Computer-Aided Quantity Survey Software VHStation

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Abstract: Many aspects in construction design have been computerized. Yet, most quantity surveying work are still done manually. One of these examples is the measurement of steel reinforcement of a construction project. This hinders further modernization of the industry. A series of software, named as VHStation, is developed to transfer this situation. VHStation adopts the technologies on graphics recognition and artificial intelligence. It assimilates quantity surveyor's professional knowledge and experience, which substantially improves the efficiency and accuracy of the quantity surveying process. The development of VHStation is a milestone achievement on the automation of the construction industry.

Keywords: quantity survey, graphics recognition, engineering drawing

1 Introduction

Engineering drawing is the language of engineers. Many works have been done for knowledge detecting or recognition via analyzing and understanding engineering drawings [1][2][3].

Many aspects within construction industry, from structural analysis to drawing production have already been computerized, but the quantity surveying work such as the measurement of steel reinforcement used in reinforced concrete construction is still being done manually. It is a common industrial practice that drawings are drafted in some kind of CAD (Computer Aided Design) format. They are then printed out by Quantity Surveyors to form an integral part of a tender document for tendering purposes. Steel reinforcement is basic raw material used in construction. The calculation on the quantity used (i.e. taking off process) in a construction project is a very time consuming process. At tender preparation stage, an architectural consultant has to put in 4 to 5 man-months of an experienced Quantity Surveyor to complete the measurement work of a reasonable size, high-rise project. After the contract is awarded to a contractor, they will send their own Quantity Surveyors to do the measurement all over again. The purpose of it is to find out if there are any discrepancies between the measurement records undertaken by two separate quantity surveying teams. If discrepancies are found, the two quantity surveying teams need to check and rectify their differences since a small percentage of error may mean millions of dollars due to the huge number of reinforcement used in a building project. The total time spent in measuring and checking steel reinforcement may add up to even 20 man-months, making this a very expensive process.

This situation will be changed. A series of software, named as VHStation, is developed to computerize the taking off process. VHStation consists of three programs: VHFraming, VHDetails, and VHQuantity. VHFraming is designed to recognize the framing plan of a structure. VHDetails is designed to recognize the steel reinforcement in the drawing of a particular structural elements such as column, beam, wall, slab, staircase, etc. Finally, VHQuantity combines the results of the two programs and generates the bending schedule of steel reinforcement. VHStation adopts the technologies on graphics recognition and artificial intelligence. It assimilates quantity surveyor's professional knowledge and experience, which greatly improves the efficiency and accuracy of the quantity surveying process. Hopefully, the achievement of the VHStation will encourage more automation software being developed in the construction industry.

2. Design considerations

In order to make VHStation popular in the Q.S. field, it is necessary to include correct development strategies, appropriate functions and friendly user interface in the system design.

2.1 DEVELOPMENT STRATEGIES

VHStation adopts its development strategies in the following three aspects: data source, data content, and application concepts:

a. Data Source

Although nowadays quantity surveyors perform their tasks based on paper drawings format,

VHStation uses electronic drawings as input. Since drawings are prepared by some kind of CAD software such as AutoCAD, it is important for VHStation to adopt the commonly used data format particularly the DXF and DWG formats. This does not only save a lot of time in plotting and copying mass amount of drawings but also guarantees data integrity. As for those construction projects that do not have electronic drawings, a Vectorization software, VHVector[5] can help to convert paper drawings into DXF/DWG format file before applying VHStation for the taking off process (Fig. 1).

b. Data Content

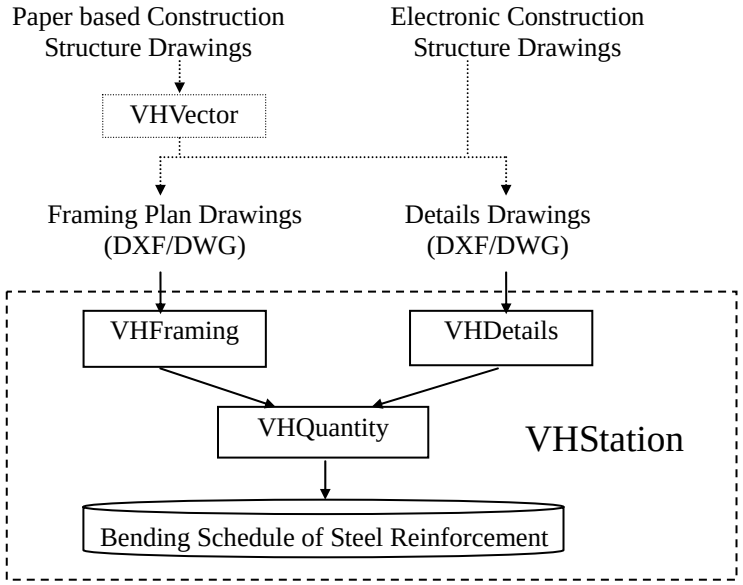
Most of the source data for the quantity surveyors comes from both framing plan and details drawings. Framing plan drawings show the overall layout of a building usually in a floor by floor basis, while details drawings show the detailed steel reinforcements design of each structural element. As such, VHStation chooses framing plan drawings and details drawings as the two object sources to be processed. There are also small amount of information scattered around in different drawings such as the typical drawings or some general notes within the detail drawings that are essential in the calculation but relatively difficult to be located automatically. User usually inputs this information manually, thus the system process efficiency and information integrity is guaranteed.

