Control information	A scale distance (PhotoModeler)	Scale distance with rotation axes (PhotoModeler)
Resultant accuracy	5mm	> 10mm

Table 5.4.3 Results in the two groups from Fig. 5.4.3a and b

- Monitoring the two different roofs:

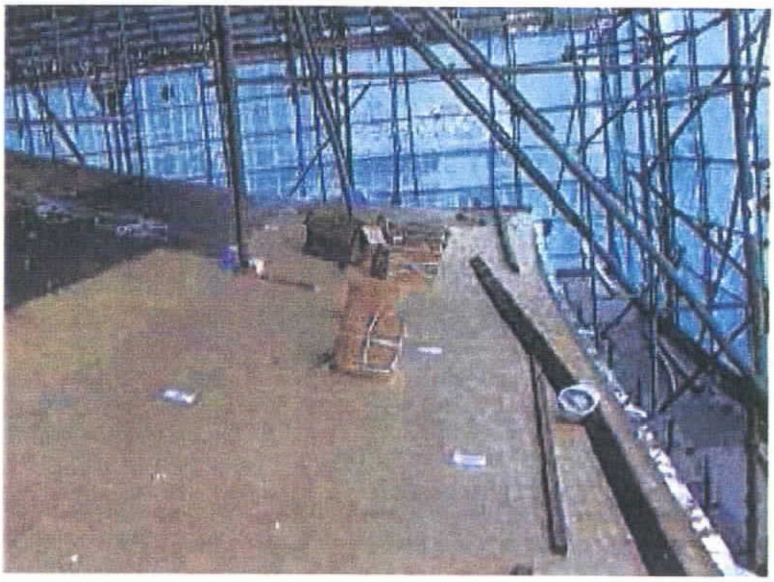

Fig. 5.4.3 Diagram showing the wooden roof on the Main Hall

To discuss the conventional surveying techniques applied in the two testing areas, the detail surveying technique was applied to all of roof surfaces (Fig. 5.4.3). A total of 8 survey crews worked out the whole wooden roof surface on the Main Hall in 5 working days (40 man-days). On the other hand, the concrete roof surface required 3 survey crews to complete by 12 days (36 man-days). This was because the concrete construction on the Tower of Millions of Buddhas was finished level by level (7 levels of the tower in total), while the wooden surface had been completed in a manner for the author to investigate. For the resultant accuracy, the wooden roof monitoring resulted in 10-20mm accuracy and the concrete roof was completed with a 5-10mm accuracy. The greater error in wooden roof monitoring was believed to be mainly from the non-stable behaviour of the wooden surface. The following table 5.4.4 compares the two tasks:

Criteria considering	Wooden roof surface on Main Hall	Concrete roof surface on Tower of Millions of Buddhas
Resultant accuracy	10-20 mm	5-10 mm
Equipment applied	Electronic theodolites, and rule measures	Electronic theodolites, and rule measures
Working days required	5 days	12 days
Manpower involved	8 survey crews (2 surveyors)	3 survey crews (1 surveyor)

Table 5.4.4 Differences in two roof surfaces monitoring by conventional techniques in 3rd testing set

On the other hand, results were not as successful using the photogrammetric techniques. Although the Vexcel FotoG-FMS software with advanced orientation process was applied in this testing set but not the low-cost commercial modelling software (Appendix B.2) was not used, as it resulted in failure for the both tasks with bad orientation results in the software. The photographic exposures were taken in convergent angles towards the roof surfaces due to the limitations of the existing location (Fig. 5.4.3). Afterwards, the author tried the alternative by applying PhotoModeler (low-cost modelling software) to model the framework of the wooden roof surface on the Main Hall. It showed a reasonable result with the aid of the control points originally existing (for working in FotoG-FMS). However, there was a shortcoming of the model with inadequate data points to regenerate the surface due to the limitation of PhotoModeler in manual construction of framework models (Appendix B.2).

5.4.3 Tsim Sha Tsui old building

5.4.3.1 Background

Another project of the teaching company was to check whether an old building of five storeys tall in Tsim Sha Tsui East would be affected by the foundation work of the neighbouring construction site or not (Fig. 5.4.4). The basic requirement from the client engineer was to obtain any horizontal or vertical displacements but with a high precision of ±10mm for prediction of any hazardous movement of the building. It would have been more beneficial if extra information from the surfaces of the building (e.g. cracks) and any relative movements with reference to other neighbouring buildings (e.g. the skyscraper next to the old building in the above figure) could have been obtained to provide a reliable and repetitive check.

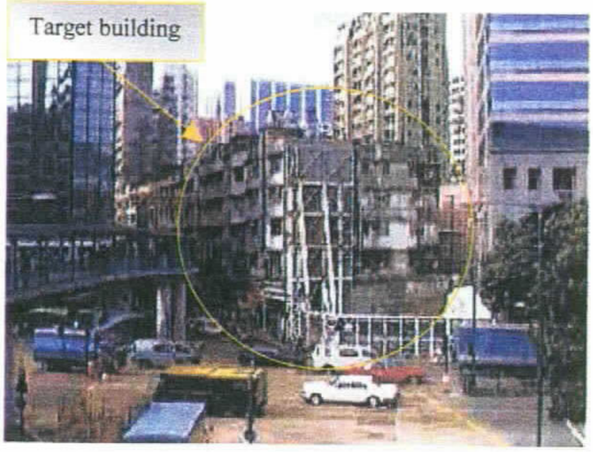

Fig. 5.4.4 Photo showing the location of the old building

5.4.3.2 Discussion

This project was again compared by applying both the conventional surveying and photogrammetric techniques. The conventional technique required a control network, which was completed by a 3-member survey team in one day (3 man-days). There were another 2 days taken for vertical displacement checking (plumb-line method), and measurement on specific monitoring points built by the engineer (6 man-days). The later processing was completed in 1 man-day for calculation and presentation. The resultant precisions were ±5mm for control points established, ±30mm for plumb-line checking, and ±10mm for monitoring points set up.

Three control points were established for the photogrammetric survey. Afterwards, the monitoring points previously stated together with some others laid at joints between beams and columns, window areas, and even cracks visible on the surfaces were surveyed as additional data checking (26 points in total). Moreover, 29 images were taken to cover the whole site for the regeneration of a 3D model through photogrammetric software. The cameras employed were Kodak DCS420 and Nikon 35mm film camera for a comparison between digital and film-based imagery in data acquisition. As the versatility of the old building is around 100°, the configuration of the camera network is fitted within this range.

The control survey for the photogrammetric survey was done within half a day by two survey crews (1 man-day). For the photography, there were two visits, which required the author a half-day each (1 man-day in total). Together with the later processing, it was originally planned to be completed in 7 man-days, with 5 days for the generation of the 3D model. However, the pixel resolution of images from both digital and film camera cannot achieve the measurement accuracy of ±10mm on the features. The image measurement made at this pixel resolution cannot create the 3D model accurately. Moreover, no higher resolution camera exist to be applied at this moment. It is quite infeasible to apply photogrammetric technique effectively, and thus it is considered as a failure of photogrammetry in this project.

5.4.4 Decision support process for deformation monitoring projects

To conclude the differences in benefits and costs between the two methodologies in the two above deformation monitoring projects, the conventional surveying techniques provided simpler and more accurate results than photogrammetry. With the re-assignment of different weightings of alternatives using four grades (0.4 – Great, 0.3 – OK, 0.2 – Fair, and 0.1 – Poor), the following tables 5.4.5 and 5.4.6 are the modified decision support algorithm.

Level 1 Criteria	Level 2 Criteria	Level 3 Criteria	Global Weight (G.W.)	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
				Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Technological benefits	Measurement	Measurement Accuracy	0.1296	0.4	0.05184	0.3	0.03888	0.1	0.01296	0.2	0.02592
		Complexity	0.0288	0.2	0.00576	0.2	0.00576	0.3	0.00864	0.3	0.00864
		Non-reaching	0.0288	0.1	0.00288	0.2	0.00576	0.4	0.01152	0.3	0.00864
		Repetition	0.0528	0.2	0.01056	0.2	0.01056	0.3	0.01584	0.3	0.01584
	Achievement	Resultant Accuracy	0.15984	0.3	0.04795	0.3	0.047952	0.2	0.031968	0.2	0.031968
		Progress Time	0.13896	0.2	0.02779	0.1	0.013896	0.4	0.055584	0.3	0.041688
		Output Presentation	0.0612	0.2	0.01224	0.2	0.01224	0.3	0.01836	0.3	0.01836
Economic benefits	Productivity		0.0576	0.3	0.01728	0.3	0.01728	0.2	0.01152	0.2	0.01152
	Opportunities		0.1712	0.3	0.05136	0.3	0.05136	0.2	0.03424	0.2	0.03424
	Effort		0.1712	0.3	0.05136	0.3	0.05136	0.2	0.03424	0.2	0.03424
				Total:	0.27902	Total:	0.255048	Total:	0.234872	Total:	0.231056

Level 1 Criteria	Level 2 Criteria	Global Weight	Pure Conventional Survey		Conventional Survey with Imagery		Low-cost Photogrammetric Packages		Precise Photogrammetric Measurements	
		(G.W.)	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.	Local Score	G.W.
Capital		0.128	0.094	0.012	0.146	0.0187	0.269	0.0344	0.491	0.0628
Equipment		0.277	0.106	0.0294	0.15	0.0416	0.248	0.0687	0.496	0.1374
Development		0.061	0.163	0.0099	0.163	0.0099	0.278	0.017	0.395	0.0241
Education	Training Staff	0.08489	0.091	0.0077	0.141	0.012	0.237	0.0201	0.531	0.0451
	Client Support	0.0212	0.141	0.003	0.141	0.003	0.263	0.0056	0.455	0.0096
Operation	Complexity	0.0528	0.4	0.0211	0.4	0.0211	0.1	0.0053	0.1	0.0053
	Accuracy	0.1815	0.2	0.0363	0.3	0.0545	0.3	0.0545	0.2	0.0363
	Time	0.0968	0.4	0.0387	0.4	0.0387	0.1	0.0097	0.1	0.0097
	Output	0.0968	0.4	0.0387	0.4	0.0387	0.1	0.0097	0.1	0.0097
			Total:	0.1969	Total:	0.2381	Total:	0.2249	Total:	0.34

Table 5.4.5 (previous page) Application of Benefits hierarchy into decision making process of selecting methodology in deformation monitoring projects

Table 5.4.6 (upper this page) Application of Costs hierarchy into decision making process of selecting methodology in deformation monitoring projects

For the updated benefits/costs ratio (Table 5.4.7):

Alternative	Benefits/costs ratio
Pure Conventional Survey	0.27902 / 0.1969 = 1.417
Conventional Survey with Imagery	0.255048 / 0.2381 = 1.071
Low-cost Photogrammetric Packages	0.234872 / 0.2249 = 1.044
Precise Photogrammetric Measurements	0.231056 / 0.34 = 0.680

Table 5.4.7 Resultant benefits/costs ratios among alternatives

The resultant Benefits/Costs ratios showed the alternative "Pure Conventional Survey" having the greatest benefits over costs among the alternative sets. The accurate measurement process makes the results reliable. However, it would face difficulty, requiring too much manpower and equipment for those complicated measurement tasks, like the Chi Lin Nunnery project. Some particular tests in that project showed photogrammetric techniques with limited resource, like low-accuracy equipment, and unskillful operations in fieldwork, still resulted in some advantages over conventional techniques (roof monitoring). However, it is recommended that conventional techniques be used in other similar tasks.

Chapter 6 Summary, Conclusion and Recommendation

6.1 Summary

This research is a joint research of two partners, the academic side - Department of Land Surveying and Geo-Informatics in Hong Kong Polytechnic University, and the business side – Mannars Chan & Associates.

The above partnering surveying practice has its focus of business on engineering and topographic survey projects. Therefore, the investigated application areas in this research concentrated on typical projects of the company, i.e. 3D visualization model establishment (engineering survey), terrain modeling (topographic applications), and deformation monitoring. The adoption of photogrammetry was investigated by comparing different hardware and software packages in the market together with traditional surveying techniques existing in the company in a systematic decision making process (See Section 2.7). There were four alternative work models: "Pure conventional surveying methods", "Conventional survey with imagery", "Low-cost photogrammetric packages" and "Precise photogrammetric measurements", set up for examining as many different conditions between conventional and photogrammetric surveying methodologies as feasible.

The four alternatives have their own characteristics for comparing their performance in handling the three application areas. "Pure conventional surveying methods" represents the existing techniques within the company, which can maintain acceptable accuracy in general measurements. "Conventional survey with imagery" consists of survey together with some supplementary imagery but without photogrammetric measurements. "Low-cost photogrammetric packages" applies those equipment and software packages in the market (digital cameras and 3D modeling software packages) for performing photogrammetric tasks without high precision requirements. "Precise photogrammetric measurements" applies high end imaging and processing systems such as, Kodak DCS420 digital camera and Helava photogrammetric workstation in this research. The details in different hardware and software applied in alternative applications can be found in Chapter 3 and Appendix A.

For the different hardware and software tools evaluated in this research, the low-cost photogrammetric packages, such as PhotoModeler and 3D Builder, have shown ability in a wide range of application areas (engineering survey and modeling) but with limited accuracy achievement (~20-30mm) when comparing with traditional surveying techniques. The former can accept many different image sources, such as digital and scanned imagery. The use of digital cameras together with the above modelling software packages can provide simple, cheap but rapid solutions. Such solutions cost around HK$10000 for acceptable image resolution (2000×2000) with modelling software. However, these systems need extra care in camera calibration and achievable accuracy to obtain the desired outcome in this issue. Conversely, the precise photogrammetric measurement systems can perform high accuracy results but they are too expensive in general. Most systems cost thousand of hundreds of dollars which the private surveying practices can hardly afford. The applyied imagery is also another problem because those systems require high resolution images to perform precise measurements. Those imagery (thousands × thousands pixels) are over one hundred megabytes in size and would cause problem in storage.

Besides the above major investigation areas, this research also helped the partnering surveying practice in exploiting new application areas through the adoption of photogrammetry into its business. One of the possible areas is the virtual reality presentation. Newly released photogrammetric software packages provide the function of generating their product in a virtual reality environment. Such products were well received by potential clients and deserve more attention. Appendix D shows a proposal of a virtual office environment.

Together with investigating possible application areas for the surveying practice, the technological transfer of photogrammetric knowledge is also important in this research. It is for training the staff to have a basic knowledge of handling photogrammetric projects in future. Besides the fieldwork, a guide of working procedures in handling photogrammetric software package is established. It is attached as Appendix E for reader's reference.

