PAPER NO. 84-4503

A Building Material, Labour, and Cost Information System

by

Eberhard Nacke
Agricultural Engineer

and

Hermann Auernhammer
Agricultural Engineer

Institut fuer Landtechnik
Technical University of Munich
8050 Freising, West-Germany

For presentation at the 1984 Winter Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Hyatt Regency, New Orleans, Louisiana
December 11-14, 1984

SUMMARY:

A computer program is presented to assist in farm building decision problems. The system allows both general cost estimation of various building types and very detailed calculation about natural and monetary requirements of custom-designed structures. The program provides a tabulation of labour requirements for all different construction tasks, and a detailed listing of all materials and equipment.

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

A BUILDING MATERIALS, LABOUR, AND COST INFORMATION SYSTEM

Eberhard Nacke and Hermann Auernhammer*

Introduction

Livestock production in relatively unfavorable climatic regions generally involves a high proportion of fixed capital costs as sizable building investments become necessary. In West Germany, the index of construction costs for farm buildings increased even more than for all other production factors except labour costs during the last decade. Nonetheless, building investment for expansion of livestock production is often the only possible way for farm growth. Farm land in Germany is very scarce, and if available, it is very expensive, the average price in 1981 being more than $7,000 per acre.

The tools generally used to evaluate the economics of building investments have been unsatisfactory due to the lack of readily available data and time-consuming calculations of cost factors in a manual procedure. In many cases, decision criteria have been taken from roughly estimated costs per head, square meter, or cubic meter.

In recent years, much effort was taken in writing computer software to assist farmers in all kinds of management questions. In respect to building cost calculation, developments of authors like Duncan, Wight, or Krabbe provide some valuable assistance. Since the advent of small low-cost computers, most activities are concentrated on personal computer software for on-farm use. However, the building cost information system presented in this paper is designed for use in extension offices with access to a mainframe computer system. This design seemed to be most appropriate as building investment decisions are typical strategic decision problems, which occur infrequently and are long-run in nature. Thus, the individual farmer uses such a program very seldom, and it is more advisable to provide it for a larger number of customers. Additional cost information is dependent on a sufficient data base, which can be maintained best by a centralized organization. Frequent updates, which might occur as the system is designed for use in research and teaching, too, are easy to make as well.

Objectives

Within the decision process, a user will require information by the program in three major pre-contract activity stages:

1. In the early planning stages of a project, approximate overall cost information for complete structures of different types is needed. Thus, the program would help to give some general ideas about the investment needs of potential alternatives and to eliminate financially unfeasible plans. These results may also serve for first budgeting and financing evaluations.

2. At the design stage of a project, cost information should help the designer to achieve the optimal solution. At this stage, greater flexibility seems to be necessary. To provide real support, the calculation process should allow more than just a choice between complete building alternatives. It is necessary to allow individual composition of a structure according to the specific requirements of a construction site and the preferences of the farmer himself.

---

*Institut fuer Landtechnik, Technische Universitaet Muenchen, 8050 Freising, West Germany.

3. At least in the final decision stage, even a deeper insight might be advisable. Feasibility and realization planning would gain very much from detailed information about component requirement and costs. This detailed analysis is often necessary, as decisions in this stage are also related to the question, if a project is to be built by:
    - contractors,
    - material + direct labour, or
    - do-it-yourself.

The cost differences between these three construction methods may vary with building type, but can reach up to 50 percent between the first and third alternative (Wight, 1980). To see how different organizations affect price, the calculation system has to show how the total expected costs are broken down between labour, material, plant, and equipment. The emphasis put on such a detailed breakdown is based on the fact that a high proportion of farm building constructions in Germany is either organized and supervised by the farmer himself or even the whole construction is set up using farm and neighborhood labour. To plan such activities, the farmer needs more information than just the costs of the major building parts or of the complete structure. He rather needs a complete description of all natural input factors to be inserted into the building. Beyond that, the task of organizing the full construction or parts of it requires information about the estimated worktime to complete the different construction parts. This information is considered to be very important as experience shows that farmers tend to underestimate the labour requirements, which might cause serious neglect of the care to be taken to the rest of his farming operation.

Finally, an important consideration in developing a building cost information model is not to be out of date when the guide is published. As major changes of construction forms and materials occur rather seldom, this common problem of cost guides is caused mainly by rapid changes of labour and material costs.