c. Application Concepts

The application concept is to design a system as close to a human Quantity Surveyor as possible and try to integrate the current practice into the system. All the calculation and method of measurement is based on British Standard which is commonly adopted in Hong Kong. Also, the drawing format may be different for different designers, the wording may varies from draftsman to draftsman. In order to make the software widely acceptable by the industry, efforts have been made to incorporate these variations as much as possible. This is an endless task, as the drawing format has not been standardized. Nevertheless, the present system possesses great deal amount of structural engineers and quantity surveyors expert knowledge and is able to produce very accurate results of bending schedule with current used format.

Fig. 1. System Structure of VHStation

2.2 APPROPRIATE SYSTEM FUNCTIONS



Based on the characteristics of structural engineering drawings being processed, the following points are addressed in the design of system functions:

a. Due to the fact that the steel reinforcement information is presented by the combination of geometric figures and descriptive text in the drawings, there are certain physical connections among the text and the drawing. Therefore, in order to extract the steel reinforcement information wholly, the system must bear the functions of powerful graphics recognition, high level of text understanding, and interrelation ability.

b. There are a variety of ways in representing basic graphical primitives in structural drawings and various methods of combining those basic primitives into meaningful knowledge. Consequently, analyzing techniques based upon artificial intelligence must be introduced to analyze and recognize the drawing elements in different hierarchy, particularly in their relationship, as to understand the drawings.

c. In most cases, the structure of steel reinforcement is represented in two different projection views, namely the front view and the section view. For example, a R.C. beam is usually shown by a front view with one or more section views with all the reinforcement bars represented by a line or dot respectively. Hence the system must have the certain ability of 3D-reconstruction in order to recognize the spatial shape and dimension information of each of the steel reinforcements being used.

d. The System must also be able to affirm the reliability level of the calculated results and provide hierarchical post-processing functions because the number of steel reinforcements is so large that it is too difficult to check them one by one. This reliability check is displayed in various means to the user to express the level of accuracy of the data so that in case of uncertainty, the user may choose to double check the data manually.

e. Along with the progress of a project, some drawings may have version updating. Accordingly, the system must provide the function of version management, comparing the difference of drawings of different versions and find the difference of quantity surveying results. This is particularly useful in the construction industry since variation of design is unavailable in large-scale project and quick updating may save numerous time and money.

f. System must be able to find and display abnormal data to help users to identify and correct them because most drawings contain certain errors. A human can easily deal with these errors but for a software system, this must be identified and confirmed by the user in a very user-friendly manner so as to increase system efficiency.

2.3 FRIENDLY USER INTERFACE

The friendliness of user interface is mostly about the easiness of learning and using the system. The correctness and efficiency of the system is particularly important and depending on the user interface. In order to provide a friendly user interface, VHStation makes great effort in the following aspects:

a. The operation mode provided is close to the language use of a quantity surveyor. The interaction ought to be intuitionistic, convenient, and an instant observation of the result is provided for easy checking.

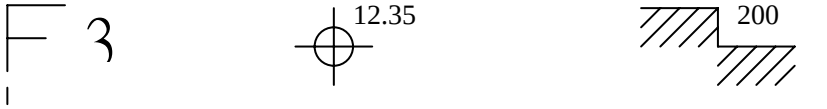
b. Displays the calculated result in tabular form, which is clear at a glance. The correspondence between each item in the table and the primitives in drawing can be consulted and revised easily.

c. Due to the complex nature of the structural drawings, the following three cases on drawing recognition may arise: (1) Nonstandard drawing manner that is unknown to the program. (2) Data distribution exceeds the processing range. (3) Incompleteness of data due to the drafting error. These will either require the user to check and affirm the result or the user will be unable to obtain a meaningful result. Once these situation are detected, the system will highlight them and let the users add his own command input to the system. This will minimize the users' effort in checking and verification.

