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An Integrated System for Design/Build Firms to Solve Cost Estimation Problems in the Design Phase

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One of the basic problems that architects encounter during the design process are keeping costs within the budget given by the client and warning the client about the impacts on building costs of various decisions. The calculation of the impacts of alternative decisions on the cost of the building must be a continuous activity. The models developed for architectural practices and construction companies should provide tools that integrate this activity into the building production process. In certain project delivery systems, e.g., design/build, the continuity and integration of the cost estimation function gains importance. That is why the cost estimation system should be designed not only to meet the requirements of a particular phase of a project (i.e., design, bidding, construction, or operation) or a certain type of firm that undertakes the project (i.e., architectural office, client organization, or contracting company) but also to integrate the information systems used by the organizations undertaking different roles in the various phases of the building production process. This paper presents an integrated system (MITOS) and its cost estimation module that have been designed primarily for design/build firms, i.e., firms or alliances of firms that do both design and construction. The cost estimation module was designed to achieve integration and continuity of the cost estimation function by introducing a model that is based on project-based productivity information in similar past projects.

Abbreviations

ABUP Table	Table of Unit Prices based on Analysis of production
C-VAR	Cost Variance
CH-GR	Group of Characteristics (parameters)
D-VAR	Duration Variance
F-COEF	Final Productivity Coefficient
F-COEF$_{TEAM-A,\ PRJ-Z}$	Final Productivity Coefficient of Team-A in Project-Z
PIPC	Production Item Performance Coefficient at activity level
PJC	Project Level Productivity Coefficient
RPV	Revised Productivity Value
SPV	Standard Productivity Value
TC-VAR	Total Cost Variance
TD-VAR	Total Duration Variance
TGPC	Team Group Level Productivity Coefficient
TMNR	Number of Teams assigned to perform the activity
TPC	Team Level Productivity Coefficient

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Introduction

The basic characteristics and purpose of project estimating are different in the various phases of the building production process. Therefore, the outputs of the estimating activity performed by different professionals in different phases vary. The estimated costs sometimes may have significant variations due to the effects of unforeseen factors related to basic parameters of *design,* e.g., buildability, complexity; or *construction,* e.g., location of project, weather conditions and their effect on labor productivity, problems related to procurement or availability of materials, labor and equipment in some locations, etc. The causes of inaccuracy in cost estimating were investigated and ranked by their reliability values in a study by Akintoye [1].

In preliminary design, the cost estimating function aims to expose whether the budget specified by the client is exceeded. It is also to inform the client about the impacts of the decisions made on project cost. The modeling tools used in cost estimating are classified into four groups: (1) experience-based (algorithms, heuristics, expert system programming); (2) simulation (heuristics, expert models, decision rules); (3) parametric (regression, statistical models, decision rules); and (4) discrete state (linear programming, classical optimization, network). Akintoye and Fitzgerald [2]] investigated the reliability of various cost estimating techniques. The most popular three methods (estimating standard procedure, comparison with similar past projects based on personal experience, and comparison with similar past projects based on documented facts) are within the domain of "experience-based" models. The authors claim that range cost estimating techniques combining Pareto analysis, heuristics and Monte Carlo simulation, eradicate or at least significantly reduce the risk associated with cost estimates. Munns and Al-Haimus [3] reported the findings of their research on cost significant global cost models that are based on Pareto analysis. Another study by Akintoye and MacLeod [4] identified the reasons of not using these methods as the lack of familiarity with the techniques, the degree of sophistication involved in the techniques, doubts whether these techniques are applicable to the construction industry, among others. Dissanayaka and Kumaraswamy [5] report that multiple linear regression (MLL) and artificial neural networks (ANN) were applied in developing such quantitative models and ANN had better prediction capabilities compared with MLL. Adeli and Wu [6] state that the traditional statistical approaches to the curve-fitting problem, such as regression analysis, fail to represent problems with no explicit mathematical model accurately in a multidimensional space of variables whereas the neural network approach can solve such problems more effectively. The studies stated above provide different theoretical solutions to the problem cost estimating and can be suitable for different individual cases, but none of them attempts to apply these theories in an integrated application model that involves the several parties and several phases of a project.

Models such as BCIS – Building Cost Information System [7], the EVALUATOR, a part of SPACE - Simultaneous Prototyping for an Integrated Construction Environment [8], OSCON – Open Systems for Construction [9] and COMPASS – Cost Management Planning Support System [10] can be cited as successful examples of integrated information systems that provide cost estimating facilities as well.

In this paper, an integrated model was developed with a holistic look, not only to facilitate cost estimating but also to perform other management functions such as *cost, time, procurement, suppliers,* and *materials management* in the building production process. The outline of the suggested approach to integrate the cost estimating function into the management activities of design/build firms is presented in the following sections.

Definition of the Problem

Any cost estimating model should take into consideration the *construction* phase parameters in addition to *design* characteristics for more accurate estimating in the design stage. Ignoring one of these sets of parameters can result in an inaccurate and unreliable project estimate. Contractors will certainly determine their bid price by considering both sets of parameters. The same approach is unavoidable for design/build firms, which are firms or alliances of firms that provide both design and construction services, or for independent design firms and construction companies as long as they are cooperating on the same project.

In some cases, the project delivery system allows basic cost management functions to have continuity not only within a phase but also throughout the whole building production process. If certain organizational patterns such as *design/build* are preferred, certain arrangements for determining cost such as *cost reimbursement* are provided, certain process structures such as *fast* *track* are used in a project, the *continuity* and *integration* of the function will be unavoidable. That is why a cost estimation system should be designed not only to meet the requirements of a certain phase (design, procurement, or construction) or a certain type of firm (architectural office, consulting firm, or construction company) but also by integrating the information systems of the organizations undertaking different functions in subsequent or parallel phases of the building production process. The databases used for cost estimation in the design or construction phases provide an architecture that does not take into consideration the impacts of project-specific and site-specific parameters on productivity, neither are these effects reflected on unit prices and the project estimate.

One of the basic project-specific problems that architects encounter in the design process is keeping the building cost under the budget specified by the client. Another problem is informing the client about the impacts of various decisions on building costs. The evaluation of the impact of alternative decisions on building cost must be a continuous activity during the design stage. The models developed for architectural practices should provide this kind of tools for architects. Although some of the CAD software provide this facility automatically, they have limitations and there is a significant amount of criticism on the rigour of their calculations and integration to the other functional information system components [11]. These software automatically extract the quantities of building components from the design and calculate building cost on the basis of a database of input items and their associated rates defined by the user or information providers. This feature makes these CAD software appealing compared to software where the user needs to take off the quantities of building components manually or through a digitizer. But design alternatives must be produced in a CAD environment first to calculate the costs of alternative solutions. This may be a time consuming approach compared to defining or replacing the types or quantities of production items in the takeoff list manually. The use of CAD software by bidders to estimate the cost of a project is very limited. Also, the measurement rules and units adopted by these software in measuring quantities and calculating the cost of building components may not agree with the standards adopted in some countries. Moreover, each stage of the design process allows the use of different methods of cost estimating. For example at the preliminary design stage, it is not possible to use estimating methods based on detailed production items. Likewise, after finishing detailed design, a more detailed takeoff list is often demanded. The CAD software must be supported by databases that allow the use of both approaches stated above. Additionally, the databases defined by the users or provided by the information providers include average, approximate or selected values for the rates or unit prices of input items. Mostly it is not possible to define alternative sets of supplier-based unit prices in these database structures making it impossible to assign specific prices to the building components.