Program Design

The program KALBAU (KALkulationssystem BAUwesen = Calculation system for Construction) tries to integrate the above reflections. One of the major characteristics of KALBAU is a strict segregation between the computing of natural input factors and monetary evaluation. This way, the more difficult part of modelling the relations between natural input factors has to be reevaluated only when major developments in construction types or building techniques occur. Meanwhile, an update of fluctuating prices can easily be handled when such data are stored separately in a data base.

Calculation of Natural Input Factors

The basic guidance for the modelling procedure was the requirement to allow principally a calculation of costs and factor needs for any reasonable design. Thus, it became necessary to establish a very detailed projection of the real building activities. To reach the best adaptability to any particular construction type, the program was designed as a sum of additively connected "modules" of the various construction elements like, for example, "Concreting of a Fundament" or "Insertion of a Window." The natural expenditure to construct such a building element is characterized by:
- the kind and quantity of the materials included in the element,
- some plant and equipment to carry out the work, and
- a certain amount of working time.

Thus, the system provides for the data to calculate the expenditure for a single element. To avoid redundancy, some 500 different materials, plant, and equipment are stored separately in a data base. Every item is stored in a definite form, including description of the item, a standard unit for calculation, and retrieval digits.

Unlike the material, the working time required for a special task is generally not a fixed figure, but depends on a number of influence factors such as dimensions of a construction part, availability of proper equipment, or training of the performer. Considering these interdependencies, some 130 basic working time data are stored as working time functions.

These functions have been validated on a number of different farm construction sites in 1982 and 1983. Generally, the discrepancy between calculated and measured data proved to be within a reasonable range (Nacke, 1983). However, some of those tabulated data were obviously adjusted to very large construction sites with specialized equipment, so that the model underestimated the real working time by far. In these cases, as well as for specific construction works to be found only at agricultural sites, additional functions have been measured on several sites using the time element method of REFA (1972).

Commonly, the building industry uses the multimoment-study as the appropriate method for worktime studies, but for the comparatively small size of most farm construction sites, this approach proved to be inappropriate.

Within the module for every small construction element, now the relationships between the different types of input factors required for the element are specified. Every module calls the related basic data for material and equipment and quantifies the number of required units. In a similar way, it chooses the appropriate working time functions and specifies the actual value of the function variables.

The adaptability of a module is provided by the "list of influence factors." This list contains all important variables to enable a proper calculation of the natural expenditures for one element. Thus, the list contains variables to enable, for instance, the dimensions of a construction part, the specific type of required material, or the equipment available at the site (Figure 1).

For convenience, all variables have default values, valid for average structures under average conditions, which may be overwritten by more appropriate specific values within every calculation.

Calculation of Capital Requirements

Capital requirement to accomplish a building element is a result of the sum of required materials and the necessary working time to accomplish the task, multiplied with the appertaining price per unit. Additionally, a proportional price for the use of plant and equipment has to be taken into account. Thus, the cost calculation can be performed easily by relating a price file to the basic material, equipment, and labour data. A simple sub-routine then can multiply the results of the natural input factor calculation with the wages and unit prices for every item. For a complete building, several extra costs still have to be considered, but can all be modelled in a similar manner.

```
L I S L            Landtechnik Weihenstephan, Nov 29,84             K A L D O K (V4C)
*********************************************************************************

Calculation of Model 1050: Foundation (4th level model)
=================================================================================
(Replace default values, if convenient)


        Actual Values of Influence Factors (Model No. 1050)
        ---------------------------------------------------
 1. Number of identical foundations                              1.00 Foundation(s)
 2. Length of the foundation wall                               50.00 Meter
 3. Width of the foundation wall                                60.00 Centimeter
 4. Height of the foundation wall                                0.65 Meter
 5. Foundation with Footing? (0=yes; 1=no)                       1.00 (Code)
 6. Material: 1=concrete; 2=concrete masonry; 3=combin.          1.00 (Code)
 7. Forming? (0=no; 1,2,3...=No. of sections)                    2.00 (Code)
 8. Reinforcement Code (see Contents!)                           2.00 (Code)
 9. Concrete order: 1=self-mix; 2=ready-mix                      1.00 (Code)
10. Concrete Type (5=B5; 10=B10; 15=B15; etc.)                  25.00 Concrete Code
11. Number of recesses                                           3.00 Recesses
12. Average size of the recesses                                 0.30 Square Meter
13. Concrete working layer necessary? (0=no; 1=yes)              1.00 (Code)
14. Labour efficiency in percent                               100.00 Percent
```

Figure 1. List of Influence Factors

Aggregation

Depending on the site and diversity, up to a hundred and more element models have to be computed once or several times to calculate the total expense for a given structure. Obviously, this procedure is not really practicable. In consequence, an aggregation becomes necessary.