6.2 Conclusion

The four alternatives under testing: "Pure conventional surveying methods", "Conventional survey with imagery", "Low-cost photogrammetric packages" and

"Precise photogrammetric measurements", were investigated and evaluated via the economic issues affecting fieldwork operations, manpower distribution, later processing time, output requirement and achievement of the required accuracy. A well-known analysis process was implemented for this research – Analytical Hierarchy Process (AHP) (Chapter 4) as a benefits/costs analysis study. The above issues (or criteria) are involved to help make decisions on selecting the most suitable methodology in individual projects.

In existing engineering projects (Section 5.2.2), technical issues, such as accuracy achievement, and the resource issues, such as manpower and limited investment, are the important criteria to be considered. Therefore, "Pure conventional surveying methods" and "Conventional survey with imagery" showed advantages over the other two photogrammetric routines. However, the greater the importance of rectified imagery on the resultant model for the application, the more beneficial the photogrammetric methods proved to be in recording/visualization purposes (Section 5.2.3). "Low-cost photogrammetric packages" can provide quick production of the required results deliverable under user-defined precision levels.

For topographic mapping or terrain modeling projects (Section 5.3), there is a more stringent accuracy requirement. Together with large ground coverage, "Precise photogrammetric measurements" (digital photogrammetric workstations) showed definite advantages over the other three alternatives in both technical and economic issues. It should be noted that only the economic constraints of using the system were examined. The cost of obtaining the systems was not included as it was assumed to already exist in the company, like the equipment of traditional survey does. The two conventional surveying alternatives consumed a lot of manpower in fieldwork and later processing, while "Low-cost photogrammetric packages" faces difficulty in matching poor/similar image texture for calculating elevation point. To compare the fieldwork saved through photogrammetric workstation, it costs half the processing time of conventional techniques. However, when the cost of obtaining the photogrammetric systems are included, the net benefit to the company makes this alternative less attractive.

Monitoring building structure (deformation) is a very complicated project by nature and requires very high precision standard (Section 5.4). Unlike 3D visualization model establishment, the monitoring projects require periodical checks and thus measurement techniques of good repetition can earn more benefits.

Moreover, conventional survey provides quick and simple procedures with reliable results but not from the photogrammetric techniques. The resultant precision from conventional method was maintained at 10-20mm but many parts of the photogrammetric survey did not reached this level in the investigated projects of this research. Therefore, conventional survey is still the more beneficial methodology in deformation monitoring purposes, in the studied company.

6.3 Limitations and Recommendations

In the constraint of the Hong Kong private surveying practice, projects are limited in the amount of time that can be devoted to thorough study and preparation. The following problems became evident in this research were treated as limitation or weaknesses, and some recommendations were drawn for any further investigation.

The main weakness in this research is the manual or user-defined establishment of benefits-costs hierarchies. Such arrangement can cause resistance from users not familiar with the process and neglect its use in analyzing the making of decisions in selecting a methodology. It is recommended that an automatic process of analyzing different projects can be adapted to the benefit-cost hierarchies. It means if the project in hand is an as-built survey, the relevant criteria within the hierarchies can be automatically or command keyed in order to justify the project with respect to an as-built option set in the program. Inexperienced surveyors would find the automatic process in the decision support algorithm assists and supports their decision making more deeply.

In a different direction, the limited time in different projects of the partnering company restricted in-depth study of problems generated in the hardware and software applied. Starting from the high-end Helava system, Vexcel FotoG-FMS, to the low-cost PhotoModeler and 3D Builder, there were unexpected difficulties when employed to produce solutions for the case studies. As examples, the unsuccessful terrain modeling in the Tuen Mun highway project, early mislocated points in the Kwai Hing warehouse project and similar problems in the plant revamp project in the Sai Kung swimming pool. Time was too short to try to solve every problem encountered in the projects. This resulted in some of the projects ending without any results in photogrammetric technique to compare with the conventional techniques. Unfortunately, these reduced the reliability of the evaluation and decision making process in this research.

This project is targeted for investigating the technology transfer of digital and close-range photogrammetry into a single private surveying practice. The research coverage concentrates on the specific needs of the company. In general it was found that digital photogrammetry showed advantages over conventional survey techniques with acceptable costs in equipment and staff training for the tasks of 3D visualization model establishment, photographic survey, and terrain modeling. Anyone wanting to establish a wider view of the suitability of digital photogrammetry as an alternative in supplementary measurement tool in a private surveying practice should use the results as a point of reference only and make a wider study of the land surveying market.

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Appendix A: Calculation of Maximum Eigenvaule and Eigenvector (Olson, 1996)

The following is an example showing the computation of a selected problem using decision matrix in the concept of eigenvector:

For the matrix:

$$\begin{array}{c} \\ X \\ Y \\ Z \end{array} \begin{array}{c} \begin{array}{ccc} X & Y & Z \end{array} \\ \begin{pmatrix} 1 & 5 & 9 \\ .2 & 1 & 3 \\ .111 & .333 & 1 \end{pmatrix} \end{array}$$

The eigenvector technique would require solution of:

$$\begin{pmatrix} 1 & 5 & 9 \\ .2 & 1 & 3 \\ .111 & .333 & 1 \end{pmatrix} - \lambda \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 4 \end{pmatrix} = 0 \text{ yielding } \begin{pmatrix} 1-\lambda & 5 & 9 \\ .2 & 1-\lambda & 3 \\ .111 & .333 & 1-\lambda \end{pmatrix} = 0$$

This can be solved by determinants, yielding the formulation:

$$(1-\lambda)^3 + 5/3 + 0.6 - 3\,(1-\lambda) = 0$$

which simplifies to $\lambda^2 (3-\lambda) = -0.26667$

This is a cubic form, meaning that there are three solutions for λ. Not all of these solutions have to be real numbers, but Saaty established that the **maximum** value for λ (λmax) will be a real number, and will also be $\geq n$. For perfectly consistent matrices, λmax =n. For this problem, a search will yield λmax =3.02096. The consistency index is (λmax –n)/(n-1). For this matrix, that would yield 0.015, a very consistent matrix. The other two solutions for λ in this problem are complex numbers: -0.014532+0.29635√(-1) and -0.014532 -0.29635 √(-1).

Once λmax is determined, the eigenvector of weight can be obtained by solving the set of n simultaneous equations. For each row of the pairwise comparison matrix *A*, $Aw = \lambda max^{w}$.

$$1w_1 + 5w_2 = 9w_3 = 3.02906w_1$$

$$.2w_1 + 1w_2 + 3w_3 = 3.02906\ w_2$$

$$1/9\ w_1 + 1/3w_2 + 1w_3 = 3.02906w_3$$

An additional requirement is that $w_1+w_2+w_3$. Because any two of the first three equations (in general, *n* equations) contain all the necessary information, one of them can be deleted, and replaced with the additional requirement, thus yielding a system of *n* equations in *n* unknowns, which can be solved many ways, including linear programming. In this case, the eigenvector of weight is:

w_1 =0.751405;

w_2 =0.178178; and

w_3 =0.070417.

Appendix B. Conventional and Photogrammetric Survey Equipment in Hong Kong

B.1 Common hardware application

The conventional surveying methods are for collection of information through direct measurement process in fieldwork. The common equipment is electronic total stations and level in vertical (height) measurements.

The common total stations applied in Hong Kong private surveying companies are mainly from Aga Geodimeter (Fig.B.1.1), Topcon, and Leica (Wild-Leitz), which are specialists in developing these types of measurement equipment. The precision of reasdings in those total stations is around ±1", while some of them are lower, around ±5" for the different purposes in applications. The applications areas for total-stations can be hydrographic survey, topographic survey, setting out, and as-built survey. Such instruments from foreign companies range from a few ten to a hundred thousand Hong Kong dollars. However, the more rarely applied theodolite – gyrotheodolites are much more expensive, especially the modern automatic models, like from Leica (HK$500,000 and up).

Fig. B.1.1 Aga Geodimeter 444 (Burnside, 1991)

Back to the EDMs, there is a type of EDM using infrared radiation mounted on a theodolite which acts as a special total-station for some applications. It is the non-reflective type of EDM, like Wild DIOR 3002, which can derive distances without the use of retro-reflectors at ranges up to 250 meters (Fig.B.1.2). The resolution of this equipment is ±5mm but there are other factors affecting the resultant accuracy, like the feature of the features and configuration of the network in fieldwork. The author will describe the application of this non-reflective EDM with photogrammetric technique in the Tuen Mun Highway expansion project (Section 5.3.3). The instrument can range up to an average of 200m but depends on the nature of the natural surface being used for reflection. An accuracy of between 5 and 10mm is quoted (Burnside, 1991).

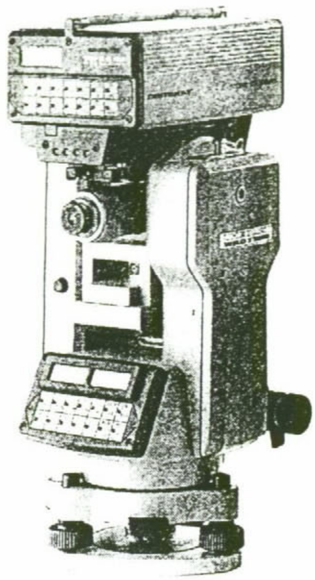


Fig B.1.2 (left) Leica DI-3000 (Burnside, 1991)

Beside total-station, a level is the next mostly commonly applied equipment by land surveying companies. It applies the differential leveling concept to determine the differences of elevation between two points. With the use of a spirit level and a rod, the accurate measurements of the stations can be achieved. For more precise data requirements, a well-know method in leveling technique is commonly applied in private land surveying companies in Hong Kong. It is called precise leveling, which requires the mounting of an optical micrometer on the ordinary level. It is to obtain more precise readings for determining any difference on the objects. The accuracy of readings can be up to 0.00001m for those precise levels.

Level measurements are traditionally manually booked on data sheets but computer automation has become involved in the instrument and later processing, such as electronic digital levels and data loggers. The digital level uses a barcode rod instead of traditional ones with metric scale (Fig .B.1.3 and B.1.4). Through the infrared radiation sensing and digitizing the incoming images, the microprocessor with the level can detect the reading on the barcode rod at the centerline. The standard deviation is stated to be ±1.5mm for a double run of levels over 1km (Bannister et al., 1992). Moreover, the horizontal distance to the rod can also be measured at a precision of 3-5mm per 10m because of the concept of tachometry. Therefore, a more precise measurement process can be achieved.

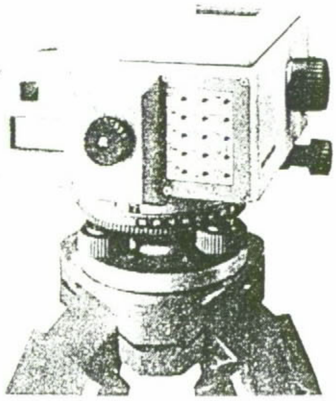


Fig.B.1.3 (left) Wild NA2000 digital level. (Moffitt and Bossler, 1998)

Fig.B.1.4 (right) Barcode on leveling rod used with digital level. (Moffitt and Bossler, 1998)

The prices of different models of level do not vary a lot. The models from well known foreign measuring science equipment companies cost around a few to ten thousand dollars (digital levels). In contrast, the levels manufactured in Mainland China cost around two thousand dollars only. This is very reasonable for such precise instruments.

B.1.1 New hardware adoption

- Laser instruments:

  The laser radiation technique is applied in instruments for drainage work or work on compact, level surfaces like car parks and floor slab construction. There are two major types in usage: the rotation laser and the pipe laser. First, the laser tube in the rotating laser is mounted vertically in the unit, and an extra sensor attachable on level staffs can be employed to detect the level. The instrument is also self-leveling to within 15° of horizontal.

  Second, the pipe laser is always set up in a manhole or the end of the pipe to provide alignment with the emission of laser rays. Similar to rotating lasers, the modern pipe lasers can also be self-levelled and then aligned for directions within around 15°. The latest model of such laser instrument claims that it can achieve a precision of ±3mm per 30m.

  The laser alignments described above range from a few to ten thousand HK dollars, and thus there are increasing opportunities from various disciplines to apply them in their tasks. Their greatest benefit is their ease of operation and acceptable accuracy for general applications.

- GPS systems

  GPS has become a popular application method in private surveying companies of Hong Kong. There are two major techniques for tasks applying general GPS systems: static and kinematic positioning. The two techniques have been commonly applied in various private surveying practices in Hong Kong. The costs for GPS receivers are continuously reducing, and the small private practices can also gain benefits from its mobility, quickness, and accuracy with reasonable prices (a few tens of thousand of Hong Kong dollars).

  A newly developed technique with the advanced usage of kinematic positioning is called the real-time kinematic (RTK) GPS positioning. It can perform measurements of cm-level accuracy in real time. Its advantage is the omission of post processing because of the real-time collected data.

However, its major disadvantage it that it requires a direct communication link, which makes the system more expensive and more difficult to implement (over HK$500,000). It is not quite affordable for private surveying practices in Hong Kong to buy such systems because of their high costs.

B.1.2 Software

The formerly described measurement systems are the hardware to collect required information in individual projects. Unlike the need for manual calculation for the result in the past, the surveyed data can be handled through engineering software packages, which can transfer the raw data into computers, and process and present the result in the desired format. Furthermore, the influence of such software package can be observed in most operation procedures in the surveying companies. Firstly, feature codes (symbols) provided by the packages are applied in fieldwork stages to save production time. Secondly, the data transfer also requires software. Thirdly, the later processing and presentation are mainly under the environment of computer software to improve the quality.

There are a variety of engineering software packages applied in Hong Kong private land surveying companies, such as InSurvey® and GeoComp®, CivilCAD®, AutoCAD™ and MicroStation™ (around HK$10,000-20,000). Some of them can download data from compatible total-stations or digital levels (e.g. InSurvey and GeoComp) and then convert them into the suitable format. Some others may even process least square adjustment for which redundant measurements were considered necessary to obtain more precise results. The first two can carry out all the required procedures, which are feature code application, data transfer and later processing, for individual projects. The last three packages are for later processing and presentation, like CivilCAD which concentrate on civil engineering projects. When the private surveying companies are involved in various projects, like topographic, engineering and hydrographic survey, they will purchase packages in different specialties to maintain the speedy production of the projects. The fact that their surveyors are trained to handle the various packages guarantees the competitive power of the companies.

For many GPS systems, they will provide the softcopy linkage from their instrument to computers together with some post-processing software packages. However, it has been more common for the application of network adjustment processes to enhance calculated results from the observations. Besides the above processing package, there are pure least square adjustment programs on the market and one of the famous packages is called STARNET® (a few thousand dollars). Either traditional survey or GPS projects can also be performed to provide adjustments in observations. It would be an advantage for surveyors to handle GPS tasks when they have relevant knowledge to implement their results.