Estimating the construction cost of a given building is not a final operation at the end of the design stage. The building cost should be calculated throughout the building production process. That's why the models developed for the automation of architectural practices and for contractor companies should include a component that fulfills the cost estimation function and this component must:

- support different cost estimation methods that can be used in different stages of the building design process,
- expose in a short time the impact of design-related decisions on building cost in various phases of the building production process,
- be available to designers, consultants and construction contractors,
- be integrated into information systems of the different types of organizations involved in a construction project,
- provide the continuity of cost estimation/ planning/control functions throughout the building production process,
- be linked to a database that is updated periodically and based on a supplier-based real world rates and unit prices,
- provide a model that takes into consideration the impacts of project-specific parameters on labor productivity and these effects must reflect on the unit prices and project estimate as well.

The problem is that there is a lack of practical cost estimating models that are designed to meet all the requirements of the building production process from the beginning of design to the end of the construction phase. The ideas of *integration* and *continuity* throughout the building production process need to be applied to the cost estimation function. New models need to be developed that function with interrelated databases reflecting the effects of *project and site-based construction productivity* *parameters* extracted from projects that have similar characteristics.

MITOS: An Integrated Automation System

The idea of managing efficiently the functional components of a construction company or a design firm by means of computer applications is not new. Various studies that attempt to solve the integration problem can be located in the literature [12-17]. Other examples include reference or application models such as RATAS - Infrastructure for Computer Integrated Construction [18], I3CON - Intelligent Integration of Information in Construction [19], COMMIT - Construction Modeling and Methodologies for Intelligent Information Integration [[20], COMBINE - Computer Models for the Building Industry in Europe [21].

MITOS (**M**ulti-phase **I**ntegrated Au**to**mation **S**ystem), a relational database model, was designed for solving the integration and continuity problems stated earlier. The conceptual structure of the model is presented in Figure 1.

The basic components of MITOS are:

- ASAP (**A**utomation **S**ystem for **A**rchitectural **P**ractices)
- ASCC (**A**utomation **S**ystem for **Co**nstruction **C**ompanies)

These basic components of MITOS use the same external components for certain functions. These components can be used individually and independently or can be integrated to these systems. The shared components are:

- ASCE (**A**utomation **S**ystem for **C**ost **E**stimation)
- MS PROJECT (Project Planning and Programming Software)
- SIS (**S**uppliers and **I**nput Items Information **S**ystem)
- QIS (**Q**uality **I**nformation **S**ystem)
- AXIS (**A**cademic e**X**ternal **I**nformation **S**ystem) Library Module

After the conceptual model was completed and different software architectures were considered [[22], the model (MITOS) was converted into a relational database in an object-oriented environment. The database file was developed in *MS Access for Windows'95* and then the help and content files were prepared by *MS Access Help Workshop* and finally all the files were compiled and prepared for an automatic setup process by *MS Access Developer Toolkit*.

Five of the components of MITOS, i.e., ASAP, ASCC, ASCE, MS PROJECT, and SIS are essential for the operation of the cost estimation module presented in this paper as each provides some of the information required in the cost estimation process.

ASAP: Automation System for Architectural Practices

There are only few conceptual and practical models that were developed as a response to the needs in the design stage, such as those developed by Platt [23], Baldwin et al. [24]; Tippett and LaHoud [25], Mokhtar et al. [26] and Eldin [27]. However, any comprehensive conceptual or application model especially designed for architectural offices could not be located in the literature. ASAP (**A**utomation **S**ystem for **A**rchitectural **P**ractice) was developed by Kanoglu [28] for solving the information handling and management-related problems in architectural offices by taking into consideration a holistic view of the design process (Figure 2). All information is organized in the *Projects, Clients, Engineering Offices, Suppliers, Human Resources, Time, Design, Cost, Communication, Quality, Archive*, and the *Library Management* Modules.

ASCC: Automation System for Construction Companies

ASCC - Automation System for Construction Companies is the outcome of a research project [29] whose aim was to develop a management information system for construction contractors. The model contains the *Projects, Clients, Subcontractors, Suppliers, Human Resources, Time, Design, Materials, Equipment, Cost, Communication, Quality*, and the *Procurement Management* Modules organizing various sets of information required by related management functions. The standard performance values of the teams in various trades is an important piece of information that is used in the cost estimating process and these values are generated by the Teams and Productivity Submodule of the *Human Resources Management Module.*