For the system KALBAU, a hierarchical structure of aggregates on four different levels has been built, each element of a level functioning as a sub-model of the preceeding level. Hierarchical structure means that each sub-model on the first aggregation level comprises the calculation range of several of the basic modules. The second aggregation level does not refer directly to the basic modules, but comprises again several sub-models of the first aggregation level, and so forth. Running the program, every aggregated sub-model refers to those it has been derived from, so that finally the real calculation is always performed within the basic modules (Figure 2).

Just as the basic modules, the aggregates on higher levels contain lists of influence factors. These lists, however, do not include all the variables of those sub-models it has been derived from. The aggregates are rather showing only the most significant variables to properly identify the structure it shall represent. Within the aggregates, some calculations are automatically performed as well to compute some so-called auxiliary-variables, which correspond to the variables of the sub-models on the next lower level. Calculating the program, the values of variables and auxiliary-variables are transferred and replace the related variables in the sub-models of the next lower level. As only the most significant variables are overwritten, the remaining influence factors are assumed to be correct with their default values.

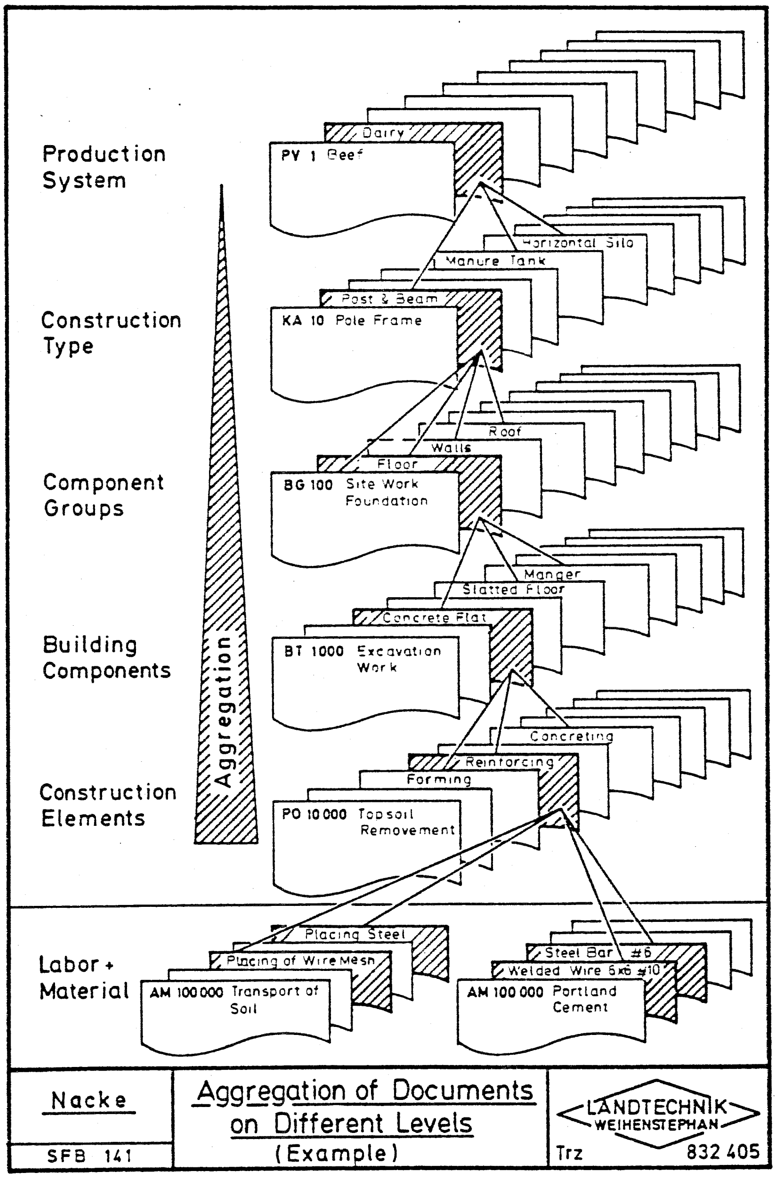

Figure 2. Aggregation of Documents on Different Levels

Data Organization

The previous description already suggests that the program comprises a considerable number of sub-models, modules, and basic data. To certify a definite system structure and a trouble-free use of the program, each sub-model, working time function, or item of material has the same data structure, called a "document." Each document is designed for up to ten sections with one hundred lines each. Presently, just five to six sections are occupied, so that there is enough room for further enlargement of the system. The contents of each document is dependent on the objectives of the whole system. In addition to formula, functions, and the list of influence factors, a document contains a description of the construction the document should represent in order to clarify the calculation path. The "contents" section