INTEGRATED DESIGN OF AN AUTOMATION SYSTEM TO SOLVE COST ESTIMATION PROBLEMS IN DESIGN PHASE

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ABSTRACT: Building production process have a complex nature due to the characteristics of project type productions, i.e., number of participants, organizational patterns, multi-phased production etc. One of the basic project-based problems that architects encounter through the design process is to keep the construction cost under the limit given by the client of the project and to enlighten the client about the impacts of the decisions on building cost. Calculation of the impacts of alternative decisions on building cost must be a continuous activity through the design (and sometimes in construction) stage(s) and the models developed for the architectural practices and construction firms should also provide this sort of tools that provide an integration and continuity through the building production process for the architectural offices and construction firms. In certain organizational patterns and contracts the information that is the output of cost planning and estimation function in design stage may be needed for the cost estimating, planning, and control function in tender and construction stages too. Some of the currently available information system solutions in both conceptual and practical dimensions try to provide an integration and continuity through the subphases of building production process in terms of cost planning/estimating/control functions. This paper presents an integrated design of computer-based office automation system (MITOS) that basically comprises three relational database models; ASAP (Automation System for Architectural Practices); ASCC (Automation System for Construction Companies); ASCE (Automation System for Cost Estimation) that may work independently or integrated to solve the problem of integration and continuity of cost management functions and the problem that stems from the traditional database structures through the subphases of building production process by proposing an interactive and dynamic structure of databases in these models.

KEYWORDS: Architectural office, architectural practices, construction companies, information system, information technology, office automation, cost planning cost estimation, cost control, relational database, software development, AEC firms.

1. INTRODUCTION

The basic characteristics and purpose of project estimating function in various subphases of building production process are different from each other. Therefore, the outputs of estimating function performed in different phases by different professionals mostly varies. The variations sometimes may have remarkable values due to the effects of unforeseen factors related to basic parameters of *design* e.g., buildability or *construction* e.g., location of project, weather conditions and their effect on the productivity values of teams, problems related to procurement or availability of materials, labor and equipment in some locations etc.

In preliminary design, project estimating function aims to expose whether the cost limitation given by the client is exceeded and to enlighten the client about the results of the decisions made on project cost. The estimating methods, e.g., based on m2 or m3 unit prices of constructed buildings that are similar in terms of design characteristics, i.e., total construction area, types of finishings etc., are used instead of the methods that can be used for detailed design.

Any model should take into consideration the construction phase parameters in addition to design characteristics for more accurate estimating in design stage. Ignoring one of these sets of parameters will result in inaccurate and unreliable project estimate costs. The contractors will certainly determine their bid price by considering both set of parameters when preparing their estimate and deciding to their bid price. The same approach must be applied by the architects and the other professionals in design stage.

The information related to unit prices of input items or building components or buildings can be obtained from different sources, i.e., on-line information providers, integrated information systems, etc. One of the models providing the on-line information was developed by a research group in I.T.U. Faculty of Architecture (Orhon et al., 1996). The projects that have the desired characteristics within the ranges specified can be filtered from the database and as-built cost information can be extracted as average values in desired format. The EVALUATOR, an integral part of integrated environment prototype SPACE (Underwood and Alshawi, 1997) can be given as an example of integrated information system.

In this paper, an integrated model developed with a holistic look; not only for cost estimating function but also for all functions in building production process and the suggested outline of the approach to integrate the cost estimating function fulfilled by the responsible organizations in each subphase is presented.