B.2 Photogrammetric Equipment

The hardware involved in photogrammetric measurements, digital photogrammetric systems and data acquisition devices are under this category. A digital photogrammetric systems is a computer workstation originally designed for handling massive, large area, and complicated terrestrial (topographic) photogrammetric measurements from the past. However, current common computer systems can handle up-to-date photogrammetric software packages, like Windows NT.

A digital photogrammetric system is to handle the input data digitally and perform the calculation and presentation with the aid of mathematical models. However, there are differences in this revolution between aerial and close-range photogrammetry. Due to the necessity of the huge size of sensors in imaging system for aerial applications, the data acquisition process is still concentrated on applying film cameras (large format metric cameras)and then scanning them into digital forms for further processing (Atkinson, 1996). The computer systems designed for such processing require large memories and high-speed processors to solve bundle adjustments and feature extraction, which are commonly understood as important procedures in aerial photogrammetry. In comparison, more cameras are suitable for close-range projects, as the restriction of area coverage in those works is of less concern because of the larger are of CCD sensors. Furthermore, the high cost of precise scanning systems together with highly precise measurement systems in topographic mapping through photogrammetric techniques prohibits many potential users from investing. However, those systems are getting cheaper as the computer technology is advancing.

Besides the software package running in the computer workstation, there are specially designed peripherals for controlling the systems. First, the must be able to reach sub-pixel measuring ability to improve the accuracy. The common devices applied are for example: a digitiser, and a mouse together with stereoscopic display devices in 3D measurements (e.g. crystal Eye glasses and polarized glasses). However, the low-cost commercial packages may not provide the stereoscopic display function and most measurements within need to be determined by the users themselves. Second, the storage capacity in the computer must be huge because images generally require large disk space; for examples, a digital camera image with resolution of 1524x1012 is already 4 megabytes in size (TIFF format). Those scanned images can be much greater as the resolution increases.

B.2.1 Data acquisition devices

In applications of digital photogrammetry, two main data acquisition devices are used: digital cameras and computer scanned photos. Having a comparison between them, the digital cameras, which sense the scenes directly with the aid of charge couple devices (CCDs), can have a quicker access in data transfer into DPSs. On the other hand, the scanned film images can have a higher and more flexible resolution for determining details.

B.2.1.1 PhotoModeler

The PhotoModeler software is divided into two streams: Pro 3.0 and Ver 2.1. For Pro 3.0, its tasks may involve texture-mapping purposes, like 3D database, architectural recording, image reengineering etc. The operation will be a bit more complex than Ver 2.1. The Ver 2.1 is mainly for exporting DXF format products. The biggest weakness of Ver 2.1 is the necessity for the manual locating of camera stations. This process can give an approximate location for camera stations, but in a longer time. It is because the best location requires a lot of trial and error to get the final positions of the cameras.

In the control information requirement, no object space co-ordinates are needed to be located in simple measurements. However, it is essential that control points exist in the project if high precision measurements and results are expected. Both the above versions provide three levels of precision of user controlled information that can be added into their projects: basic baseline scaling, baseline with know directions of co-ordinate axes, and precise control import. Firstly, the basic baseline scaling is for simple modeling purposes with coarse dimensions required. Secondly, the baseline with know directions of co-ordinate axes can improve the orientation results within the algorithmic calculation. Thirdly, the adoption of control points can best provide highly precise result in the project.

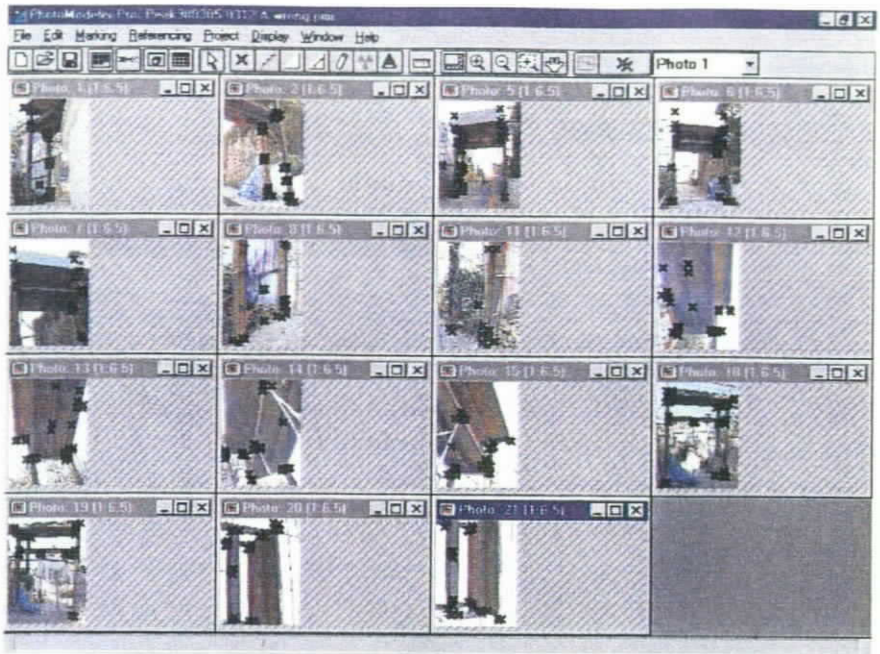


Fig.B.2.1 Setup of the Peak project in PhotoModeler Pro 3.0

The relationship of individual points in various images is the first "key" factor when performing a calculation. The photo coordinates of each point relating to different perspective centres (different camera stations' position) are recorded. Through the bundle block adjustment, the resultant co-ordinates of each point can be computed. The aid of self-calibration by several known control stations (or known 3D distance) and camera parameters are also very important. The following are the major features from the manufacturer: (PhotoModeler, 1999)

- Works with numbers of photographs,
- No need to input point positions, angles, distances, or axes,
- No need to input camera positions,
- Many image formats for input,
- New photos may be added at any time,
- New details from photos may be added at any time,
- Professional quality assurance tools,
- Many formats for 3D data export,
- Texture and colour mapping is available,
- Supports images larger than 16Mb,
- Advanced modeling tools: cylinder and curve drawing tools,
- Inverse camera feature (reverse engineering),
- Orthophotos generation, and
- Single photo capabilities.

The following are two images of resultant 3D models established in PhotoModeler Ver 2.1 and Pro 3.0 respectively. They can represent the two major outputs of low-cost photogrammetric software package nowadays (Fig.B.2.2 and B.2.3).

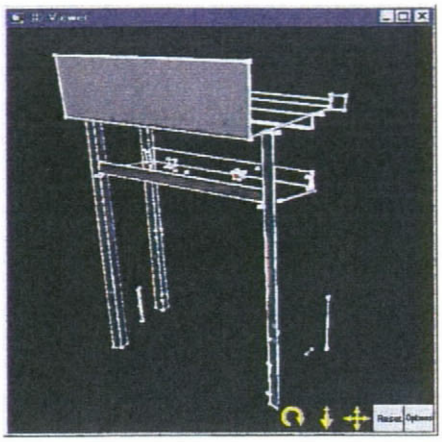


Fig.B.2.2 (left) 3D preview in PhotoModeler Pro 2.1 showing CAD model
Fig B.2.3 (right) 3D preview in PhotoModeler Pro 3.0 showing VRML model

B.2.1.2 3DBuilder

The 3D Builder is divided into two classes: Pro and Powerlite. The Pro version provides all of the functions of the design. The major advantage is in texture mapping for the resultant 3D model. Single camera set-up is also practical because the co-ordinate axes are required. The calculation can then accord to the configuration to provide the result. Common multi-image geometry requires recognition of the same point in different images. The following diagram (Fig.B.2.4) shows an example:

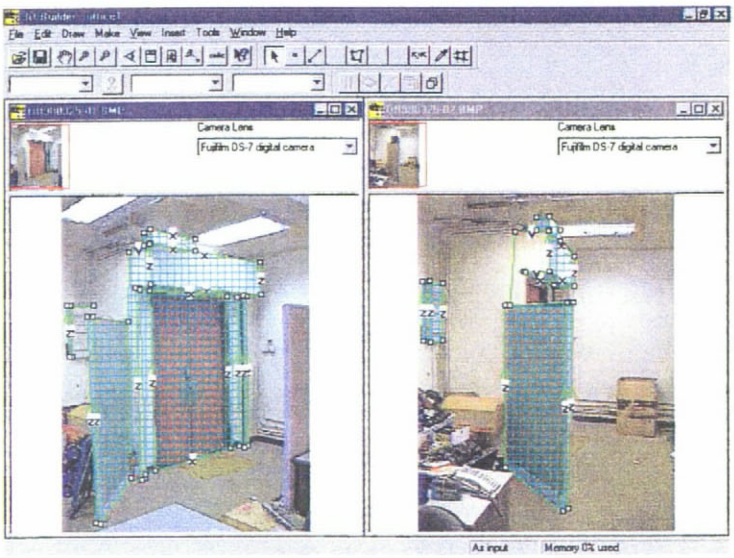


Fig.B.2.4 Screen showing setup in a project of 3D Builder

This software package is under the development and publishing of 3D Construction Company in the USA. The generation of a 3D model is based on points measured before the computation. Drawing tools are limited to modeling regular shapes only. However, texture mapping makes the software useful in image reengineering tasks, like virtual reality. The following are major features from the manufacturer: (3D construction, 1999)

- Works with one or an unlimited number of photos (Pro version only and limited by memory available),
- No need to modify camera in any way,
- Can work without known points, distances or lines,
- Photos may be inserted into the project at any time,
- Camera positions do not need to be know or surveyed,
- Lenses may be fixed in the project,
- Wide angle lenses can be used as well as close-up lenses,
- Works with scanners, digital cameras, video cameras as well as 35mm film cameras,
- Exports DXF, 3D Studio, VRML, Inventor, IGES and Wavefront file formats (partial for Powerlite),
- Creates textures and colours directly from photos for a seamless interface with rendering package,
- Different drawing tools: points, lines, coordinates axes, polygons mesh directly on photos. A modification feature is provided for editing or repositioning,
- Geometric constraints can be applied, like coplanar, collinear or equal length (Pro version only),
- Lens calibration program provided (Pro version only).

The configuration of a project in 3D Builder is basically according to the co-ordinates axes assigned. Once they have been located, the software can have basic reestablishment of object-space coordinate axes for the working project. The measurement process of the image points is to reference the same point from different images visually. This is the major reason human error occurred in resultant residuals. Images of the same point from different angles may have been mislocated. Thus, large residuals may occur in the final result. It is recommended that model points should be selected from the fewest intersecting angle viewpoints.

In the image measurement stage, polygon meshes are used in different ways: triangular, regular and irregular quadrilateral, and multiple line polygons. Although the computation is still in triangular method (split the polygons into numerous triangles for calculation and image matching), the processing speed can be improved when handling large objects with irregular shape. A maximum of 800 points was recorded in an individual set-up for the Pro version. It is mainly limited by the memory available of the working computer. For the Powerlite version, objects under 200 points can be practical because it is the maximum number of model points. Moreover, the Pro version provides a more powerful varirty of export formats, like VRML format only. Fig. B.2.5 shows a 3D preview of a product with texture mapping:

Fig.B.2.5 3D preview in 3DBuilder to show the resultant model

B.2.1.3 Vexcel FotoG-FMS

FotoG-FMS is one of the photogrammetric products from Vexcel Company in USA. It provides an alternative for engineering and industrial applications, which are major disciplines in close-range photogrammetry. It is a MicroStation, AutoCAD or CAD independent version, which eliminates the tedious process of measurements and the post-processing to load into a CAD package. The model establishment process is directly under CAD environment. It gives an instant checking of the products by the operator also experienced in CAD tools. The reporting and error checking software provides feedback that permits evaluation of the quality of results, and qualifies the measurement accuracy to be expected.

The FotoG-FMS software has the following capabilities: (VEXCEL, 1999)

- Unlimited number of photos per project but up to 50 per block,
- Tag functions to aid in the management of large projects,
- Cylinder, edge, and steel modeling tools,
- Capability to overlay the CAD model on top of any image to ensure model

completeness,

- Provides users with the flexibility to use a variety of imaging technologies- e.g. digital cameras, conventional film cameras and video cameras,
- Control information (needed to accurately scale 3D measurements) requirements are minimal and can be input or generated by the software,
- Photogrammetric processing rather than full automatic computation of other software packages,
- Built-in image processing options to enhance image quality,
- Camera self-calibration routines are provided,
- Works independently of any other software packages,
- Fully interactive access to all CAD drawing tools. The photogrammetric measurements are passed directly to the CAD system. This allows the capture of highly complex areas.
- Software Configuration and Analysis.

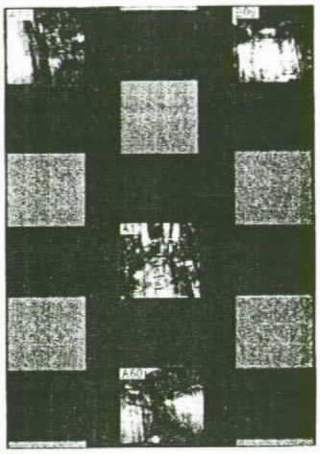
For the number of photos in a project, it is unlimited but a maximum of 50 per block. The term "block" is similar to "strip" in photogrammetric usage. Most projects involving the close-range technique have convergent photography rather than parallel shots. It will be less common to have 60-80% parallel overlapping in close-range applications than in aerial tasks. Most shots come from different incident angles from the object. On the other hand, control points information is essential in FotoG-FMS because they are a must in the absolute orientation process. A minimum of 4 control points must be established in every group of photographs (2 to 50), i.e. at least 4 controls are needed per block. Unlike the automatic calculating algorithms of other software, a fill routine in photogrammetric procedures should be followed within FotoG-FMS. It shows that minor parts in the processes can be corrected.

Through the "residual meter", we can evaluate the liability of points selected as tie points in each pair. We can have improvement in the point measurement process of those points or choose other points in the worst case for high residual ones.

For the procedures within the calculation, the FotoG-FMS cannot provide various lenses of photos in the same project. This is because of configuration in the set-up of the software. On the other hand, any non-metric or digital cameras lens calibration needed should be processed before the calculations. The software provides only the input of cameras parameters (including distortion parameters).

There is no calibration program for obtaining the initial data. Self-calibration routines are used in the computation (bundle block adjustment) for providing a reverse engineering property in the results. Similar to those high-end photogrammetric workstations, the FotoG-FMS has the whole flowchart of operations according to the concepts of photogrammetry:

- Interior orientation,
- Exterior orientation (relative and absolute),
- Block formation, and
- Bundle block adjustment.