functions as a help device and provides information about interpretation of certain variables, validity of data, or restrictions for a meaningful use of a document. As far as the documents of the basic level contain worktime functions, statistical information such as distribution parameters, F- and t- values, and correlation coefficients are documented. Figure 3 gives an overview of the further contents of the different sections.

Section	Line-No	DOCUMENT SECTIONS AND CONTENTS	
1	1 ... 100	No. XXXX	Identification Code Title, Author, Locality Date of Creation and last Update Starting and Ending Point
2	101 ... 200	CONTENTS	Annotations and User Restrictions Explanation of Model Flow Chart Explanation of Influence Factors Interpretation Aids
3	201 ... 300	INFLUENCE FACTORS	No. of Influence Factors and Sec. Var. Definition of Influence Factors Default Values, Dimension Definition of Secundary Variables, Dimension
4	301 ... 400		
5	401 ... 500	DATA AQUISITION	Influence Factors Local Definition of Data Storage Storage Format and Dimension
6	501 ... 600	FUNCTION	Function incl. Statistics, OR No. of Sub-Models to be recalled Formula to compute Secundary Variables Selection of Sub-Models, Transfer of Values
7	601 ... 700		
8	701 ... 800		
9	801 ... 900		
10	901 ... 1000		

Auernhammer Nacke	CONTENTS OF DOCUMENT SECTIONS	LANDTECHNIK WEIHENSTEPHAN Pö 832 399

Figure 3. Contents of Document Sections

All documents are organized in a strictly hierarchical structure on the basis of the decimal system (Figure 4). At the highest, most aggregated level (No. 1-9), documents allow a calculation of complete "building systems" for dairy facilities, hog fattening structures, etc. The next lower level comprises sub-models for different "building construction types" such as pole frame or rigid frame constructions. At the third level, with 3-digit ID-numbers, one can find "building part groups" like sub-structure or roof. At the next level, with sub-models numbered 1,000 to 9,999, "building parts" such as stable floors or walls for a milking parlour may be calculated. For "building elements," which are the basic modules, ID-numbers from 10,000 to 99,999 are reserved. The basement of this pyramid structure finally consists of the natural input factors (materials, equipment, and working time functions) with 6-digit codes from 100,000 to 100,999. Of course, the basement may be extended to up to 999,999 documents.