3. Symbol Recognition

Symbol recognition is one of the essential jobs of automatically understanding engineering drawing[4]. In VHStation system, the recognition of construction symbols is the basis of understanding both the framing drawings and detail drawings.

In construction structure drawings, each symbol consists of some simple graphics primitives such as lines and strings (Fig. 2). Its appearance, or the characteristics and the relations among its ingredients



a. Section Symbol b. Level Symbol c.Level-Difference Symbol

Fig. 2. Construction Symbol Examples

are relatively steady. According to the standards in designing and drafting the construction drawings, VHStation organizes the “standard symbol database” storing the templates of all kinds of symbols. In this database, each template gives the normative description for the relevant symbol's constitution characteristics. Each characteristic has some experiential thresholds for admitting of minor errors and been given the priority based on its speciality degree. These descriptions are acquired during the symbol characteristic analysis procedure. Through the similar way, analyzing the candidate symbols and matching with the template in the standard symbol database will then fulfill the symbol recognition.

The characteristics of the construction symbol include: geometric features of each line, geometric relation among the lines(conjoint, intersectant etc.), geometric priority of its relevant lines, content of the text notes (strings) and the relationship between the position of the string and the graphics etc. “Symbol” is always looked on as one kind of combination of some certain geometric elements. The graphics part of it is always stressed while the text part is relatively neglected. In construction drawings, the meanings of quite many symbols are indicated by their text notes. Then the relationship between the graphics and the text would be the important criterion of the recognition. So taking the text notes as one indispensable part of the whole construction symbol is a good way to improve the efficiency and precision of the recognition and also benefit organizing high-level entities from the result directly for later use.

Each template is described in four aspects:

1. Entities, of which the symbol consists.
2. Conditions, that each of entities should satisfy.
3. Relations among the different entities.
4. Thresholds, that describe relations in detail.

As for Slab mark shown in Fig. 3, its template can be like below.

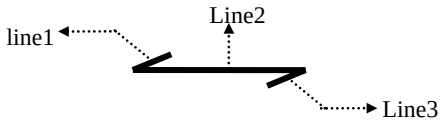


Fig.3. Symbol: Slab Mark

Entities: { line1, line2, line3}
Conditions: { line1 != NULL, line2 != NULL}
Relations: { line3 != NULL $\rightarrow$ ABS(LEN(line1) - LEN(line3)) $\subseteq$ th1,
LEN(line1) < LEN(line3),
ABS(LEN(line1) - LEN(line2)) $\subseteq$ th2,
ANGLE(line1, line2) $\subseteq$ th3}
Thresholds: { th1= ⟨min(LEN(line1), LEN(line3)), <, S0.1, E0.5, 0.1 ⟩,
(th1 can be explained as follows:
initial request is "less than (max(LEN(line1),LEN(line3)) * 0.1)
and more than (min(LEN(line1), LEN(line2)) * 0.1)". When failed to meet initial request, we can relax it by step(0.1) to "less than (min(LEN(line1), LEN(line3)) * 0.5)") ,
th2= ⟨min(LEN(line1), LEN(line2)), >, S2.0, E1.0, -0.5⟩,
th3= ⟨10(degree), <, S1.0, E3.0, 1.0⟩ }

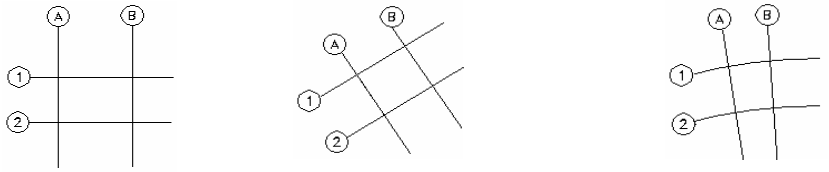
4. Recognition of framing plan drawings

Framing plan drawings show the layout of elements and related dimension information in each floor of a building.

4.1. RECOGNITION OF COORDINATE SYSTEM OF A FRAMING DRAWING

Each framing plan drawing has one or more coordinate systems, which are used throughout the project. Through them, the distribution and dimension of each structural element are described and identified. Coordinate systems are the basis of recognition of framing plan drawings.