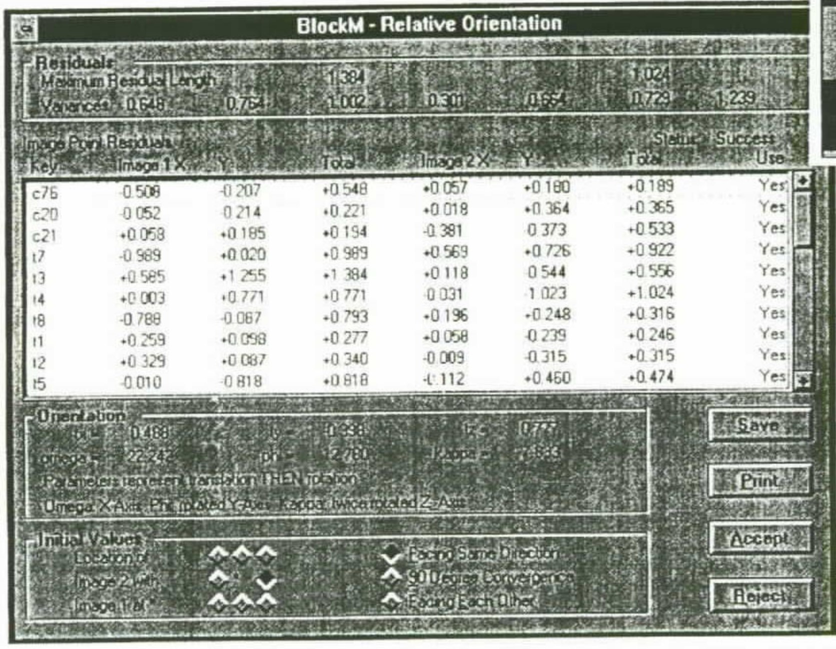


Fig.B.2.6 (right) A Series if images formed a "block" in FotoG-FMS

Fig.B.2.7 (bottom) Relative orientation scene in BlockM of FotoG-FMS

The interior orientation needs the camera parameters. Like focal length, dimensions of sensor, principal point location and lens distortion parameters. For those film cameras with reseau information, the locations of fiducial marks are needed. Before the relative orientation, point measurements are necessary for linking the two adjacent images (Fig.B.2.6 and B.2.7). For precise location of control points, the function of automatic target location detection can be applied. After the initial part of exterior orientation, the latter part – absolute orientation and block formation follow. The block formation is to connect all the images within the same "block" and do preparation for transformation of object space information into the block. The last process – bundle block adjustment acts as a refinement of the block model through a simultaneous least square adjustment to the geometric parameters of the photogrammetric bundle. This is accomplished by shifting the camera positions and orientations and the locations of ground control points to uniformly distribute errors, which exist in the block. It can provide an overall minimum error solution at the expense of localized increases in error. This step will not add information to the solution but modifications or refinements may be input into the solution. The bundle adjustment can have two effects on these results; first, to distribute residual error among all measured image co-ordinates and also among object points. Of most interest is the residual error associated with control and checkpoints for which co-ordinates are know prior to the adjustment. Second, to redistribute error from the object space into the image space or vice versa. This represents a trade-off between precision and accuracy in the final data collection.

- 3D Modelling:

  The FotoG-FMS has its image measurement and analytic stage independent with other software. This is to eliminate tedious processes in measurements. However, in the 3D modeling process the software has direct access to the CAD environment. The concept is to establish the 3D model through computation of adjacent images before the determination of 3D co-ordinates of points. It provides an instant presentation of results of the project. The functions of CollectM in FotoG-FMS provide various drawing techniques for the engineering and industrial applications (Fig.B.2.8). This is to collect three-dimensional points, edges and cylinders that are placed into the CAD design file. Another module is PipeM to deal with modeling of pipes, I beams, L beams, C beams etc. This is all accomplished by clicking on the

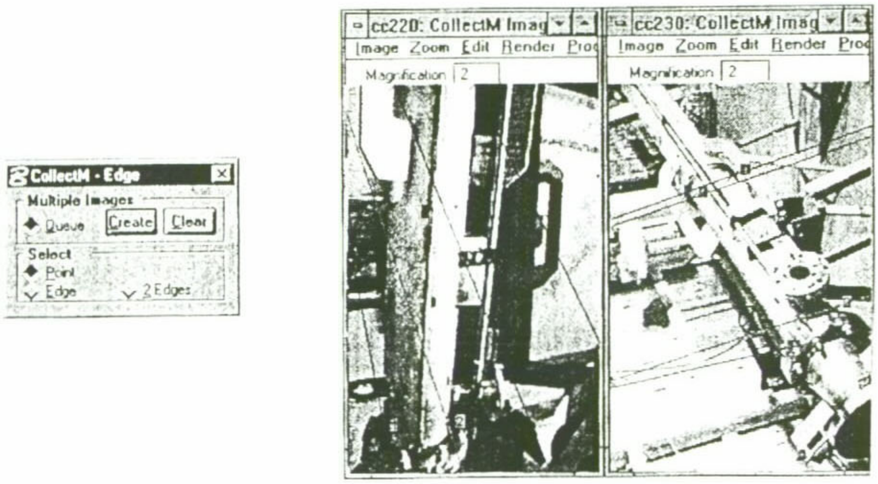


Fig.B.2.8 The scene showing the edge creation in CollectM same point in two or more images. If a second 3D point is measured, its co-ordinates will also be found as well as the 3D distance between the first and second points. The co-ordinates of the points or of the line connecting the points can be placed into the CAD model.

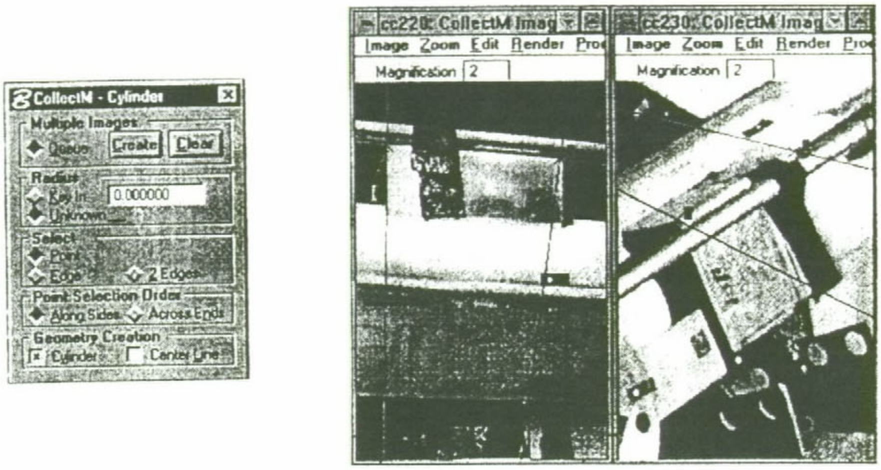


Fig.B.2.9 The scene showing the cylinder creation in CollectM

After the rendering of the 3D model, any images can be overlaid on it by using the Render menu of that image. This is for overlapping both materials to form photomap (product from orthophoto generation). Hence, the lack of orthophoto generation within the software can be overcome through this alternative method. Moreover, the rendered model will be more suitable for engineering and industrial applications according to their special configuration and requirements. This is because most tasks in these disciplines need 3D models to examine the situation of plants or industrial areas.

According to the configuration and requirement from the software, the following applications will have the most benefits:

- Engineering as-built survey.
- Industrial precise survey: 3D modeling for plant revamp, deformation monitoring, etc.

However, the area of terrain modeling is not very suitable for FotoG-FMS. One of the reasons is that the drawing tools in software concentrate on point and line modeling.

A.2.1.4Helava PPW700

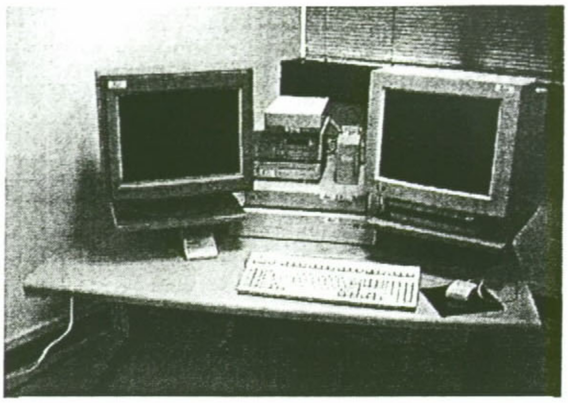


Fig.B.2.10 A scene showing the set up of a Helava system

Helava is especially designed software for digital photogrammetric applications (Fig.B.2.10). It is mainly for aerial tasks but can also be used for close-range applications. It has the full procedures of the whole photogrammetric production run-down. In the later procedures of the Helava systems, it provides the function for different applications, like orthophotography for cartographic purpose, or GIS purpose. It also provides the programming capabilitu for users operation in their requirements. From Georgiou and Vozikis (1999), the photogrammetric applications inside Helava system include:

- Stereo visualization,
- Automated triangulation,
- Automated generation of digital terrain models (DTMs),
- 2D and 3D feature collection including semi-automated tools,
- Orthophoto and mosaic production,
- Image maps,
- Photo interpretation,
- Mission planning and rehearsal simulations,
- Virtual reality,
- Close-range / industrial measurement,
- Processing of aerial, panoramic, SPOT, Landsat, IRS-1, JERS-1, ERS-1, Ers-2, RADARSAT and close-range imagery,
- Import and export of a wide range of popular formats of imagery, orientation parameters, block adjustment data, DTMs and features,
- Grid and TIN DTMs,
- Perspective scenes, fly throughs, walk throughs.

The software does not have the camera calibration function of most DPSs, the users have to input lens distortion parameters by themselves. Moreover, the data computation method is based upon photogrammetric techniques. The orientation procedures are in sequence and thus planning is preferred before the start of operation.

like choice of cameras (metric or non-metric), digital vs. scanning, and control points establishment.

The Helava software concentrates on large-area photogrammetric applications. The major applications are for mapping purposes, like orthomaps or photomaps. The software mostly provides determination of land information. However, handling close-range applications can also be feasible. Through some extra orientation software packages, it is able to provide tools and algorithms that can accommodate irregular geometry occurrences in close-range tasks.

Appendix C. VRML

The Virtual Reality Modeling Language (VRML) is a commonly applied programming language in the 3D modeling arena. Because of the development of Internet to present 3D features, together with 3D games, animation, and etc., the application of virtual reality presentation provides many opportunities in program development. VRML is one of the programs developed which can build virtual reality models with coloring or texture mapping effect to demonstrate the desired simulation.

VRML is a text-script language, which can provide many different functions to create objects, textures, and presentation methods. The language has been developed to the third generation: currently VRML 2000. The commonly applied older versions are Ver 1.0 and 2.0 chronologically. The photogrammetric software packages investigated in this research can be adapted to those two older versions well, like PhotoModeler and 3D Builder. As discussed in the relevant chapter, the generated model from those packages is the frame model only. If the texture mapping is required, the programming language is needed to combine two into one. There are many technical books on the market providing the algorithm for texture mapping in VRML.

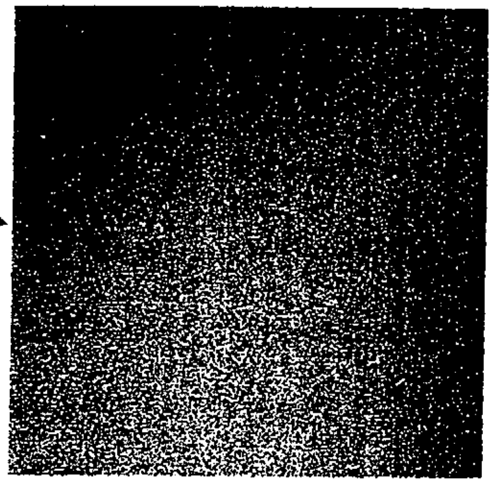
Luckily, there are programs arising to help users solve the programming problem. One of the introduced software packages is called 3D Webmaster. It is based on another virtual reality programming language called SVR. However, it also adapts VRML models and provides users with the texture mapping function through simple commands from the menu. The 3D Webmaster costs around HK$150 for its updated version. It provides VRML import but not export function, and thus the output file format is set to SVR only, which requires plugin browser to be present in the web.

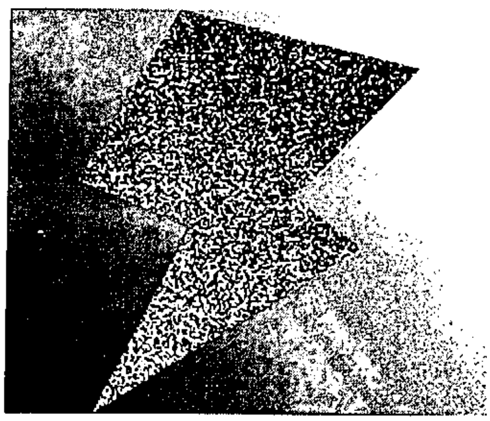
For the program codes that handle texture mapping functions of different shapes, the following are the fundamental code linking the frame models with the image textures: Box, Cone, Cylinder, Sphere, Text, PointSet, IndexedLineSet, IndexedFaceSet, ElevationGrid, Extrusion

The first fice are for frame models of simple and regular shapes, while the latter five can hable irregulat, complicated, and multiple-surface models, which are the areas of major concentration in this research. The previously described porjects are mostly complicated and irregular in shape, like the seawall project and plant mapping project in the Sai Kung Swimming Pool.

However, those who are interested in the above or relevant programming codes can find further details in the references list. The author provided an example from Ames et al. (1997) showing mapping image textures onto face-set shapes, which is relevant (but simplified!) to most engineering projects discussed in this research:

```
#VRM  V2.0  utf8
Shape  {
        appearance  Appearance {
                material  Material {  }
                texture  ImageTexture  {
                        url  "bolt2.jpg"
                }
        }
geometry IndexedFaceSet  {
        coord Coordinate  {
                point  [
                # Lighting bolt tip
                        0.0 0.0 0.0,
                # Front perimeter
                        5.5 5.0 0.88,
                        4.0 5.5 0.968,
                        7.0 8.0 1.408,
                        4.0 9.0 1.584,
                        1.0 5.0 0.88,
                        2.5 4.5 0.792,
                # Back perimeter
                        5.5 5.0 -0.88,
                        4.0 5.5 -0.968,
                        7.0 8.0 -1.408,
                        4.0 9.0 -1.584,
                        1.0 5.0 -0.88,
                        2.5 4.5 -0.792,
                ]
        }
        coordIndex  [
        # Front
                0,  1,  2,  3,  4,  5,  6,  -1
        # Back
                0,  12,  11,  10,  9,  8,  7,  -1
        # Side
                0,  7,  1,  -1,
                1,  7,  8,  2,  -1
                2,  8,  9  , 3  -1,
                3,  9,  10,  4  -1
                4,  10,  11,  5,  -1
                5,  11,  12,  6,  -1
                6,  12,  0,  -1
        ]
        convex FALSE
```





Appendix D. Constructing a virtual office environment

Project Title: 3D Virtual Reality Simulation of Interior Office Environment

Location: Partnering company office

Objective: Investigate the functionality of 3D modeling package (3D Builder), and the feasibility of simulating interior office environments under limited number of exposures for the simplest but acceptable resultant 3D model

Equipment: Low-resolution digital camera (Fujifilm DS-7), 3D modeling package (3D Builder), and a tape measure.