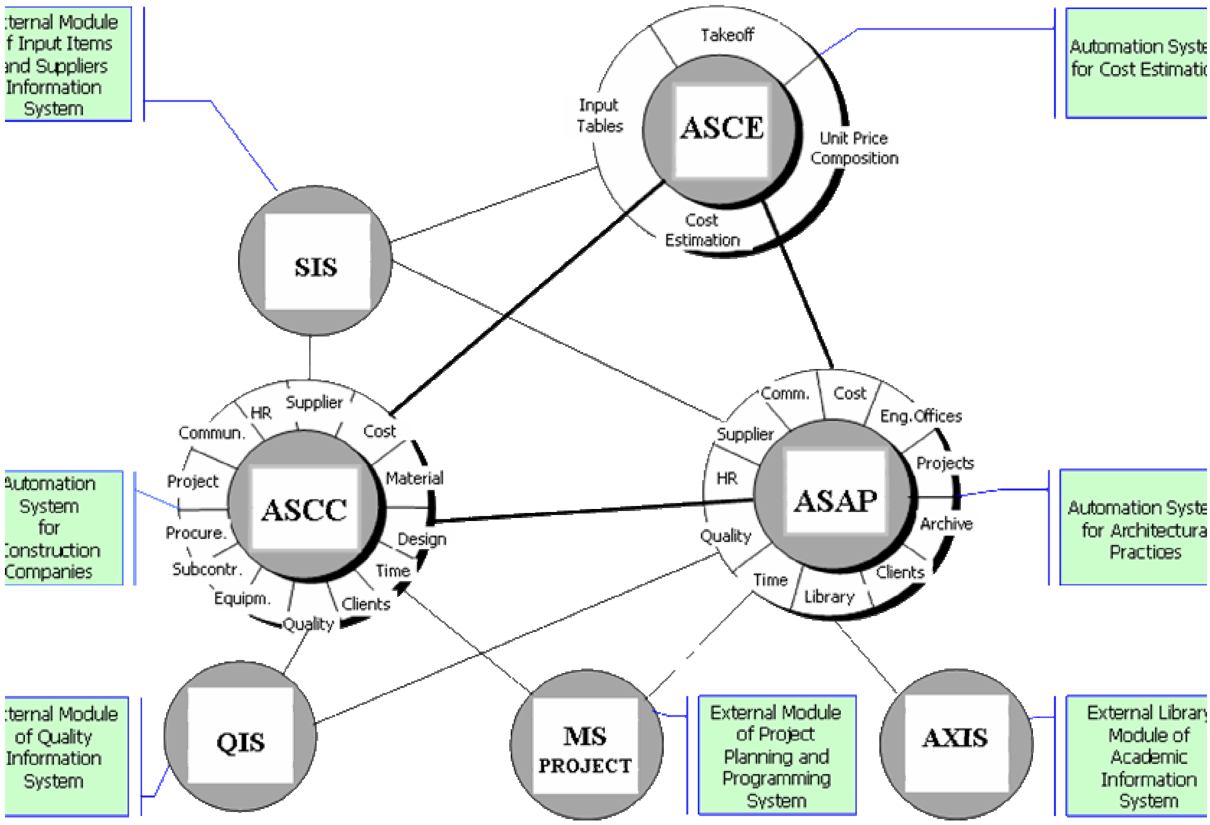

Figure 1 The conceptual structure of MITOS

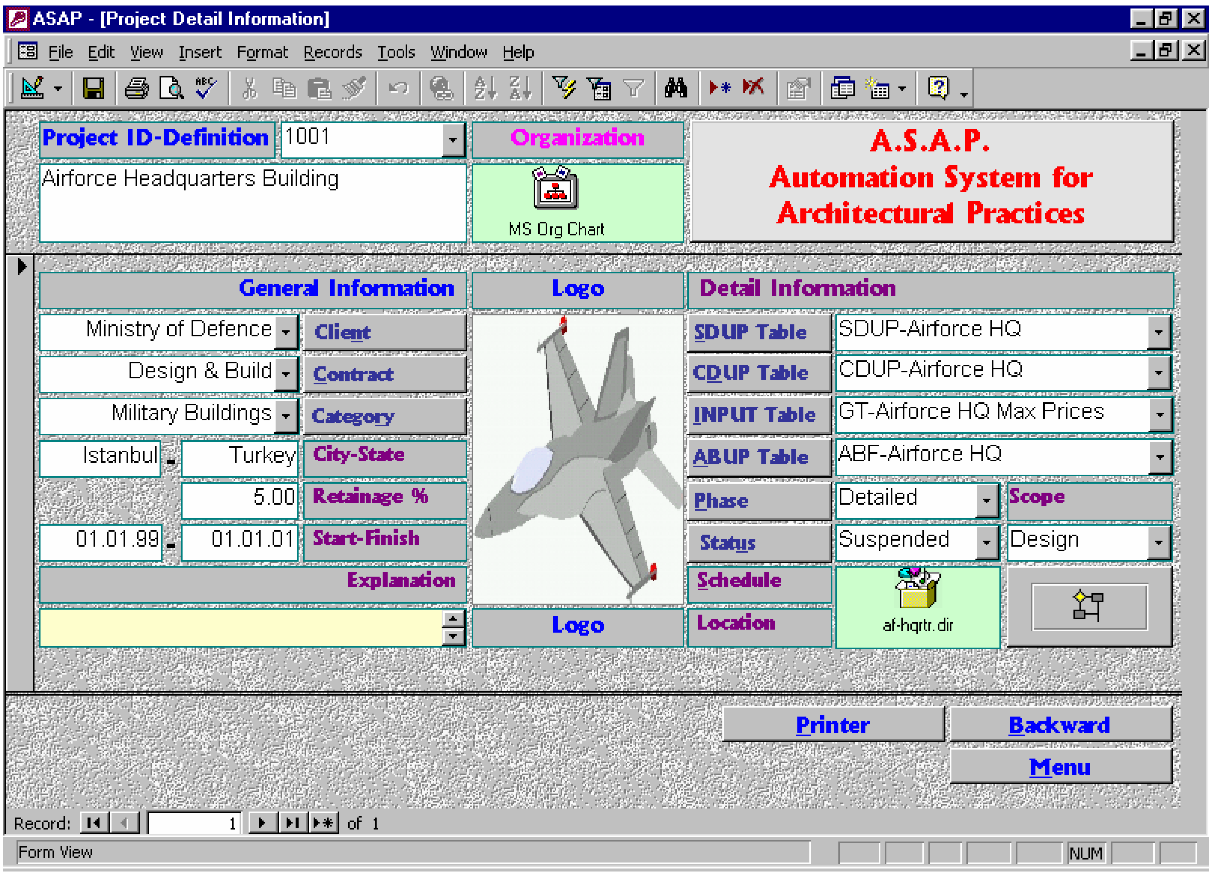

Figure 2 Project detail information

MS PROJECT: Project Planning and Programming System

Large design offices have to maintain a complex production process in which a large number of participants take part. In order to save time, coordination must be provided not only among these participants but also among the sub-processes of the projects. MITOS calls on MS PROJECT – Project Planning and Programming System, not only for project planning and programming purposes but also for the cost estimating process which requires as-built project information as well as team group level and team level performance data.

Using a commercially available software for project planning and programming that provides performance data for the cost estimation process is a more reasonable solution than developing a module from scratch. The reasons and enabling technologies for using such packages are explained clearly by Rao et al. [30] and Wu and Hadipriono [31]. *MS Project for Windows 98*, a low-end project management software, has been integrated to the model for the management functions related to time, cost and resources in design offices. The relational database file created by MS PROJECT and saved in (mdb) format consists of several tables. Four of them, i.e., project, task, resource, and resource assignment tables, are essential for the integration of components mentioned earlier. The relationships of the database files are seen in Figure 3.

SIS: Suppliers Information System

The Suppliers Information System is not an optional component. It is needed by and linked to all the three components ASAP, ASCC, and ASCE. The supplier companies are defined by ID and name and they are classified according to the input category (labor, material, equipment) they deal with. International standards, such as CI/SfB are used in this module for coding input items. A list of input items supplied by the companies, the normal and firm-specific discounted rates/unit prices, and specifications associated to these input items and companies that supply specific input items can be obtained by applying filter parameters, such as supplier, material, CI/SfB code, etc. The inputs supplied by different firms and their unit prices are used by the *Cost Estimating System* for creating alternative input tables. These tables can be assigned to the current project to calculate alternative project estimate.