Coordinate system is generally orthogonal systems, and occasionally polar systems (Fig. 4). Sometimes both of them appear in the same framing plan. VHFraming obtains coordinate lines through



a. orthogonal Coordinate System

b. orthogonal Coordinate System (inclining)

c. Polar Grid System

Fig. 4. Coordinate Systems in Framing Plan

two groups of coordinate symbols, {'A', 'B', 'C', …} and {'1', '2', '3', …}. These symbols are embedded in a circle respectively and each circle is connecting one dot-dashed line. They make grid-lines and establish the coordinate system.

4.2 SEQUENCE OF ELEMENT RECOGNITION

Primary types of structural elements in framing drawings are BEAM, WALL, SLAB, STAIRCASE and COLUMN. Each element is shown in an outline format in a framing plan drawing. The visible part of the outline is drawn in solid lines while the invisible part is drawn in dashed lines. Each element outline has certain relation with coordinate lines. For example, the center of a column is commonly located at the grid point of the coordinate system. Beams include two classes: "beam on column" and "beam on beam"; the former is normally located between two adjacent grid points while the later is normally parallel to a grid line. Outlines of a slab lie on beams or walls, etc. Based upon those geometric relations, VHFraming recognizes elements in a sequence of "column - beam - wall - slab - …"

4.3 METHODS OF ELEMENT RECOGNITION

Considering characteristics of the graphics expression, the special difficulties in recognizing framing drawings can be concluded as follows:

- Farraginous Geometric Elements: Quite many graphics primitives that are useless for recognition mix with those useful ones and outlines of different elements are also mixed up.
- Individual Vagueness: Outline of a single element always has no strict geometric representation, but only need to have correct shape visually.
- Group Vagueness: Outlines of different elements and also different types of elements interweave with each other. Their ubieties are full of high-level construction semantic implications that are very important for recognition.

In a word, the difficulty is that how to extract precise and integrated information of the construction element from those vague, imprecise and incomplete geometric information (geometric element and the relations among themselves) under the support of domain knowledge in construction quantity survey field.

4.3.1 RECOGNITION OF EACH ELEMENT

Each element is represented by its outline, its characteristics of position and name. The name is expressed as a string. It denotes the high-level meaning of its related outline which is expressed as some other kinds of basic geometric elements such as lines and indicates the characteristics of the element position. This shows that understanding the relation among these three aspects is indispensable. Consequently, the recognition begins with recognizing the above three kinds of primitives and then makes decision after synthesizing them.

For instance, the recognition of a column is confirmed by searching column name, classifying column shape and extracting the location and outline. VHFraming recognizes columns through the following BNF syntax description of columns.

<COLUMN> ::= <COLUMN SHAPE> <COLUMN LOCATION> <COLUMN NAME>
<COLUMN SHAPE> ::= RECTANGLE | CIRCLE | ELLIPSE | POLYGON
<COLUMN LOCATION> ::= GRID POINT | OTHERS
<COLUMN NAME> ::= <'C'> <COORDINATE OF ROW> <COORDINATE OF COLUMN> {<ADDITIONAL SYMBOL>}
<COORDINATE OF ROW> ::= 'A' | 'B' | …
<COORDINATE OF COLUMN> ::= '1' | '2' | …
<ADDITIONAL SYMBOL> ::= 'a' | 'b' | …

4.3.2 INTELLIGENCE IN RECOGNITION

There are always many situations such as the draftman's carelessness, which can result in the nonstandard or incomplete data representation. Then the syntax analysis shown above may not give the correct result. Here VHFraming uses the intelligent recognition method that is based on the dynamic parameterized rules.

The basic rules are a group of controlling judgement requirements that are summarized through the understanding of the construction domain knowledge (e.g. drafting and quantity survey field).

Dynamic parameterized rule-based recognition is such a process that, when the result cannot be confirmed to be correct during the first turn of recognition, backdate partially according to the situation, select from the basic rules and reorganize them to preparing for the new turn of recognition.

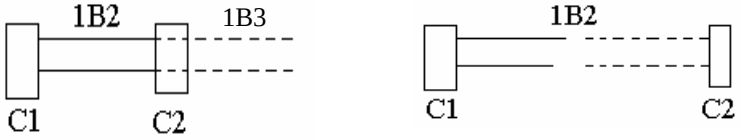
The “dynamic” characteristic embodies in two aspects:

a. In each basic rule, the primary thresholds are parameterized. Their initial values are experiential but will be changed dynamically during recognition process.
b. New judgement requirements are always composed of some basic rules that are selected dynamically during backdating procedure.