Procedure(s):

1. Due to the special situation of the office environment (limited space), convergent network was considered to be the best method for photography (Fig. D.1).

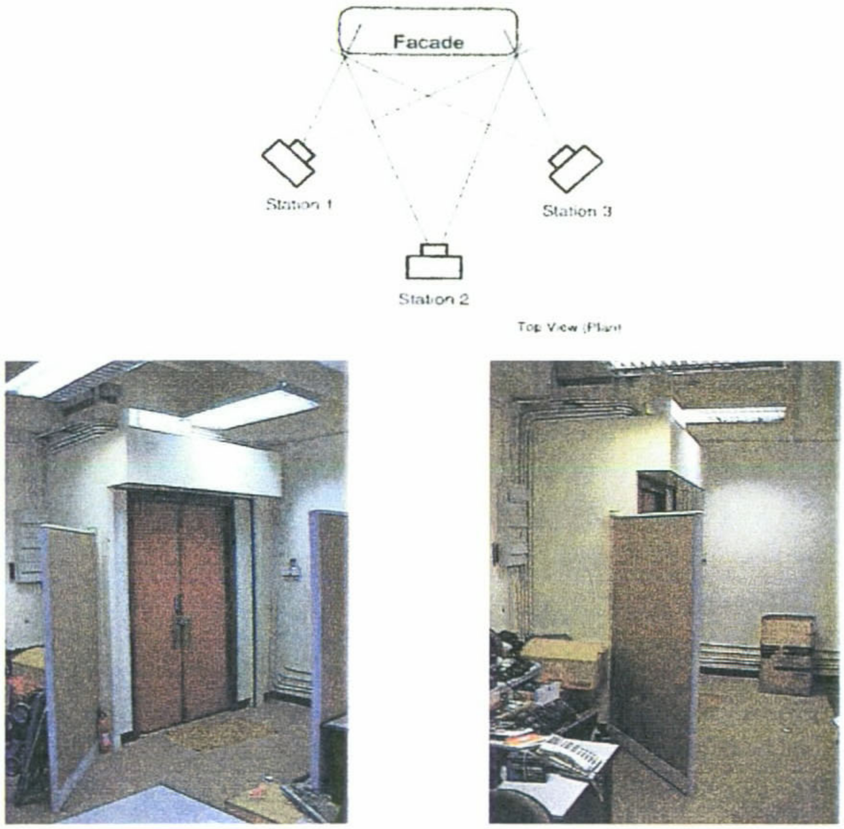


Fig. D.1 Camera Network and sample images

2. The two photos (above) were used for investigation in this project. Their acute convergent angle (<45°) degraded the accuracy of the details to be modeled because of lacking redundant measurements, and too similar rays on model points.

3. After taking images, they were downloaded from the digital camera onto a PC. Most digital cameras on the market provide speedy and simple data transfer process (like laplink cable,

memory card, floppy adapter or USB plug) to computers.

4. The images were imported into the 3D modeling package, i.e. 3D Builder in this project. These modeling packages required manual digitization of features onto respective images. Having more than one image of features appearing, the model points describing the same feature were referenced among the images applied in the same project. (Fig. D.2)

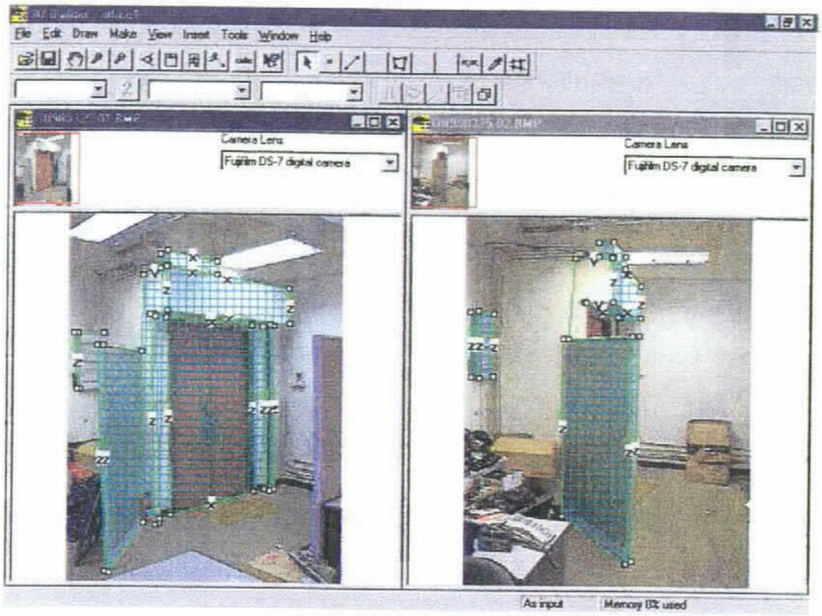


Fig. D.2 Dump-screen from 3D Builder

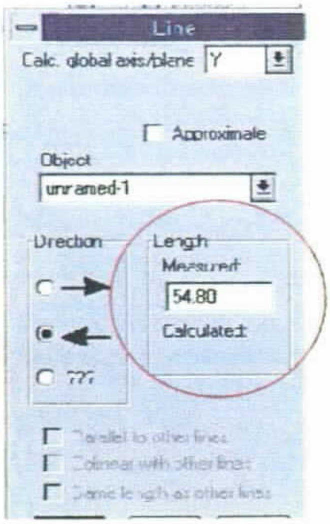
5. The level of details within the digitization process carefully considered. Digitizing excessively detailed features would only increase model points quantitatively but not qualitatively. This is because the client requirement may not include centimeter zed objects having too many surfaces. In this project, the Exit lamp and electric switch box have too few points roughly describing their shapes. (Fig. D.3)

Fig. D.3 Features Digitizing

The digital camera used in this project was a very low resolution one (640×480). The detail features cannot be provided via its imagery except extra detail shots for particular areas of interest.

6. Using 3D Builder in modeling purposes had a benefit over PhotoModeler. Features appearing on a single image still had a 3D model generated through the application of rotation axes on different features (previous figure showing setup in 3D Builder).

PhotoModeler required at least 2 overlapping photos on the same feature to calculate the location of model point.



7. A few distance measurements were applied (don't need all!) from existing features to provide in-scale dimensions of resultant 3D models. In this project, a tape measure was used to collect actual dimensions of the door for scaling. 

Fig. D.4 (right) Distance Measurement Toolbox

8. Calculation was simple within 3D Builder by clicking the button only. Results were checked to compare the computed dimensions with the originals. The precision of model points were viewed as percentage of error between input and calculated. (Fig. D.5)

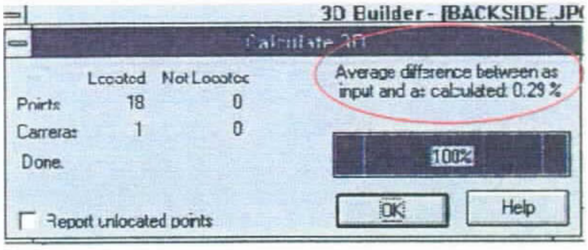


Fig. D.5 Calculation Toolbox

9. The output 3D model was previewed within 3D Builder with the aid of its function of 3D Preview. If texture mapping had been necessary, images can be added onto specific surfaces very effectively.

   The resultant model could be exported to other VR model formats, like VRML and 3DS (3D Studio) for further implementation.

Result(s):

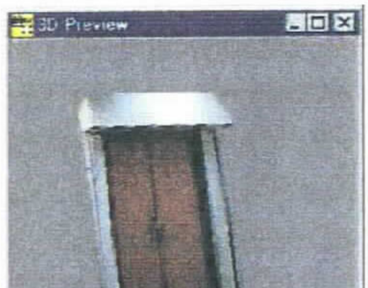


Fig. D.6 Resultant Preview in 3D Builder with texture mapped

The resultant precision of resultant model of this project was 50mm in average (Fig. D.6). Those model points with lower precisions resulted from poor image quality during the point measurement process in 3D Builder. The specific precision of model points on the door was 20mm. On the other hand, there were a few erroneous points at the bottom partition area because of the acute convergent angle between the two images applied in this project.

Digital camera and modeling package in this project were both economical models that cost not more than HK$10000 in total. The total processing time of this project was a half of a man-day. However, the total number of model points was lower than 50 (20 something actually). It could be considered in some application areas but more complicated situations may not be suitable.

Appendix E. PhotoModeler 3.0 Working Guideline

E.1. Preparation

For PhotoModeler handling tasks, there are five considerations within the Preparation Stage:

- camera parameters computation,
- camera calibration,
- software requirements,
- rays intersection, and
- control information.

E.1.1 Camera parameters

In relevant applications through such simple photogrammetric software, DIGITAL cameras are widely used as data acquisition devices. Their CCD diagonal dimensions can be obtained from manufacturers, eg. ½", 1/3" or 2/3". The X, Y dimensions can then be computed with the aid of pixel resolution (most cameras manufacturers state this when promoting their products, like 1280*1024 or 640*480). The computation is as follow:

$$\frac{Py}{Px} = \frac{Y}{X}$$

$$X^2 + Y^2 = Z^2$$
$$(P_y X)^2 + (P_x X)^2 = (P_x Z)^2$$

$$\therefore X = \frac{Px}{\sqrt{Px \cdot Px + Py \cdot Py}} \cdot Z$$

$$\therefore Y = \frac{Py}{Px} \cdot X$$

where X & Y = X- and Y-dimensions of CCD sensor
Z = Diagonal dimension of CCD sensor
Px & Py = Pixel resolutions of CCD sensor

For an example, Px = 1280
Py = 1024
Z = 2/3" = 16.93 mm
⇒ X = 13.22 mm
⇒ Y = 10.58 mm

i.e. The dimensions of the CCD sensor are 13.22 mm and 10.58 mm respectively.

Thus, we can use the above parameters together with camera focal length (by manufacturer) to input in the software in the initial stage.

Remark: all the above parameters are necessary in software operation.

E.1.2 Camera calibration

After retrieving the camera parameters, we may need to run the PhotoModeler's Calibrator. It is used to obtain the lens distortion parameters for maintaining accuracy in later computation processes. The detailed procedures are described in "Procedures in handling Calibrator".

E.1.3 Software requirements

Normally, the PhotoModeler software welcomes any types of photography. However, how will the result be with poor photography? Is it acceptable for accuracy standards and relevant to the original object?

In planning the measurements, we should be careful and have a clear understanding in the requirements for good accuracy results through the software:

- Features should to appear in at least 3 photographs. If it is in 2 photos only, there is no redundancy for providing extra degree of accuracy;
- Record and measure as many features as possible: it is not realistic to tell PhotoModeler to calculate a complicated object, like a car, from only a few model points. Recommended minimum model points: >20;
- Clear relationship in camera focal length and CCD dimensions. If an inaccurate estimation is drawn, the scale will be affected and wrong results will occur. For a more detailed description of their relationship, please refer to the manual – Chapter 7;
- Most features can be directly measured within the software, like corners, edges, shape or even colour difference. However, many others do not have such benefits. PhotoModeler cannot provide drawing tools to measure curve a surfaces, flat plates or other features. Additional tools can be added to increase the details, like grid-projector, mesh or etc.

E.1.4 Rays intersection

The following are the considerations commonly needed when practicing the photography:

- As good convergence angle at both horizontal and vertical directions as possible as you can (by case), close to 90° intersection will be best:

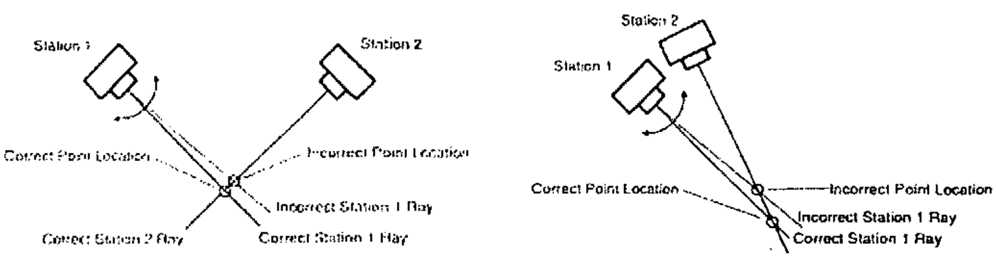


Fig. E.1a & b Diagrams showing difference in point location accuracy with different convergent angle.

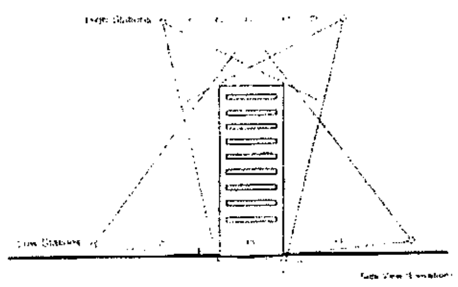


Fig. E.2 Horizontal and vertical intersections are both important in modeling tall buildings or objects

In the first two diagrams (Fig. E.1a & b), we can see the basic relationship between convergence angle and point accuracy. The greater the convergence angle (intersection), the lower the chance of error in 3D points after modeling. The same concept applies for both horizontal and vertical planes; We need to cover a tall object by dividing it into several sections of photography, as in third diagram shown (Fig. E.2).

- At least three photographs are needed for the whole area with as many important features included as possible. This maintains a more reliable environment for most model points on the object (Fig. E.3). For two directions only, no redundancy can be archived. It is easier to occur the case in previous description. However, in a three-stations setup, we can obtain extra information from the third camera station, and thus the precision of resultant 3D model points can have a more reliable status.

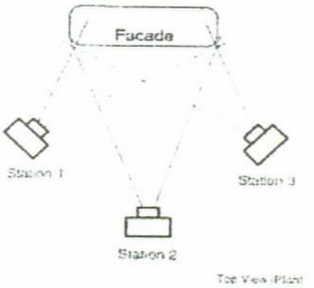


Fig. E.3 3 or more photos are recommended in any overlapping area

- Work from whole to part, ie. build the whole area through a few wide angle shots and then adding some other shots with details which are necessary within the area. It will save processing time and storage because only the necessary details are recorded. Moreover, the accuracy and precision are much more appreciable (Fig. E.4).