ASCE: Automation System for Cost Estimation

The cost estimation system is one of the independent components integrated to MITOS and comprises four modules, i.e., input table composition, production item (PI)/building component (BC) unit price composition, takeoff and cost estimation modules (Figure 4). This component obtains the unit price information from the *Suppliers Information System*. The database in this system provides supplier-based up-to-date information of the rates and unit prices. The *Cost Estimation System* allows the user to compose unlimited sets of alternative input tables. Thus, the cost information used in the estimation process is based on supplier-provided real values. Variations in estimation (if any) may only stem from the project and/or variations in team performance caused by unforeseen factors. As already stated, a reliable model should take into consideration construction-related parameters in addition to the characteristics of the design for more accurate estimating throughout the design phase. Ignoring one of these sets of parameters is likely to result in inaccurate and unreliable project estimates and this in turn will increase the number of claims and disputes during the construction phase.

The module allows the user to define/import project takeoff items at different stages of design. At the conceptual design stage takeoff items can be defined in terms of quantities of building components. After completing detailed design, it is possible to define takeoff items in terms of production items if desired. The items are chosen from a periodically updated database in the *Suppliers Information System*. It is possible to compose alternative input sets in different *input tables* and the client can be informed about the impacts of alternative input sets on project cost by assigning alternative input tables to the current project consecutively. The user can also define an unlimited number of sets of unit prices (Figure 5). These tables may include an unlimited number of production items (Figure 6). These sets use input tables for calculating alternative results for project estimates. Thus, the unit prices of the production items (PI)/building components (BC) are automatically calculated based on the unit price and input tables assigned to the project. When the user defines production items and their quantities in the project, the price of the item is automatically calculated and the project estimate is updated in the cost estimation table.

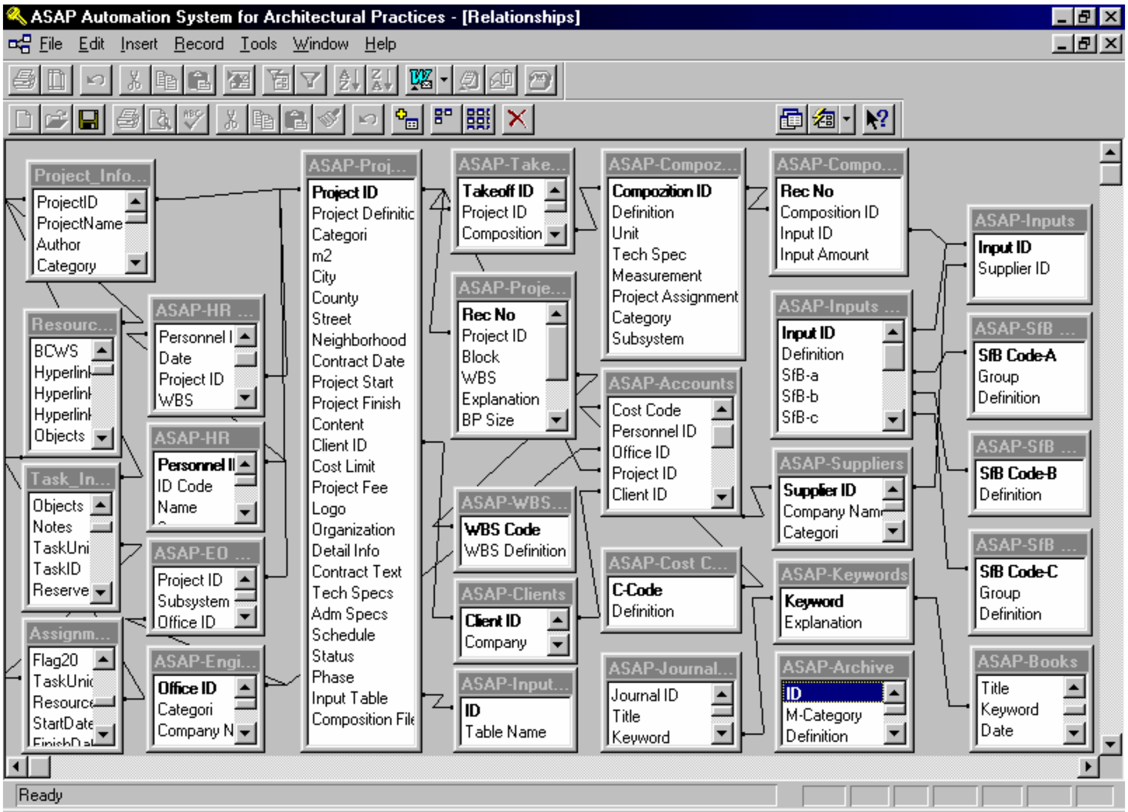

Figure 3 The partial relationships screen of the integration of MS Project and MITOS