The primary principle of organizing rules dynamically is that "circumstance" - geometric information gotten from the drawing directly, high-level information of the recognized element (such as its position, its relevant dimension note, size and position of its adjacent elements, and to which coordinate region it belongs etc.) and actual situations brought on by different recognition course. During times of dynamic recognition, through synthetically analyzing all the information mentioned above, the judgement requirements are reorganized each time to be from complex and strict to simple and loose, fulfilling one optimizing process with continually excluding and approaching, achieve relatively best recognition result eventually (Fig. 5).

5. Recognition of details drawings

Details drawings show the detail of steel reinforcement of each structural element. VHDetails obtains the required data by analyzing and understanding shapes according to the various ways of



a. case 1 b. case 2

Column “C1”, column “C2” and beam “1B3” are all the adjacent elements of beam “1B2” which is to be recognized；

a. If two lines that belong to different beams are colinear, then they may be drawn as only one line, (see 1B2 and 1B3 in case 1). When recognizing 1B2, dashed parts are automatically cut off and removed, remained solid parts are the correct outline of 1B2.
b. There are two separated lines, but actually they denote just one line (see dashed parts and solid parts in case 2). When recognizing, they are connected automatically and form the correct outline of 1B2.

Fig. 5. Legend of Dynamic Parameterized Rule-based Recognition

representing steel reinforcement structure of elements such as COLUMN, BEAM, SLAB, WALL... etc.

5.1 FEATURES OF STEEL REINFORCEMENT REPRESENTATION IN DETAILS DRAWINGS

There are many different representation forms associated with the shape features of different elements in the details drawings.

a. Grouping of same class: A group of steel reinforcements having the same shape and length and certain relationships in their geometric positions are often shown by one polyline with some suitable annotation. For example, "5Y20-02" means a group of 5 steel reinforcements whose diameter is 20 mm and serial number is 02.

b. Viewing related: Some steel reinforcements are not located in the plane perpendicular to the view direction, therefore two or more views are required to describe the steel reinforcement information. For example, the shape of stirrup is presented in a section view, while the amount of stirrups being used is shown in a front view.

c. Symbolic hinting: Some steel reinforcements, such as the U-Bars in walls or slabs, are represented in a symbolic form with some fixed view point projection. A segment of steel reinforcement which is in the direction parallel to the view direction is represented by a point.

d. Tabular form: The structure of the steel reinforcements of a wall is often shown in one of several

tabular forms.

e. "Typical" referencing: Some elements are designed exactly the same as the other structures. They are often shown as "Typical". The steel reinforcement distribution of a “typical” element is being referred to the elements that are referring to, but the dimension of the referring element is depending on its environment.

f. Textual description Referencing: When a steel reinforcement structure exists in more than one element, usually only one element shape is shown, and the others are referring it by using the string of "Same As … "

5.2 RECOGNITION OF GRAPHICAL PRIMITIVES

The graphical primitives in details drawings can be classified as "line", "symbol", "point" and "text" etc. Lines include "element outline", "steel reinforcement line", "dimension line", "coordinate line", "leader line", …. Symbols include section symbol, steel line-ending symbol, and line-cutoff symbol. The symbol, which defines the end-position of a dimension line, can be an arrow or a point. On the other hand, a point sometime means the section of a steel reinforcement, or the intersection position between leader line and reinforcement line, or between a leader line and an auxiliary leader line. A text string may provide a steel reinforcement annotation, an auxiliary annotation, a dimension figure or some other general comments.

The successful recognition of each shape element depends on such features as the geometric shape of its own, its location and relations with other objects or text, etc. Some can be recognized intuitively while the others must be affirmed after a series of steps of analysis and reasoning.

5.3 INTERRELATIONSHIPS BETWEEN PRIMITIVES

As the representation of an element in framing plan drawing, a steel reinforcement in details drawings is represented by a combination of a number of primitives. So the interrelationships among primitives must be analyzed on the basis of recognition of graphical primitives.

When there is no conflict, related primitives can be grouped by the "nearest" rule. A steel reinforcement symbol string can be connected to a leader line by this method in most cases, while the entire environment nearby to the element should be analyzed when conflicts exist among similar primitives.