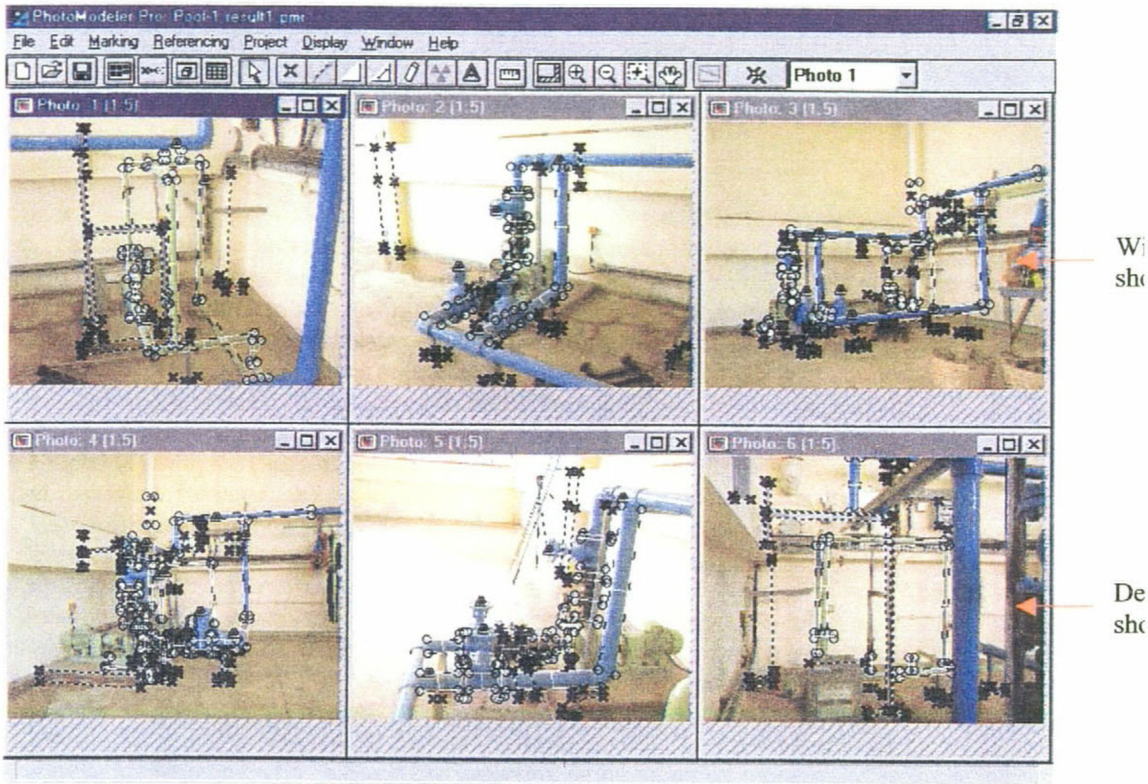


Fig. E.4 After a few shots to include the whole area, add extra detail shots to build up the components left.

- Try to have greater overlap between adjacent photos, and cover with upper and lower incident angles to the objects / areas. Besides the better calculation among visible model points, we can also cover the points missing in adjacent photos due to any obstruction (Fig. E.5).

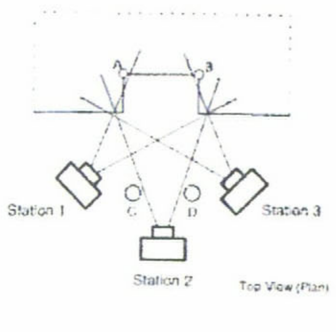


Fig. E.5 Try covering the effect of obstruction with the aid of adjacent photos

- In some cases, we need not photograph all the details within the area to reduce workload. We can re-establish the remaining parts of the objects from other tools, like CAD techniques. It will then save time and resource when obstruction occurred and no supplementary shots are available (Fig. E.6).

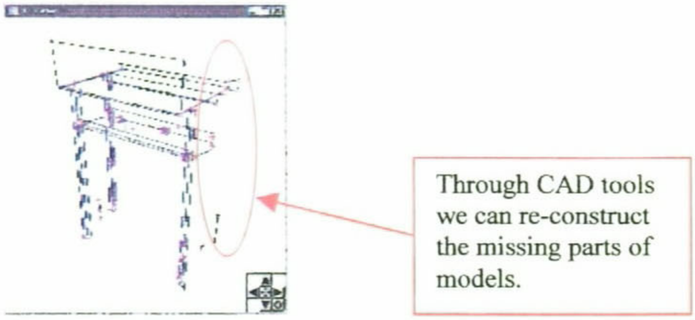


Fig. E.6 If obstruction is very serious, reconstruct the framework with other drawing and graphics tools.

E.1.5 Control information

According to the accuracy required in different natures, we can input different formats of control information to strengthen our project. The following are the common types:

- Control points, have either 2- or 3-dimensional coordinates information included. The most common control information among the field can provide very accurate scaling and coordinate fixing function. At least 3 corelative control points are put together in a project. Their application areas are geomatical measurements with precise location, plant modeling in industrial measurement discipline, or other high accuracy requirement projects.
- Scaling distance, the particular length used for scaling the model into object-space size. Comparing with the usage of control points, scaling distance can also provide the original size of the object. However, the actual coordinates cannot be achieved in this process. At least 1 known distance is enough to locate the model, but most applications will use at least 2 distances to prevent being error involved in the model. The best selection for location of scaling distance is the central part of the model, otherwise, the precision of model points in either side will be biased and wrongly distributed. The common application areas are simple object modeling in most, or other high speed but low accuracy requirement tasks.
- None. Sometimes we need not applying the control information into our model. This is because we are in the initial stage but would like to preview the resultant model. Or even if we produce the model to supplement the conventional survey, like a feature of irregular shape on a building. We can simply model it and retrieve it in CAD environment to link with the other parts.

2. Field Work Stage:

Take as many photographs as you can or that the budget will allow, to avoid needing another visit to the site. Repeating photography is expensive or the object features may not exist or will have changed. Another reason against redo the photography is that the site may be hazardous. On the other hand, it becomes more and more inexpensive to have a large load of photographs, especially digital images.

We should record the camera stations and distances between some easily recognizable features onto a plan drawing for referencing in later processing. The following is an example of the paper work: (Fig. E.7)

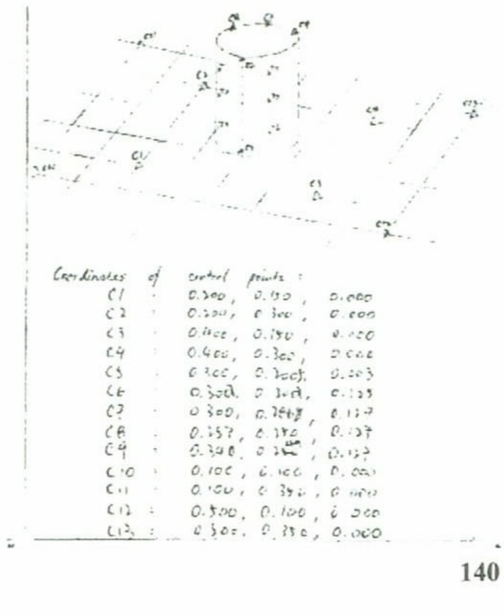


Fig. E.7 A well-presented datasheet can help the later processing stage.

3. Procedures in handling PhotoModeler 3.0

3.1 Preparation

For a NEW task, open a NEW project in FILES menu, a dialog "Project Information" is called up for users to enter the basic information. (Fig. E.8)

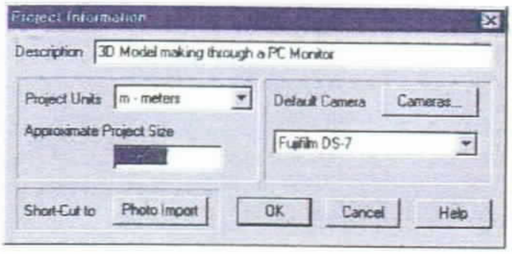


Fig. E.8 Project Information Dialog

The "Project units" and "Approximate Project Size" are units of measurement and the original size of the targeting object respectively. The "Camera" choosen is based upon what type of were used in fieldwork.

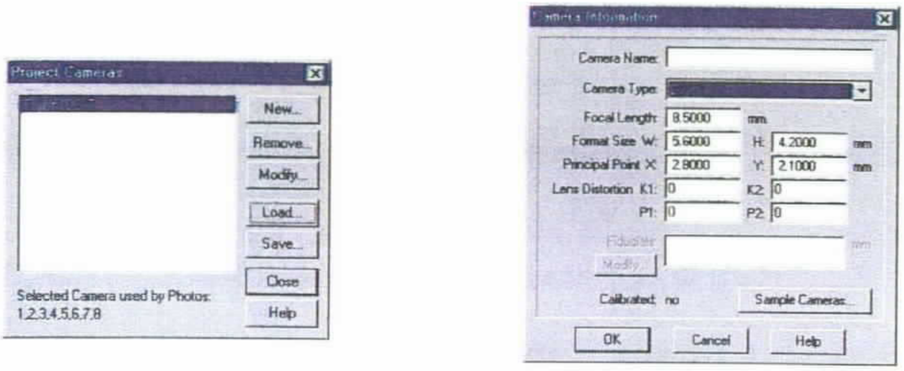


Fig. E.9a&b The left diagram (9a) shows the Project Cameras dialog and the right diagram (9b) shows the Camera Information dialog

Inside, we input the various camera parameters: focal length, CCD dimensions, principal point, and lens distortion parameters if camera calibration was done previously. The details have been described in 1.0 already. For the Calibrator program, we can retrieve the camera done by entering LOAD with the correct path of the camera file. More details are included in "Procedures in handling Calibrator".

The final step is to have Photos Import. Select the appropriate path for images to be used. (Fig. E.10)

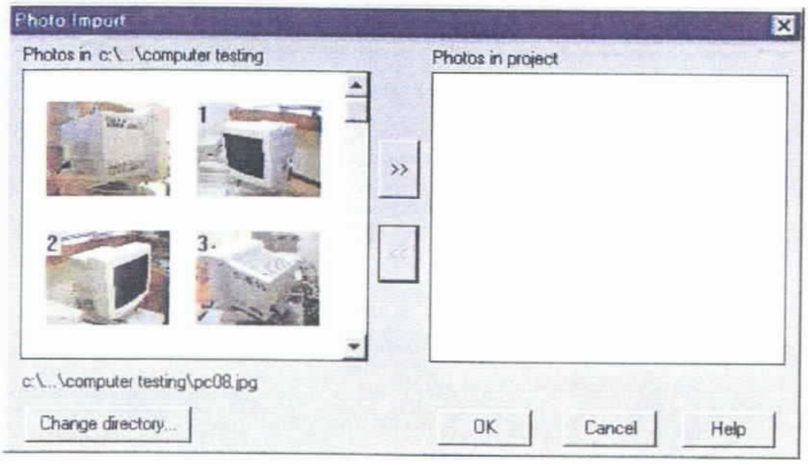


Fig. E.10 Photo Import dialog in Project Information

4.2 Modeling

Construct the model framework before adding extra feature shots into the project. This can result in the reduction of complexity in handling complicated objects. Otherwise, the greater the numbers of images, the more difficult the image measurement process in software. (Fig. E.11)

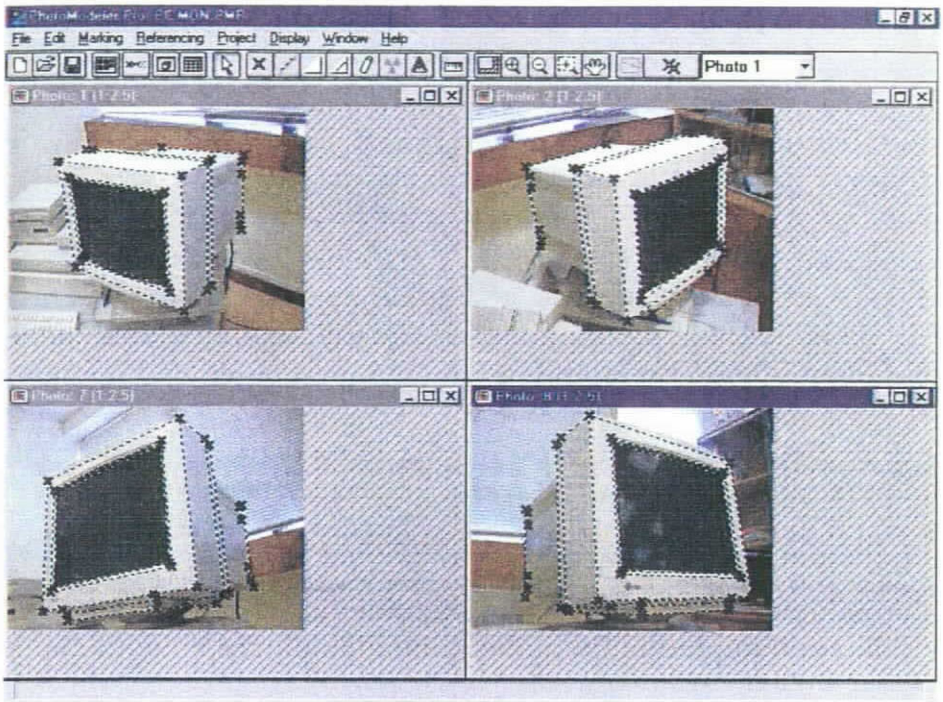


Fig. E.11 Setup in PhotoModeler showing a few main shots only

The process for drawing or linking the features is very simple. What we have to do is just "click and drag"; Click to measuring point features, like corners, points or turning points on huge features. It is the Point icon in the toolbar. (Fig. E.12)

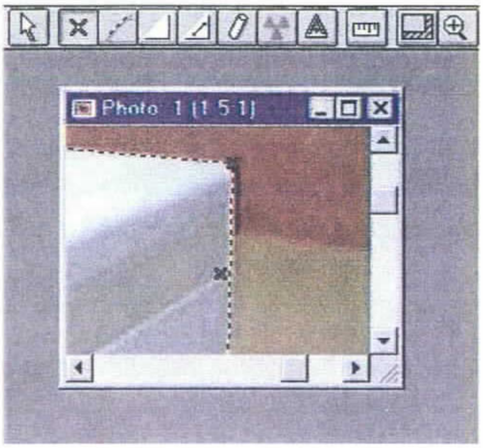


Fig. E.12 Enlarged image showing one particular shot in drawing a point

On the other hand, drag is to draw lines linking two points – simply click the first point and then move the mouse to a second point and the line will connect the two. (Fig. E.13)

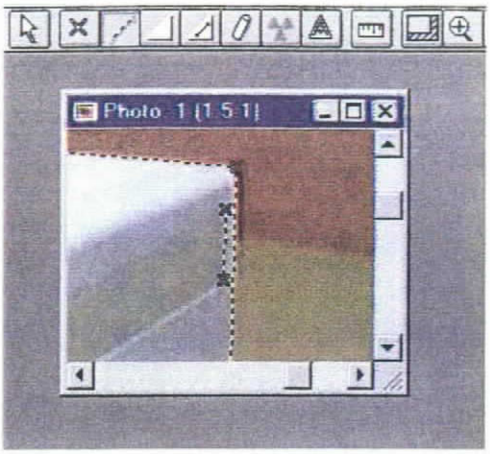


Fig. E.13 Enlarged image showing one particular shot in drawing a line

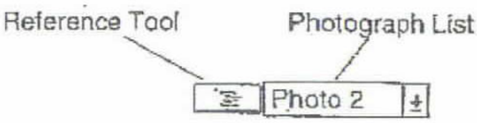
There are some drawing tools in Pro/3.0 for users to fit irregular objects into point-line computer models. Curve and Cylinder Draw in toolbar are examples. (Please refer to PhotoModeler Manual)

For special purposes like visual database or surface draw applications, surfaces formed when lines and points are crossly joined on the objects, are also necessary. In PhotoModeler 3.0, the technique is to divide the polygons into pieces of triangles for the software to form surfaces. It is not an automatic process and so we need to draw the surfaces by hand. There are 3 ways to establish a surface: (Fig. E.14a, b & c)

- Selecting 3 points (i.e. the 3 corners of triangle);
- Selecting 1 point and 1 line (i.e. the length and its opposite corner);
- Selecting 2 adjacent lines (i.e. either 2 of the 3 lengths forming the triangle).