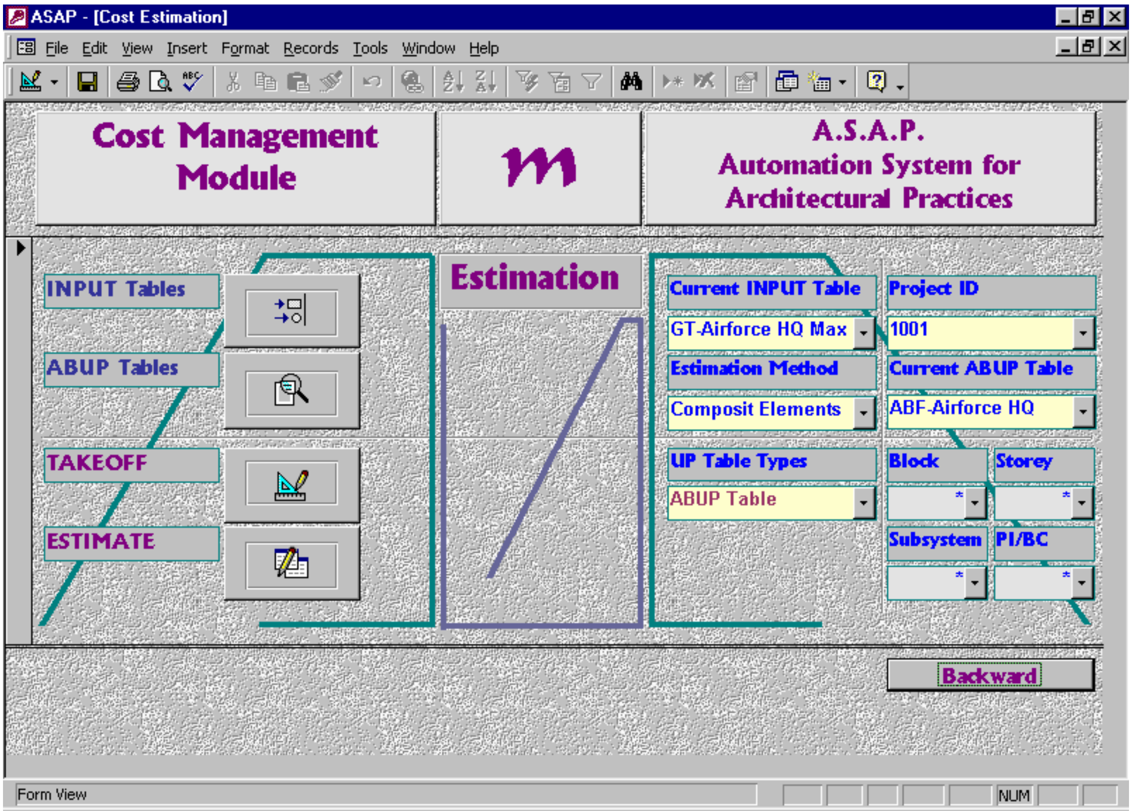

Figure 4 The cost estimating system

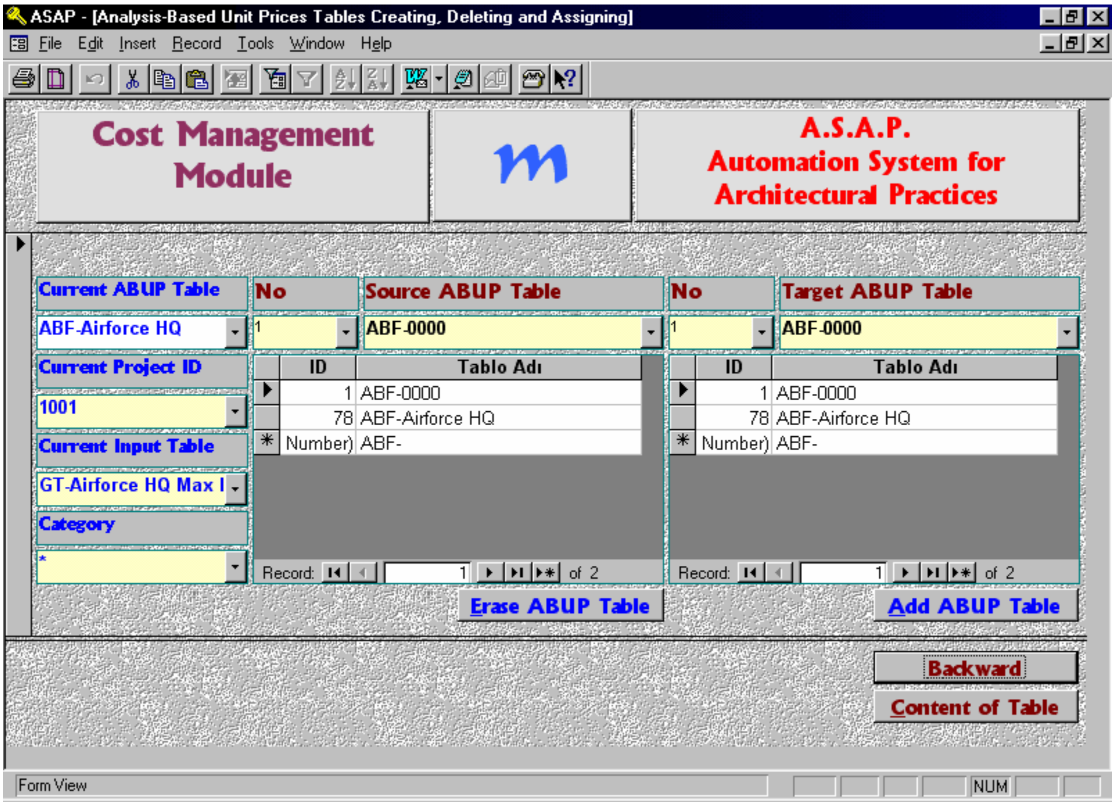

Figure 5 Assignment of input tables (IT) and analysis-based unit price (ABUP) tables to projects

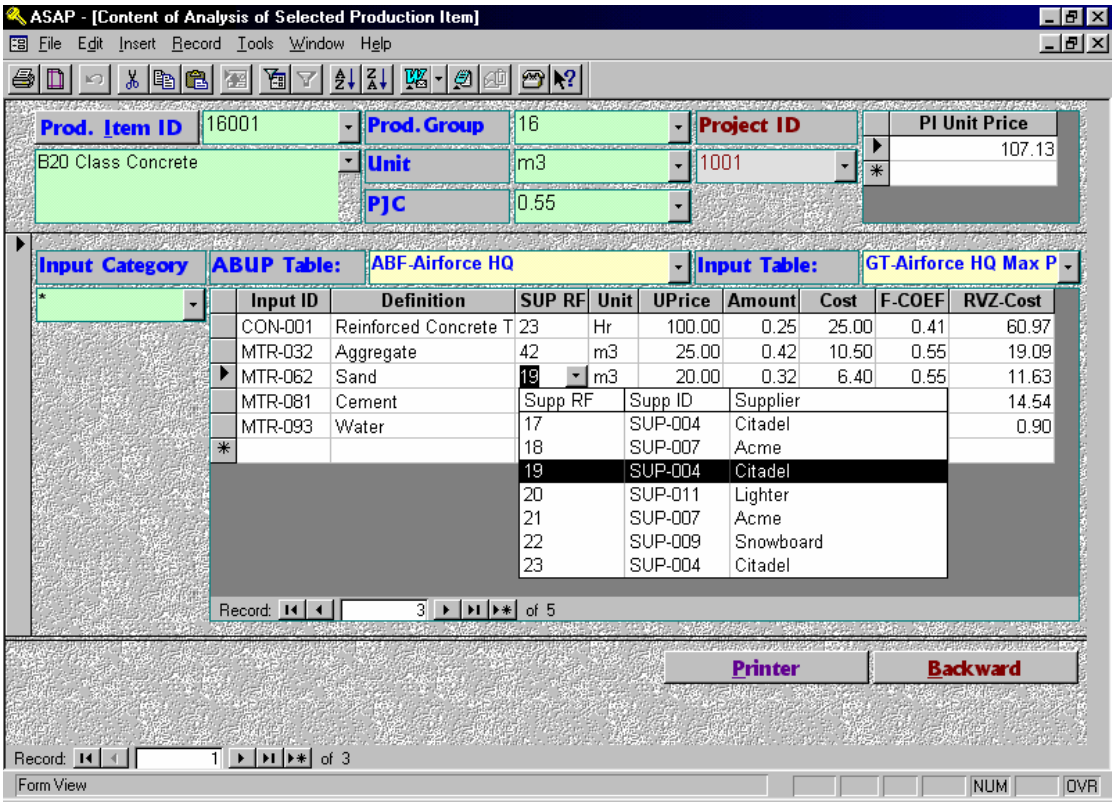

Figure 6 The composition of unit price of production items and calculation of project estimate by revised prices

The Process of Performance-Based Cost Estimation

Basic Concepts of the Performance-Based Cost Estimation Model in MITOS

The model presented combines two of the most popular three methods, i.e., "comparison with similar past projects based on documented facts and based on experience" that take place within the domain of "experience-based" models defined in Akintoye and Fitzgerald's study [32].

The model suggests the use of the as-built productivity information and team performances of filtered projects that have already been constructed and are similar to the current project in terms of certain parameters, e.g., type, size, total cost, location, climate conditions, etc. Criteria for these parameters are specified by the user, e.g., building cost is between x_1 and x_2, building size is between y_1 and y_2, etc. The actual team productivities are revised by coefficients that represents the effects of site-based factors at different levels. These factors and coefficients are explained below.