5.4 RECOGNITION AND UNDERSTANDING OF STEEL REINFORCEMENT INFORMATION

Standard steel reinforcement information is represented via three parts: steel reinforcement annotation, leader line and steel reinforcement line. Steel reinforcement annotation shows the amount of steel reinforcements used in the group, such as the steel material type, diameter, serial number, and distribution, etc. For example, "2Y20-03" means two steel reinforcements, whose type is "Y" for high yield steel, diameter is 20mm, serial number is 03. Another example (Fig. 6), "25R10-102, 101-200 D.S" means two groups of 25 double stirrups, whose serial number is 101 and 102, diameter is 10mm, the space between the adjacent double stirrups is 200 mm. A steel reinforcement line is generally a polyline, sometimes a point or combination of them. Leader line connects annotation and steel reinforcement line. The recognition of steel reinforcement is accomplished by analyzing their relationships in terms of the following BNF descriptions.

<LEADER-TYPE STEEL REINFORCEMENT> ::= <STEEL REINFORCEMENT ANNOTATION> <ASSOCIATION BETWEEN ANNOTATION AND LEADER> <LEADER LINE> <ASSOCIATION BETWEEN LEADER AND STEEL REINFORCEMENT LINE> <STEEL REINFORCEMENT LINE>

<STEEL REINFORCEMENT ANNOTATION> ::= {<NUMBER OF STEEL BARS> <SEPARATOR>} <STEEL REINFORCEMENT MATERIAL TYPE> <STEEL REINFORCEMENT DIAMETER> <SEPARATOR> <STEEL REINFORCEMENT SERIAL NUMBER> {<SEPARATOR> <STEEL REINFORCEMENT LOCATION> <OTHER COMMENT>}

<SEPARATOR> ::= ‘ ’ | ‘-‘ | ‘,’ | ‘&’

<STEEL REINFORCEMENT MATERIAL TYPE> ::= ‘T’ | ‘Y’ | ‘R’ | ‘ET’

<STEEL REINFORCEMENT DIAMETER> ::= ‘10’ | ‘16’ | ‘20’ | ‘25’ | ‘32’ | ‘40’

<STEEL REINFORCEMENT LOCATION> ::= ‘EW’ | ‘EF’ | ‘FF’ | ‘NF’ | ‘B’ | ‘T’ | ‘alt’ | ‘stgd’ …

(The contents following after this is omitted for simplicity)

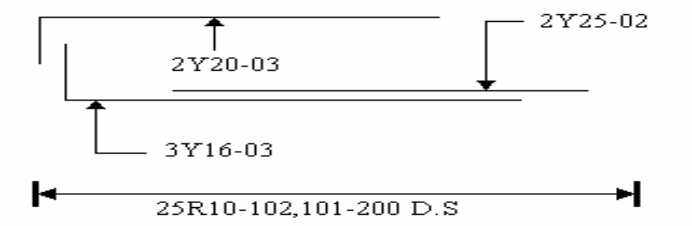


Fig.6. Steel Reinforcement Annotation, Leader Line and Steel Reinforcement Line

6. Synthesis of steel reinforcement information

Validity lies in two aspects. They are the information integrity of elements and correctness of steel reinforcement computation within an element.

6.1 INTEGRITY CHECKING OF INFORMATION

Each element in a framing drawing should have its counterpart in the details drawings, and vice versa. According to this rule, VHQuantity checks the information integrity before quantity survey computation.

6.2 SYNTHESIS OF STEEL REINFORCEMENT INFORMATION

There are mainly the following kinds of data that are used in computing the steel reinforcement bending schedule:

- **a.** Given by details drawings, such as the width and height of a beam.
- **b.** Given by framing drawings, such as length of a beam.
- **c.** Shown by TAL table.
- **d.** Computed by rules, such as the computing of deducting the width of concrete cover layer.
- **e.** Computed according to scales, such as computing of some steel reinforcement by line length when explicit dimension lines are not available.

7. Conclusion

Depending on the high-speed and precision of computer, assimilating the knowledge and experience of quantity surveyors, VHStation has the following features compared to the manual taking off process.

a. Accuracy

VHStation computes abiding by predetermined rules and will not wear out, will not be careless and will always give the precise result.

b.Consistency

VHStation will get the same result when processing the same project data in different time.

c. Authoritative

The owner can authorize result of VHStation.

d. Efficiency

It only takes 4 or 5 man-days to complete a whole project, which is the 1/30 (or 1/60 taking into account of the time spent by contractor) of that spent by handwork. When considering the avoidance of checking errors, a greater efficiency can be obtained.

The launch of CAD software was a milestone in construction design, but the development and application of VHStation is another milestone that will push forward the automation of the construction industry to a new age.

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