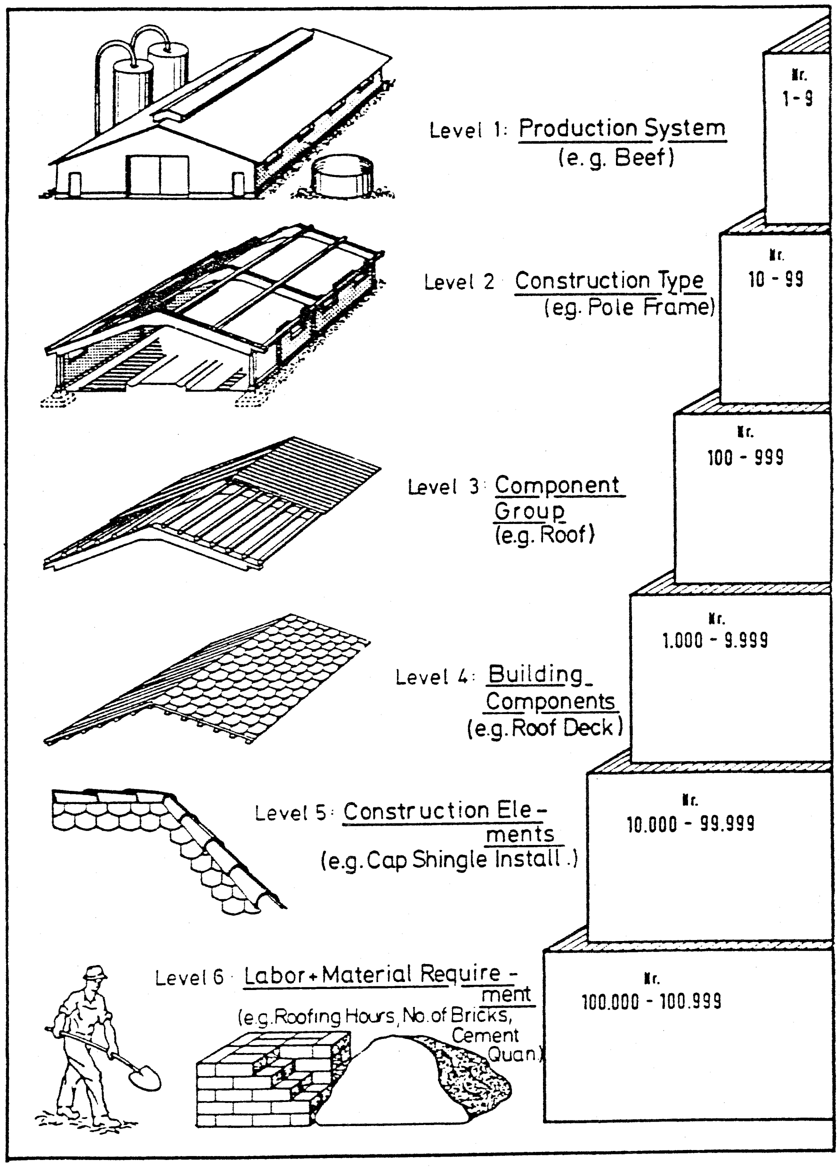

Figure 4. Hierarchical Document Structure

Operating the System

As previously described, the methodical build-up of the system started from element modules through some aggregation steps to documents, which represent complete production facilities. Common agricultural structures have been analyzed down to the individual components they consist of. The assembly of those components to building elements has been modelled, and those modules have been aggregated to sub-models of different levels.

Running the system, the program operates recursively. The user has the option to select a document from any level to start with. He may check the default values of the influence factor list and update the list with his specific data, if appropriate. The system itself then calculates necessary secondary variables, calls the related sub-models on the next lower level, and updates the variable values of those models, respectively (Figure 5).

Through repetition of this procedure, the program reaches the basic level and finally calculates the natural expenditure for materials, equipment, and the worktime requirement. Relating the unit prices of the price file to the results of the natural analysis, the expected monetary expenditures are obtained as well. In a second step, the program reaggregates the results step by step, enabling the user to control exactly how the total expenditure is composed (Figure 6).