- Project Level Productivity Coefficient (PJC): The factors that do not affect the teams individually but the whole project, e.g., location difficulties, construction complexity, effectiveness of management-related functions, level of coordination, etc., are represented by PJC. The classification suggested by Dissanayaka and Kumaraswamy [33] of factors and groups of factors that must be considered in calculating project level performance, was utilized in the model with minor modifications and additions. These groups of factors include designer-related, client-related, contractor-related, subcontractor-related, supplier-related, location-related, and nature-related factors.
- Team Group Level Productivity Coefficient (TGPC): If certain teams in a given trade, e.g., concrete works, are affected by similar factors, e.g., weather conditions, the effect of these factors is represented by TGPC instead of using TPC for each team in this category.
- Team Level Productivity Coefficient (TPC): If any team, e.g., reinforced concrete team, modular formwork team, etc., is affected by a specific factor, e.g., experience, motivation, etc., the effect of these factors is represented by TPC.
- Activity Level Production Item Productivity Coefficient (PIPC): The effects of some factors that are not related to teams but activities, e.g., the location of an activity, buildability, etc., is represented by PIPC. After the default value (1.00) is assigned automatically, these coefficients can be defined manually for each production item in the takeoff list while the others are extracted from the database of completed projects.
- Final Productivity Coefficient of a Team in the Project (F-COEF): The default value of the coefficient for a given project is assigned as (1.00).
- As per Equations 1 and 2, the Revised Productivity Value (RPV) of a given team equals the Standard Productivity Value (SPV) initially since the default value of F-COEF is (1.00).

F-COEFTEAM-A, PRJ-Z = (PJCPRJ-Z) x (TPCTEAM-A, PRJ-Z) x (TGPCTEAMGROUP-TRADE-I, PRJ-Z)……………………………..(1)

RPVTEAM-A, PRJ-Z = (SPVTEAM-A) x (F-COEFTEAM-A, PRJ-Z)……………………….(2)

MITOS uses the same approach in the estimation process of activity durations. The conceptual structure of the relationships is presented in Figure 7 as part of the integrated performance-based cost and duration estimating system.

The Structure and Relationships of the Cost Estimation Model

When implementing the model, the functions related to the design and construction phases are performed by the design and construction groups respectively in a preset order. A simplified statement of the relationships of the components and the flow of information is given in Figure 7. The responsibilities of the groups in a design/build firm and work process are defined step by step below:

- The design group defines the design projects in ASAP – Automation System for Architectural Practices, with their unique ID's; stores and maintains detailed information in the different functional modules described earlier.
- Information related to production items in projects are imported from the CAD software or defined manually by the design group in ASCE – Automation System for Cost Estimation.
- Information related to supplier firms in the marketplace is provided and updated periodically by the software vendor, recorded in SIS – Supplier Information System, and maintained by the design group.

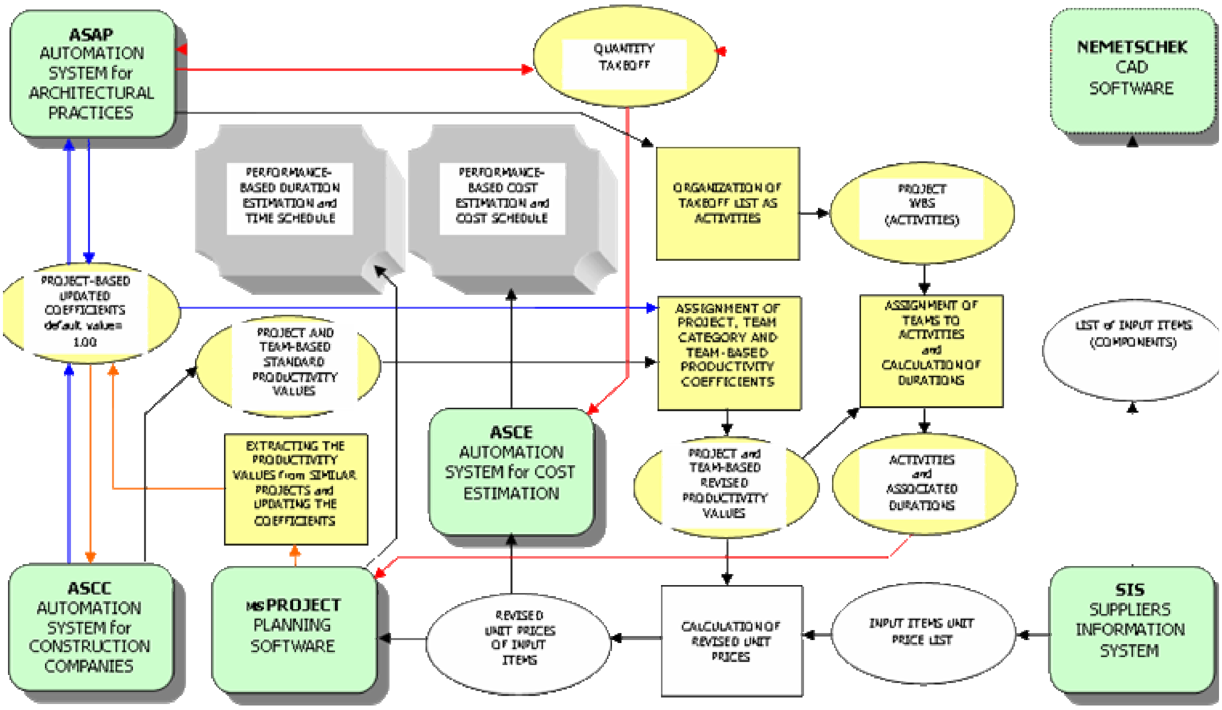

Figure 7 Conceptual structure for the integration of performance-based cost and duration estimating systems