Fig. E.14a, b&c 3 images showing the surface draw methods respectively

We should draw the framework in each image to provide more redundancy for the calculation. We should reference the individual points in various images. For selecting a basic referencing image, all the model points within are to be linked (referenced) to those at the same locations in other images. (Fig. E.15)



The Reference tool.

Fig. E.15 The Referencing tool description from PhotoModeler's manual

This process is repeated until all points are referenced in every existing images respectively. (Fig. E.16)

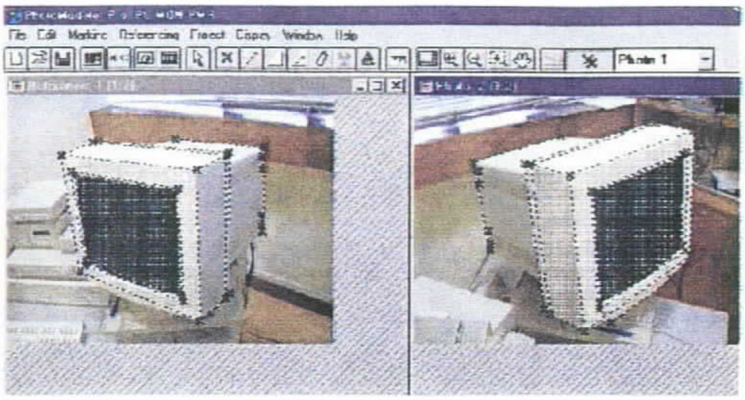


Fig. E.16 Referencing process between a pair of adjacent images

After the framework of the object has been constructed, we have to link the detail shots towards the main ones with the aid of some "common" points (Fig. E.17). They act as linkages from whole to local. It is advisable to select the control points or lengths as such "common" points or distances. It can reduce the errors magnitude because these lengths or points are actually junctions or skeleton joints in the center of the objects. The length of errors will then be limited as the balance of distribution of model points or lengths from them to the whole model.

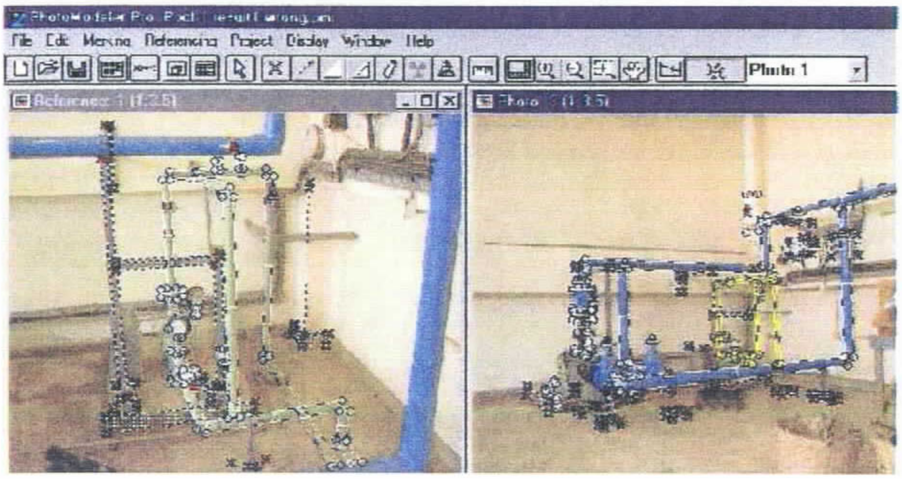


Fig. E.17 Close shot to show particular details in modeling

The level of detail is determined by client requirement together with our decision. Firstly, we have to achieve what our clients asked for or we will lose the contract. Secondly, it is important to reach the level in acceptable effort and avoid overloading of work.

For all the model points measured, the model points in the detail shots have not yet been modeled with in the framework. We should repeat the reference procedure in Step 1, but link the model points through straight lines together (Fig. E.18).

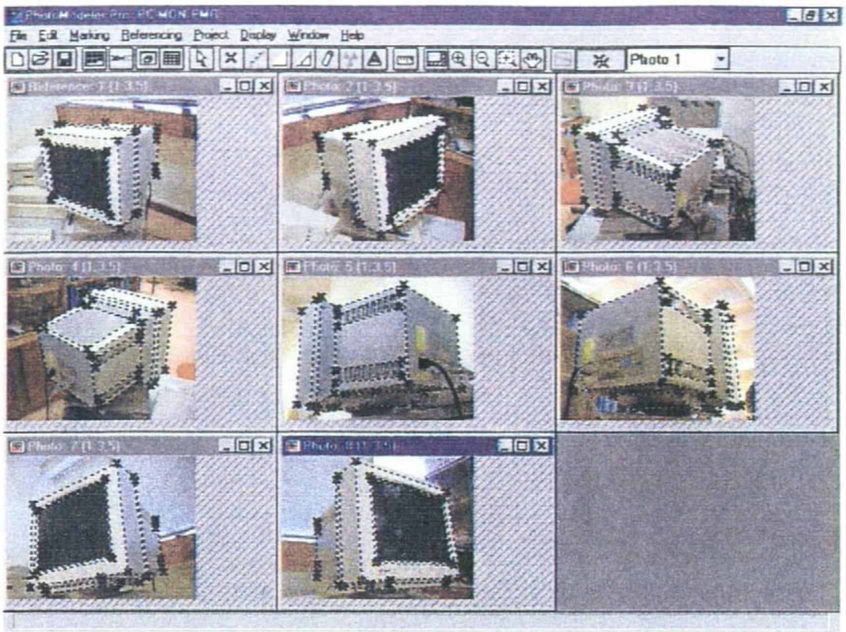


Fig. E.18 Screenshot showing most images with referencing in progress

We should examine individual images to ensure all the model points are referenced according to our planning. Remember: control and model points are both recommended to appear in at least 3 images. Otherwise, the accuracy of the resultant model will be affected. We can check the referencing process by Point Audit dialog. This is to examine each point measured within PhotoModeler (i.e. with an ID individually) (Fig. E.19). For points appearing in several images, we can check the ray tightness of indiviual point ID. On the other hand, we can be notified if single points should be referenced with others in different images.

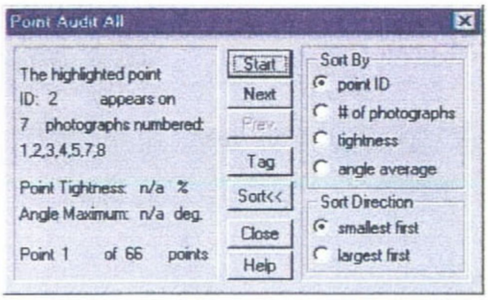


Fig. E.19 Point Audit dialog to check any tiny part

Another operation with a similar function is the Weld Unreferenced Points in Reference menu. It provides a check on unreferenced points within the project directly.

Eventually, we can have a preanalysis before running the calculation process. The function is Making Residual Display in Marking menu (Fig. E.20). It computes for assumed resultant residuals if the project is run under the settled parameters and measurements. Residual per model point (including control points) in vectorized format is shown on its own point location. Through the direction and magnitude, we can justify the model points to avoid introducing errors.

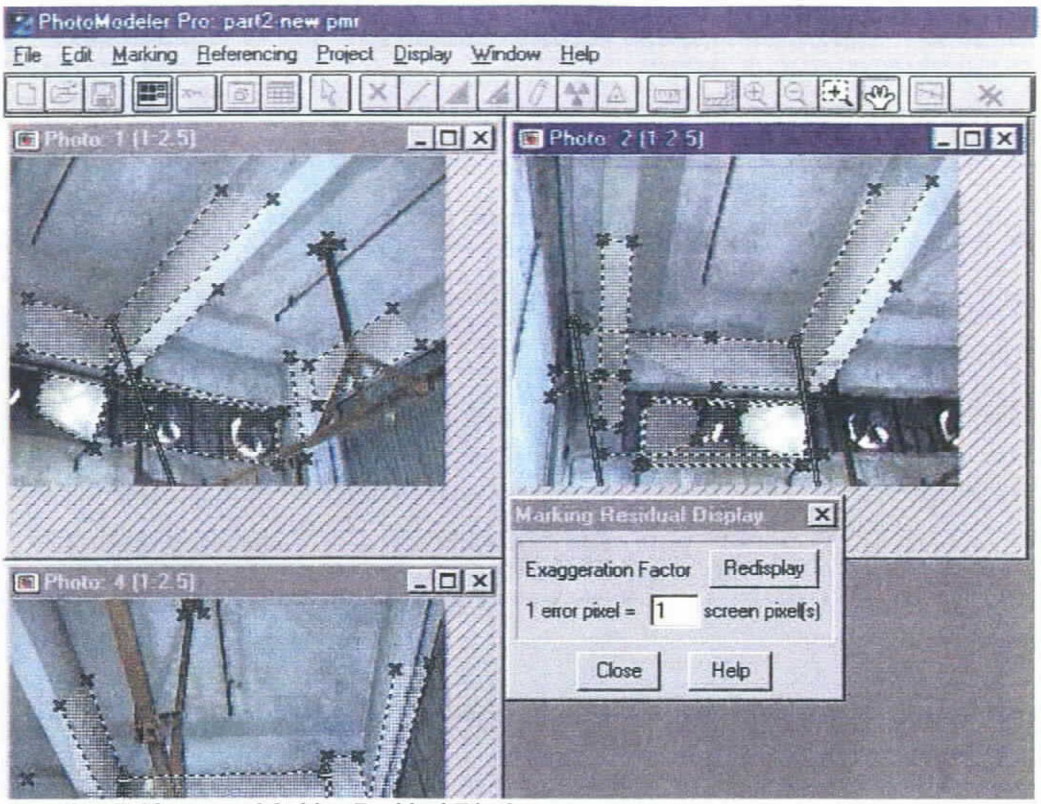


Fig. E.20 Marking Residual Display

4.3 Processing

This stage is to process the work through the calculation of software. In both Version 2.1 and 3.0, the programs have audit functions for users to check the consistency of pre-analyzed data. However, we have a brief summary page before the detail audit in version 3.0. The Audit Summary dialog box shows the brief project quality evaluation (from grade 1 to 5), and provides suggestions on poor condition in the project (Fig. E.21).

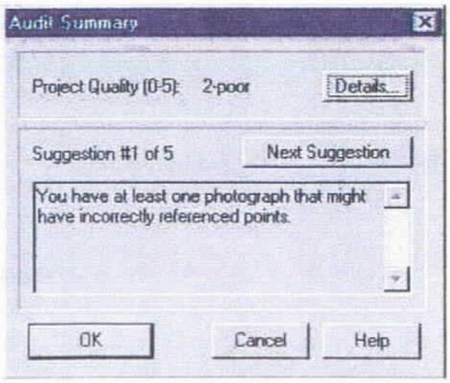


Fig. E.21 Audit Summary dialog

From the following diagram (Fig. E.22), the detail auditing or statistical presentation of task processing shows us the various criteria of considerations. Each item is commented on by the program for you to accept the result or not (Acceptable?). The items reviewed are:

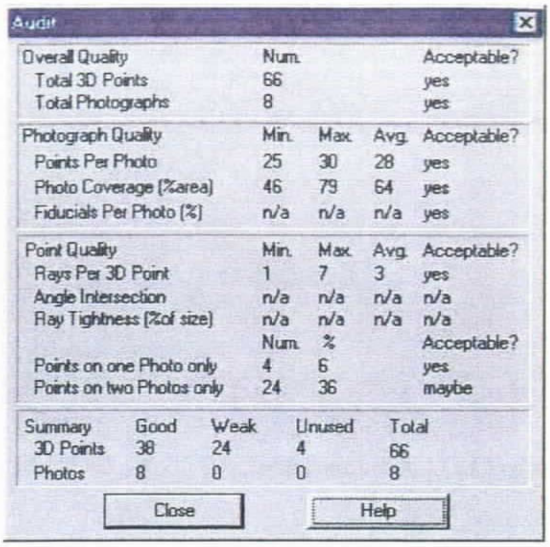


Fig. E.22 Audit dialog box in PhotoModeler

- Overall quality:
  Shows the user the total 3D points (model points can be transferred into 3D space) and total number of photos.
- Photograph quality:
  This criterion considers the number of model points and their area of coverage at each photo. The greater the numbers, the better the result. The sub-criterion "Fiducials per Photo" is for users using film cameras, those using digital cameras need not consider this part.
- Point quality:
  The most important criterion within the statistics. It considers the 3D point rays, the intersection angles from various camera stations, ray tightness and points on one or two points respectively. The "3D points rays" means how many rays (incident camera ray) intersect on individual 3D points (>3 is recommended). The "Intersection angles" shows the acuteness at various points (90° of intersection is best). The "Ray tightness" discusses the precision of model points when comparing with the original size in object space (the smaller the percentage, the better the result). On the other hand, the percentages of points in one or two photos only are as small as possible.
- Summary:
  In the summary section the program calculates for the acceptable (Good), low accuracy (Weak) and one-photo (Unused) points in the pre-analysis stage. We can determine the acceptance of the model according to the program performance. From previous experience, the "Unused" particular is acceptable if its number is under 10% of total points to be modeled.