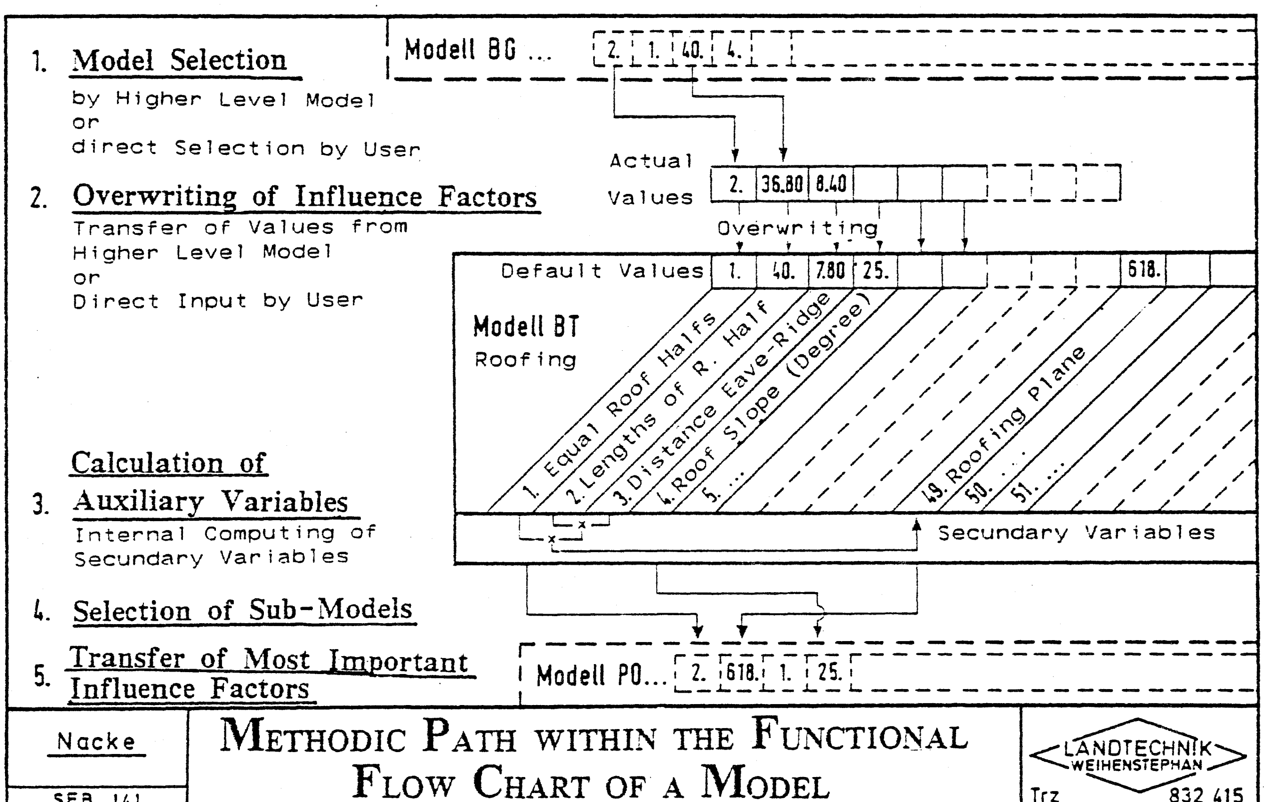

Figure 5. Methodic Path within the functional Flow Chart of a Model

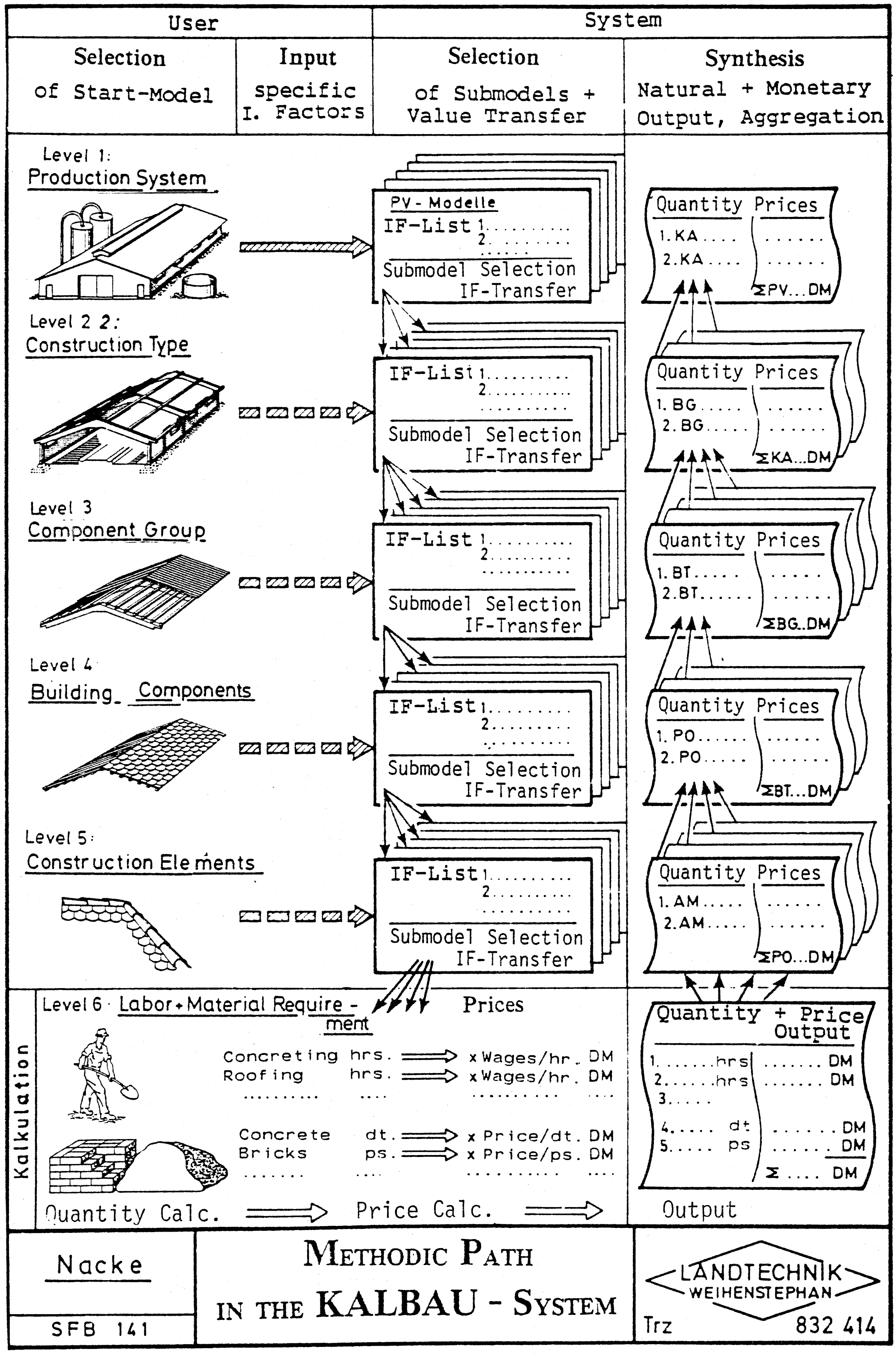

Figure 6. Methodic Path in the KALBAU-System

As a result of the system structure, users may individually determine the accuracy of calculation by selecting the entrance level. As mentioned earlier, always just the most significant variables of a document appear in the documents on the next higher aggregation level, which call back to this sub-model. Hence, to calculate a given structure, a user may choose one or just a few highly aggregated models with the consequence that, in the course of the calculation, many variables are included with their default values, which may not always be accurate. Starting alternatively on a lower level increases the potential accuracy, but increases the number of models to be chosen and specified by the user himself as well, so that the calculation ends up to be a more time-consuming process. However, calculations with more differentiated models of lower levels allow more precise planning, not just for complete units, but also for partial new constructions and reconstructions.

Within every calculation, users may not just change the default values of influence factors, but adapt all prices and wages to their individual market situation. This feature seems to be very important as prices and wages vary highly with region, and additionally, farmers achieve special contracts, which are just valid for an individual project. In the same way, users may create their individual price file, which will be loaded automatically in each of their calculations. Individual variation of wages and labour-related influence factors will also help to come to a head in the question, whether a structure should be built by a contractor, in material + direct labour fashion, or as d.i.y. projects.

Calculation Output

Users can obtain numerous informations on the strength of the system structure. A calculation output will give detailed information about the horizontal and vertical structure of required natural input factors and costs of a proposed structure (Figure 7). In detail, the output shows:

- worktime requirement and labour costs for every single item to be constructed,
- totalized worktime requirement and labour costs for all different tasks like concreting or brick laying,
- the amount of all input factors and the related costs for every building element, building part, building part group, etc.,
- a complete listing of natural amount as well as absolute and percentage costs for all items necessary for the construction,
- absolute and percentage costs of carcass and interior, and
- absolute and percentage costs of wages and of all different material groups.

Program Requirements and Availability

The KALBAU-system to provide informations for farm building construction is a part of LISL, the "Landwirtschafliches Informations-System Landtechnik" (Agricultural Information System for Engineering), which is developed at the Institute of Agricultural Engineering at the Technical University of Munich, West Germany.