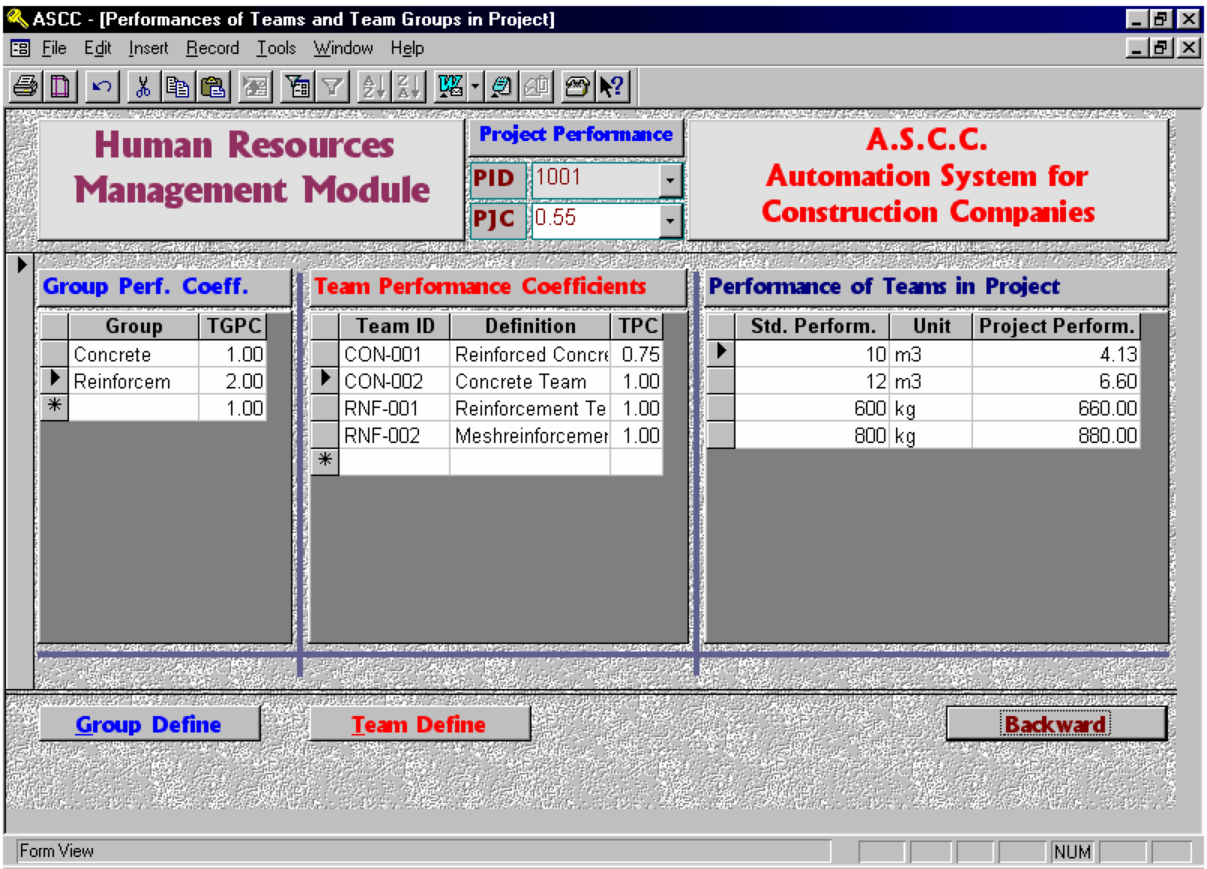

Figure 8 Assignment of coefficients and calculation of revised productivity values

- New unit price tables can be composed or those that already exist in the database can be duplicated and modified by the design group if desired.
- New input tables can be composed or those that already exist in the database can be assigned to the projects by the design group.
- The design group prepares the initial project estimate by using the project takeoff list, unit price (ABUP) tables and input tables assigned to the project, and default coefficients for project level, team group level and team level performances (Figure 8).
- The construction group defines the *construction projects* in ASCC – Automation System for Construction Companies, with their unique ID's; stores and maintains detailed information in different functional modules described earlier. Information related to the use of planned and actual resources is recorded and maintained in MS PROJECT.
- The construction group performs the final evaluations for the completed projects in ASCC. The Cost Estimation Module retrieves actual team-based quantities and durations for each activity from MS PROJECT; groups the data on a team basis; calculates the actual performance for each team by dividing the quantity produced by the team by the duration of the production; the averages of the team-based actual productivity values are obtained and then divided by the standard team-based productivity values stored in the database to calculate the team-based productivity coefficients. The as-built information of the team level productivity coefficients is stored in the database in ASCC. The same process is repeated to calculate the team group level coefficients by calculating the averages of the productivity coefficients of the team groups. As for the project level productivity coefficients, the effects of the factors (buildability of the project, experience of the contractor with the type of the building, etc.) and groups of factors (designer-related, client-related, etc.) (Figure 9) are quantified by the project team on the construction site as percentages using the information of duration and cost variances (D-VAR and C-VAR) in MS PROJECT and considering the information recorded in construction documents, e.g., claims, change orders, minutes, etc. After importing this information from MS PROJECT, group codes of the parameters (CH-GR) can be assigned to each record. Thus, summarized and total values (TD-VAR and TC-VAR) of variances for the duration and costs can be obtained as seen in Figure 9.
- The design group determines the parameters and criteria to be applied to filter the similar projects from the construction projects database in ASCC and performs the filtering operation. Averages of the coefficients of filtered projects are calculated and replace the initial default (1.00) values.
- The project level productivity coefficient can also be modified manually considering the special conditions, e.g., general market conditions, interest rates, inflation, etc., for the current project that has exceptions from those that take place in the filtered projects list.
- The design group prepares the revised project estimate by using the information defined in the project takeoff list, unit price (ABUP) tables and input tables assigned to the project, and revised coefficients for project level, team group level and team level performances.
- The model revises the prices of input items in the selected unit price composition table by applying the *project*, *team group* (*material group*, for materials) and *team* (*material*, for materials) *performance coefficients*. As it can be seen in Figure 10, the project performance coefficient, the team group performance coefficient and the team performance coefficient (in the example, 0.55, 1.00, and 0.75) are applied to the teams that include labor and equipment type input items. Revised prices are calculated by using the final coefficient (in the example, the revised final productivity coefficient F-COEF= 0.55x1.00x0.75=0.41). As for the material type input items, the project performance coefficient, the input item group performance coefficient, and the input item performance coefficient (in the example, 0.55, 1.00, and 1.00) are applied to the items and revised prices are calculated by using the final coefficient (in the example, the revised final productivity coefficient F-COEF= 0.55x1.00x1.00=0.55).