After the auditing process, we can add the control information, which has a more detailed description in 1.5, into the project. We can distinguish between technique using from the level of known controls:

- None,
- Scaling only (i.e. a known distance provided),
- Scaling and rotate (i.e. a known distance together with some known axes orientation in object space coordinates system), and
- 3 points (i.e. 3 known control point coordinates).

Another capable input function for known control points is the supporting control points file. From Marking Control Points in the Marking menu, we can apply our planned control points into our project (Fig. E.23). What we need is to select the controls from the menu and then on their locations in various images. There is no limit to the maximum number of controls in this function.

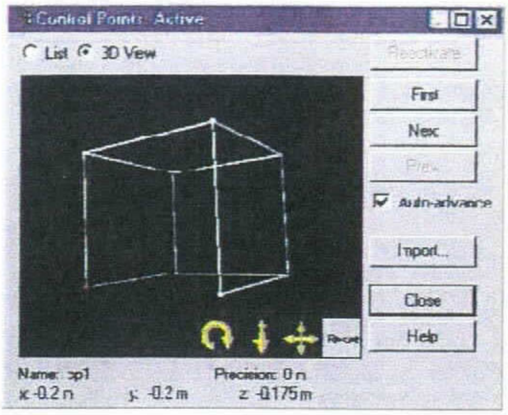


Fig. E.23 Marking controls in Marking menu

When we have settled all the above procedures, the Process function in the Project menu can be proceeded with. There are 3 criteria within the function:

- Orientation – to determine the relative positions in 3D space and the relative rotation angles of the cameras that took the photographs. For most NEW tasks, we must orientate all the photos to obtain the correct result. For tasks started previously, we can select either to orientate the added ones or orientate the who.
- Global optimization – to optimize and minimize the error in all marked points, 3D points, and camera station positions and angles. Normally, we select enable.
- Self-calibration – to optimize the results further by performing small adjustments on the parameters of the camera on each photograph to account for changes induced by focus effects etc. For digital cameras, it is recommended to enable this function because of the auto-focusing effect of most digital cameras. (Fig. E.24)

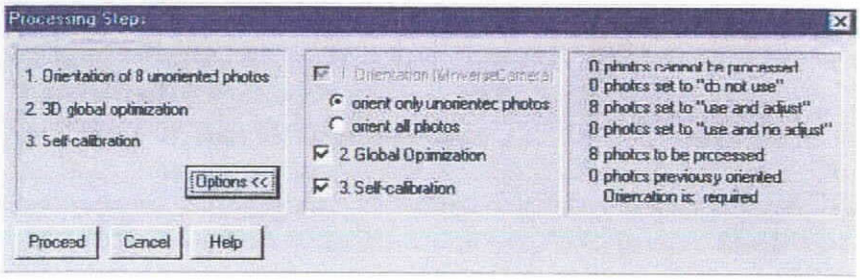


Fig. E.24 Processing Steps dialog box

As the calculation process goes on, the program generates a Total Error dialog box showing the resultant errors within the model. Similar to the Calibrator, the errors should be minimized and the following (Fig. E.25) are some common examples:

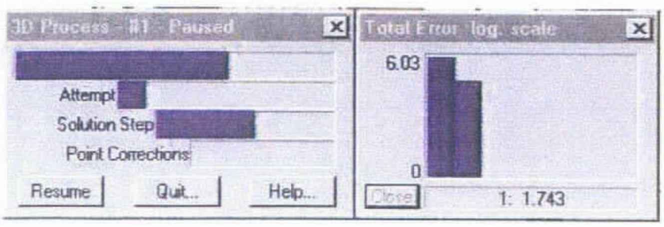


Fig. E.25 Scanned figure showing Total Error dialog in p135-136

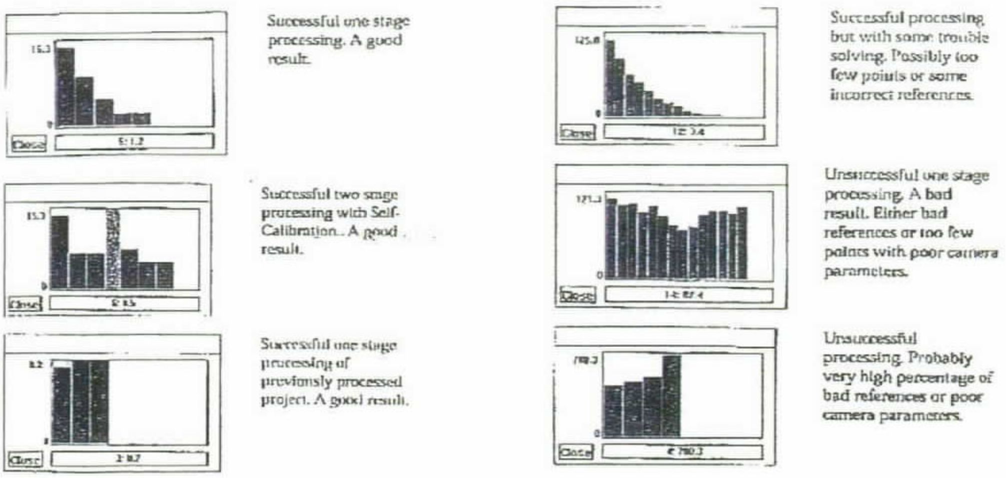


Fig. E.26 Total errors dialog in various cases from PhotoModeler manual

From the resultant model points presented, we should evaluate their accuracy and precision because any outlying points should be checked against the original positions. In PhotoModeler, we can verify the residual of individual model points and thus achieve overall accuracy (Fig. E.26). The method is clicking the Measure button in the toolbar or Measure function in the Project menu. The Measure dialog will appear and we can thus check model point coordinates and their precision if expanded mode is called up (">>"). Additional functions are distance and area calculation among points (Fig. E.27).

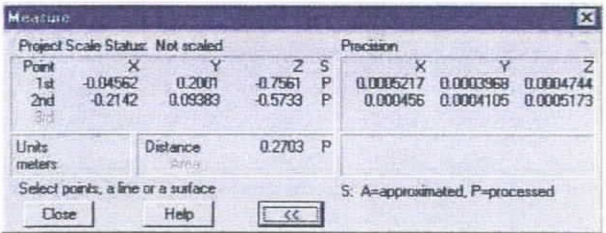
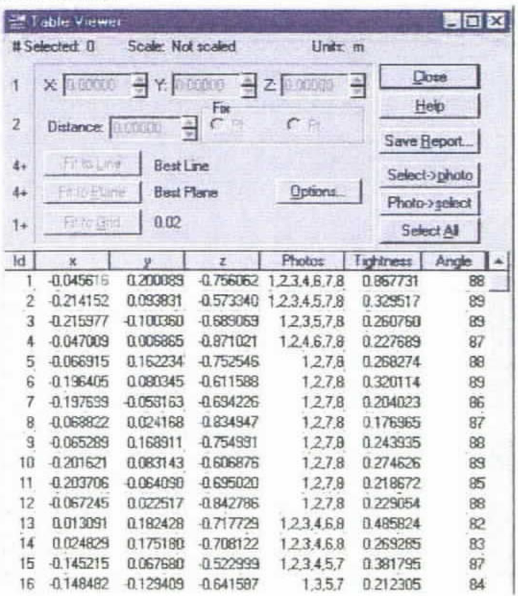


Fig. E.27 Expanded Meausre dialog

We may notice if scaling distances were used, particular residuals of model points would be greater (Fig. E.28). This is because of insufficient known information for the whole model and the accuracy of course will be lower.



Id	x	y	z	Photos	Tightness	Angle
1	-0.045616	0.200089	-0.756062	1,2,3,4,6,7,8	0.867731	88
2	-0.214152	0.093831	-0.573340	1,2,3,4,5,7,8	0.329517	89
3	-0.215977	-0.100360	-0.689069	1,2,3,5,7,8	0.260760	89
4	-0.047009	0.006865	-0.871021	1,2,4,6,7,8	0.227689	87
5	-0.066915	0.162234	-0.752546	1,2,7,8	0.268274	88
6	-0.196405	0.080345	-0.611588	1,2,7,8	0.320114	89
7	-0.197639	-0.058163	-0.694226	1,2,7,8	0.204023	86
8	-0.068822	0.024168	-0.834947	1,2,7,8	0.176965	87
9	-0.065289	0.168911	-0.754991	1,2,7,8	0.243935	88
10	-0.201621	0.083143	-0.606876	1,2,7,8	0.274626	89
11	-0.203706	-0.064090	-0.695020	1,2,7,8	0.218672	85
12	-0.067245	0.022517	-0.842786	1,2,7,8	0.229054	88
13	0.013091	0.182428	-0.717729	1,2,3,4,6,8	0.485824	82
14	0.024829	0.175180	-0.708122	1,2,3,4,6,8	0.269285	83
15	-0.145215	0.067680	-0.522999	1,2,3,4,5,7	0.381795	87
16	-0.148482	-0.129409	-0.641587	1,3,5,7	0.212305	84

Fig. E.28 Table viewer dialog box showing all resultant model points

The checking of indiviual model points is essential. There will be many reasons for difference of results:

- Poor resolution of images to locate model points within software,
- Far away from the scaling distance,
- Poor geometry of ray intersections in network, etc.

We can correct every individual model points, including control points, to our acceptable position. The only criterion we can base this on is accuracy. From the viewpoint of accuracy, the points location accuracy in relation to the provided control / known information and point measurement to achieve resultant residuals of themselves. Any outlying points can be considerd as errors introduced.

For example, an error of 10% (specific term - tolerence comparing with original size) was reported at one of the model points. We can do correction with the aid of the features from the images (Fig. E.29). It is because the images can support our decision acting as a role of referencing.

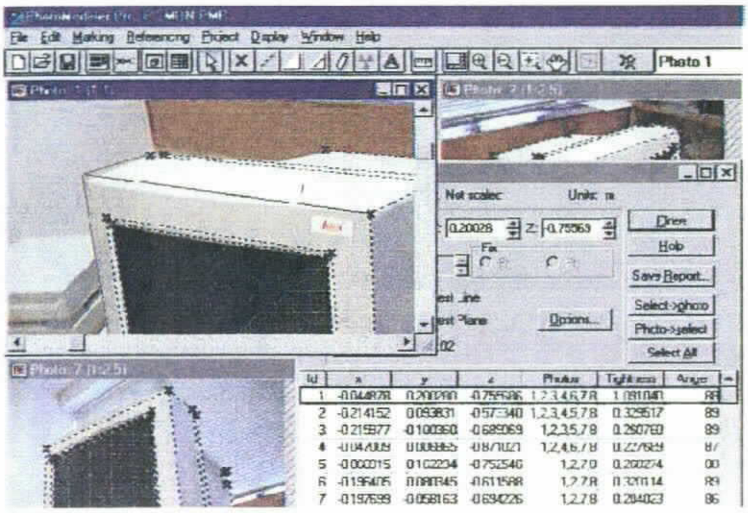


Fig. E.29 Screenshot showing correcting errors at result stage

However, the computed data may be somehow incorrect for other reasons, like camera distortion, mis-located control information – low precision control points or wrong scaling distance, etc. The resultant model may then be distorted and also calculated points. In that case we should analyze the reliability of our control information before processing. Otherwise, the results may be distorted.

4.4 Output presentation

This section describes the procedure to generate texture on surfaces of the target object. Firstly, we should have already drawn the surfaces in the measurement stage as discussed in 4.2. Secondly, we enter Object Properties in the Edit menu. The Object Properties dialog will open and in it an option to generate the texture on the surfaces (Fig. E.30).

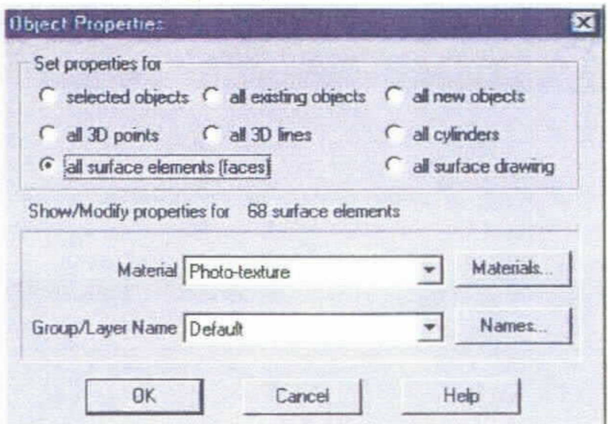


Fig. E.30 Object properties dialog in Make menu

The three sections in the dialog box subdivide the operations in applying materials onto the surfaces. For generating the photo textures from our images onto the model surfaces, we have to enter Materials firstly (Fig. E.31). In Materials dialog, we "Add" a source for our photo texture layer. The important procedure is to change Colour presentation to "Photo as Texture". The software can automatically generate the appropriate photo texture from images to our model.

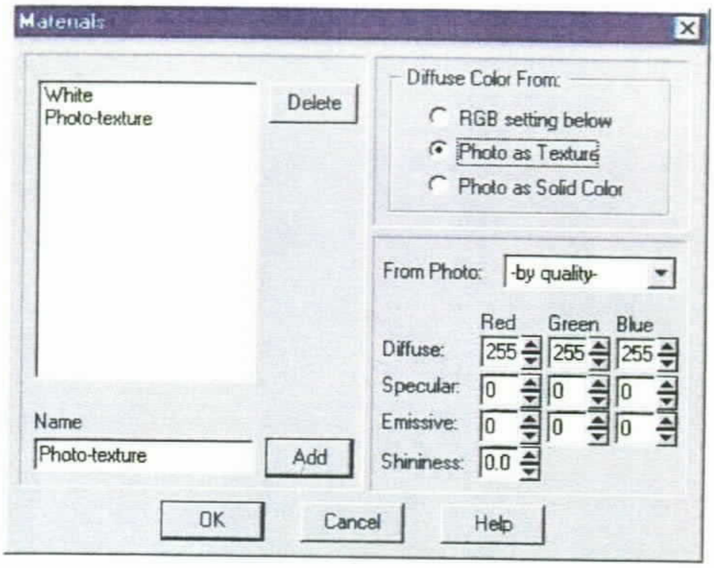


Fig. E.31 Materials dialog in Object Properties

Afterwards, we can preview the model with photo texture in the 3D Viewer in the Project menu. We should include Surface together with Photo textures to present the 3D texture mapped model. (Fig. E.32)

Fig. E.32 3D Viewer Options dialog showing preview of a resultant model

For exporting our resultant model to other software format, we can select Export Model in the File menu. The common formats provided in PhotoModeler are VRML 1.0/2.0 (.WRL), Direct 3D (.X), 3D Studio (.3ds) or CAD formats (.DXF or .DWG). We can also output camera station positions, points coordinates etc. for referencing purposes.