Bill of Labour, Material, and Prices: Document 1050 - Foundation   Nov 29, 1984

	Unit	Building Elements Quant. (units)	Price /Unit	Element Price	%	Element Groups Group Price	%	Total Price	%
A. LABOUR - REQUIREMENTS									
3 Reinforcing									
35 Placing Welded Wire	hrs.	3.39	37.60	127.40	6.0	127.40	6.0		
4 Concreting									
41 Concreting Working Layer	hrs.	1.71	37.60	64.13	3.0				
43 Concreting Foundation Walls	hrs.	24.13	37.60	907.46	42.9				
48 Preparing Time for Concreting	hrs.	5.95	37.60	223.84	10.6	1195.40	56.6		
Total Labour Requirements		35.18				1322.80	62.6	1323.	62.6
B. MATERIAL									
2. Aggregates, Binders, Concrete									
20 Cement									
200 Portland Cement, 350 F, Type II, bagged	dt	43.30	14.90	645.20	30.5	645.20	30.5		
22 Aggregates									
225 Concrete Gravel 0/32 mm	to	2.25	13.80	31.10	1.5				
226 Concrete Gravel 0/64 mm	to	30.74	0.0	0.0	0.0	31.10	1.5		
						676.30	32.0	1999.	94.6
5. Steel and other Metals									
50 Reinforcement Steel									
508 Welded Wire - R 221 - (5.0 x 2.15 M)	to	0.12	945.00	114.34	5.4	114.3	5.4		
						114.3	5.4	2113.	100.0

Figure 7. Output Example (horizontal)

KALBAU is an extension of KALDOK, a program to calculate labour requirement for all kinds of work to be done in livestock and crop production (Auernhammer, 1975). Besides it, similar programs, based on the same document structure, have been developed to calculate farm machinery costs and the economics of the use of biogas.

To ensure the compatibility of LISL, all programs are written in the FORTRAN IV programming language. In addition, a FORTRAN V version is available.

The KALDOK and KALBAU systems are running at a CYBER 175 and an IBM 3081 at Munich. Furthermore, the programs have been implemented at different computer systems at Zurich (Switzerland), Wageningen (Netherlands), Silsoe (Great Britain), and at last at an Amdahl 470V at Texas A&M University.

The presented system is not yet completed in all its parts, but can already be used for several construction types common on German farms.

References

Auernhammer, H. Eine integrierte Methode zur Arbeitszeitanalyse. (An Integrated Method for Worktime Analysis.) Muenster, West Germany: KTBL-Schriftenreihe Nr. 203, 1975.

Auernhammer, H. and E. Nacke (ed.). Arbeitszeitkalkulation in der Landwirtschaft mit dialogfaehigen EDV-Programmen an Groß- und Kleinrechnern. (Worktime Analysis in Agriculture with Interactive Programs for Micro- and Mainframe Computer Systems.) Freising, West Germany: Institut fuer Landtechnik, 1981.

Duncan, G.A., D. Walters, and S. Duncan. A Building Materials and Cost Estimator Computer Program. American Society of Agricultural Engineers, Paper No. 83-5026, 1983.

Harsh, S.B., J.L. Connor, and G.D. Schwab. Managing the Farm Business. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1981.

Krabbe, H. "Computerized Building Cost Calculation: Work in Progress." Unpublished Report, Danish Building Research Institute, Hoersholm, Denmark, 1979.

Nacke, E. "Methode zur Analyse und Minimierung des Investitionsbedarfes landwirtschaftlicher Betriebsgebaeude." (A Method for Analysis and Minimization of Capital Requirement for Farm Buildings.) Kostenguenstige Gebaeude fuer die Landwirtschaft. Braunschweig (Inst. f. landw. Bauforschung), West Germany: CIGR-Documentation, 1982: 601-614.

__________. Ein Modellkalkulationssystem zur Ermittlung des Investitionsbedarfes landwirtschaftlicher Betriebsgebaeude - dargestellt am Beispiel verschiedener Stallsysteme fuer die Milchviehhaltung. (Methodic Comparison of Capital Requirement for Different Dairy Housing Systems on the Base of a Building Cost Calculation System.) Freising, West Germany: Forschungsbericht Agrartechnik der MEG, No. 91, 1983.

N.N. Cost of Buildings Handbook. Maff Publications Unit, Reading, Great Britain, 1982.

Verband fuer Arbeitsstudien -REFA- e.V. Methodenlehre des Arbeitsstudiums. (Methodology of Time Study.) Muenchen, West Germany: Carl Hauser Verlag, 1972.

Wight, H.J. "The Use and Sources of Farm Building Cost Information." Farm Building Progress. 62(1980): 17-20.

Wight, H.J. and J.J. Clark. Farm Building Cost Guide. Scottish Farm Building Investigation Unit, Bucksburn, Aberdeen, Great Britain, 1983.