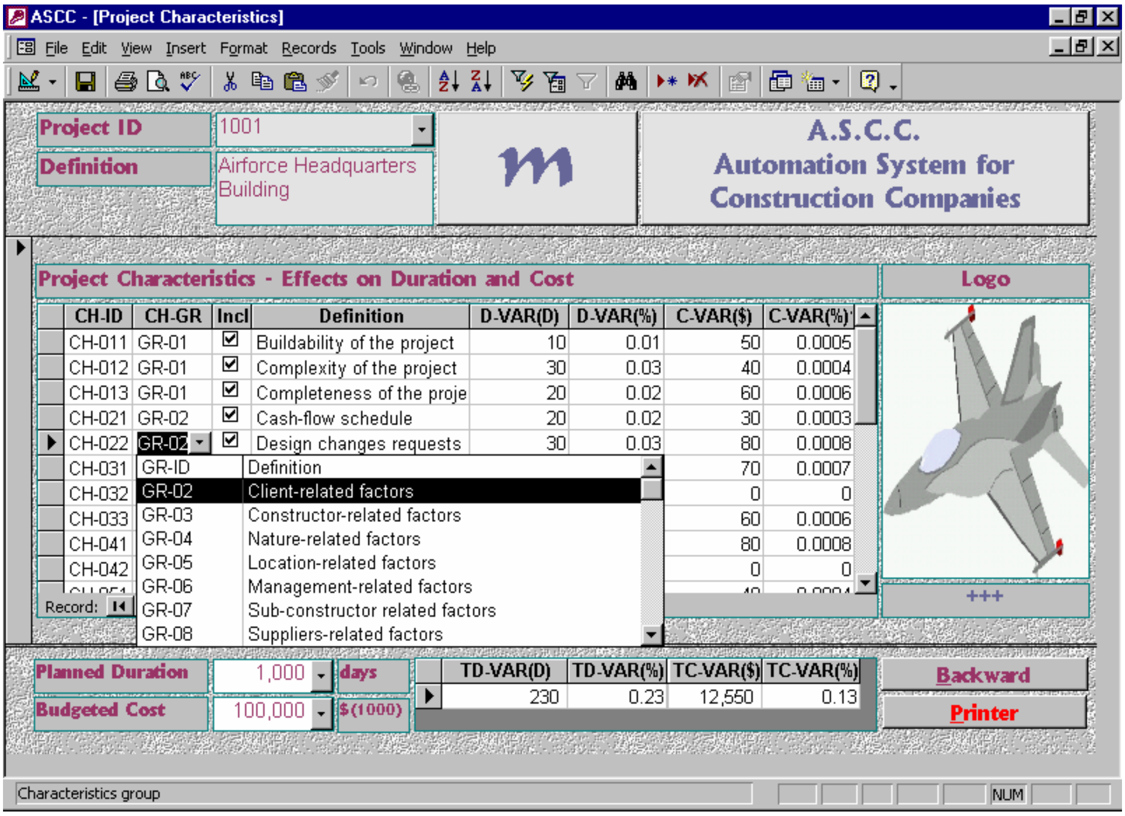

Figure 9 Project characteristics and their effects on duration and cost

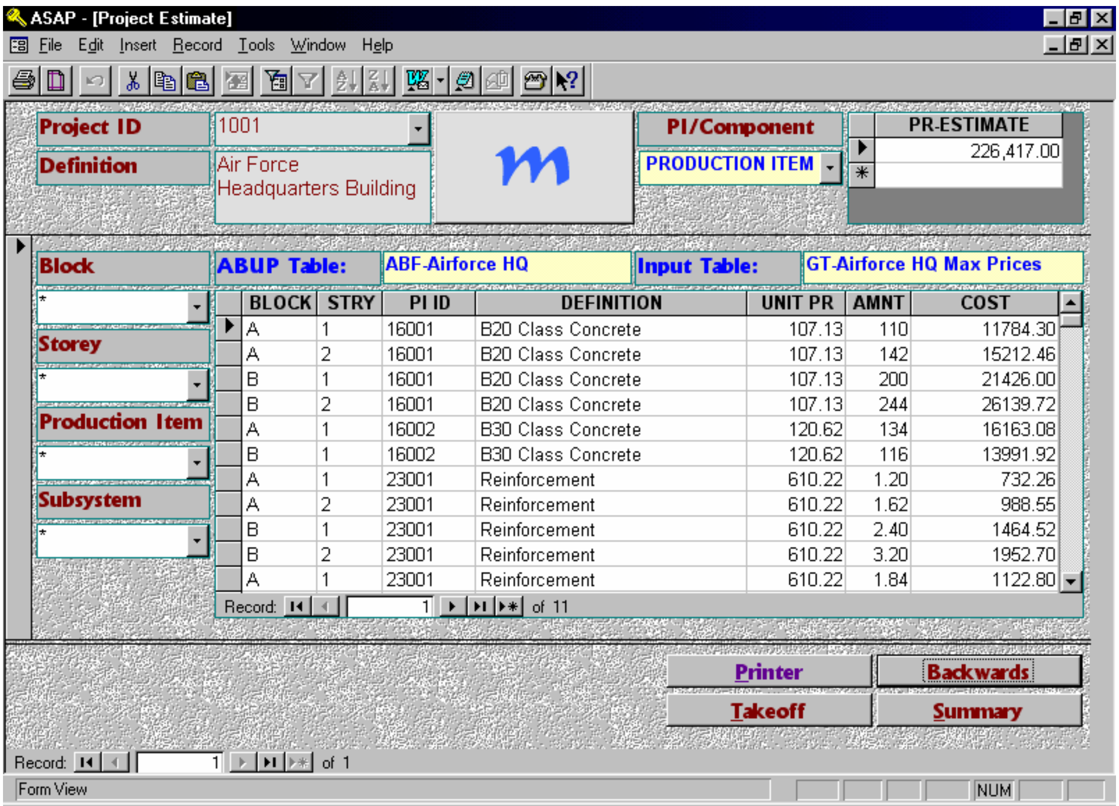

Figure 10 Project estimate

Conclusions

This paper suggests a model that integrates the information systems of different participants undertaking different roles at different phases of the building production process. This integration makes it possible to use the performance information related to certain entities, i.e., projects, team groups, teams, activities, etc., and this information can be used for more accurate cost estimating even at the design stage. This model claims that, it is possible to make accurate estimates by making use of as-built performance information of the projects that have the same characteristics. These projects can be filtered from the database of completed projects.

Any model that claims to be reliable should take into consideration the construction phase parameters in addition to design characteristics for more accurate estimating in the design phase. Currently available methods are static methods that consider only design parameters such as the quantities of the building components and their as-built cost values in similar projects; they do not consider the factors related to the construction phase that affect the productivity of the teams and consequently labor costs.

As it can be seen, the dynamic structure provided in this model (MITOS) allows the users to make their own definitions and to see the impacts of changes in decisions within a short time, and to use one of the cost estimation methods that may be suitable for different stages of building design.

It is obvious that the cost of getting the project done is of interest of the client rather than what the work will cost to do. Yet, the accuracy of the estimate at the design phase will help to reduce the number of claims and disputes during the construction phase even if traditional project delivery systems are preferred instead of design/build. The performance-based cost estimation model described here both serves and utilizes the facilities provided by the organizational setup of design/build firms. The model suits very well the organizational setup of design/build firms compared with other project delivery systems since design and construction groups are part of the same organization and typically cooperate to complete the project within the pre-defined cost, time and quality limitations.

MITOS was developed in response to the need expressed by a large design/build firm in Istanbul. The firm is a well-established firm that undertakes international projects in cooperation with international partners. The team that contributed to the development of the model was composed of experienced professionals including architects, civil engineers and construction managers.

MITOS is currently being used in only one design/build firm while ASAP is currently being used on an experimental basis by 9 architectural offices. The Cost Estimating Module is of particular importance in the model and it was developed by considering the experience and contribution of the design and construction professionals in the team. However, any significant feedback from the implementation of MITOS and from the cost estimation model in MITOS could not be obtained yet since the implementation process has just started. Especially, the cost estimation model needs a comprehensive database of the projects already constructed and time to verify the efficiency of the model.

Acknowledgements

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