One of the basic project-based problems that architects encounter in design process is to keep the building cost under the limit given by the client of the project and to inform the client about the impacts of the decisions on building cost. Evaluation of the alternative decisions on building cost must be a continuous activity during the design stage and the models developed for the architectural practices should also provide this kind of tools for the architects. Although some of the CAD software provides this facility automatically, they have limitations and there is a significant amount of criticism on the basics of their calculations. These software automatically extract the amount 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 user or information providers. This feature makes them advantageous compared to the software that need taking off the quantities of building components manually. Yet, these alternatives must be produced in CAD environment first to calculate the costs of alternative solutions. This may be a time consuming approach compared to replacing the type or amount of the component on takeoff list. Except, the measurement rules and units adopted by these software in measuring quantities and calculating the cost of building components may not fit to those adopted by the authorities or the industry in some countries. That's why the use of the outputs of these software that is related to project estimate can not be used in tender stage. Moreover, different stages of the design process requires or allows different methods for the cost estimation, e.g., at the preliminary design stage it is not possible to use estimating methods based on detailed production items. Likewise, in some cases after finishing detailed projects a most detailed takeoff list is demanded. The CAD software must be supported by the databases that support both approaches stated above. And finally, the databases either defined by the users or provided by the information providers include average or approximate or selected values for the rates or unit prices of input items in the construction market. Mostly it is not possible to define alternative sets of supplier-based unit prices in these database structures and to assign these specific prices to the building components.

As for the commercial software packages for the automation of architectural practices, they were designed mostly in an accounting-oriented point of view and do not provide cost estimation tools. The cost estimating software belongs to another category. They work independently or integrated with project management or CAD software but it has not been possible to find any example that can be integrated to the automation software for architectural practices.

In some cases, the project procurement approach selected allows basic cost management functions (estimating/planning/executing/control) to have a continuity not only within a subphase but also through the whole building production process. If certain organizational patterns such as *design and build* are preferred, certain arrangements for determining cost, such as *cost reimbursement,* are selected, certain process structures, such as *fast track,* are decided for the project, the continuity and integration of the function will be demanded. That's why the cost estimation system should be designed by not only regarding to the requirements of a certain subphase (design, procurement or construction) and certain types of firms (architectural offices, consulting companies or constructor firms) but also by considering the possibilities of integration to the information systems of the organizations undertaking different functions in subsequent or parallel subphases of building production process. The databases used for the cost estimation in design or construction stages provide an architecture that neither takes into consideration the impacts of the project-specific parameters on the productivity nor reflects these effects to the unit prices and project estimate.

2. DEFINITION OF THE PROBLEM

Estimation of construction cost of a given building is not a final operation at the end of design stage. The project cost should be calculated through 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 cost estimation function and this component must:

- support different cost estimation methods that can be used in different stages of building design process,
- expose the impact of design-related decisions on building cost in various stages of building production process instantaneously,
- be able to be used by all designer, consultant and construction companies,
- be able to be integrated to information systems of these different types of organizations,
- provide the continuity of cost estimation/planning/control functions through building production process from the beginning of design phase to the end of construction phase,
- be linked to a database that is updated periodically and based on a supplier-based real world input rates and unit prices,
- provide an architecture for the model that takes into consideration the impacts of the project-specific parameters on the productivity and reflects these effects to the unit prices and project estimate as well.

The problem is the lack of the practical models that is designed by considering all the aspects and requirements of building production process from the beginning of design to the end of construction phase in terms of cost estimation function. Some conceptual models in literature that has a holistic look to respond to the problem were located (Underwood and Alshawi, 1997). But, the idea of integrated function of cost estimation needs to be applied to practice and supported/developed by new ideas such as a dynamic architecture of interrelated databases reflecting the effects of project-based productivity parameters provided from the projects that have similar characteristics.

3. MITOS: AN INTEGRATED AUTOMATION SYSTEM

MITOS (**M**ulti-phase **I**ntegrated Au**t**omation **S**ystem), a relational database model was designed for solving the problem stated above. The conceptual structure of the model is given 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 considering the basic rules of integrating the software and the patterns for architecture of software (Fischer and Kunz, 1995), (Underwood and Alshawi, 1997) the model (MITOS) was converted to a relational database software in practical dimension in an object-oriented software development 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 automatic setup process by MS Access Developer Toolkit. The software has approximately 50 Mbytes of size and contains 35 tables, 107 queries, 32 reports, 261 forms and 238 macros. The software has a multi-user architecture. The users and their access rights to the database objects can be arranged by the system administrator.

3.1 ASAP: An automation system for architectural practices

Since a considerable part of the revenues in construction market shared by constructors, the problems associated with the construction phase and construction companies are thought to be important and occupy a large portion of the research agenda. The problems related to the other stakeholders such as designers are often ignored. Indeed, recent research studies seem to focus on conceptual and practical models organizing the information flow among project stakeholders.

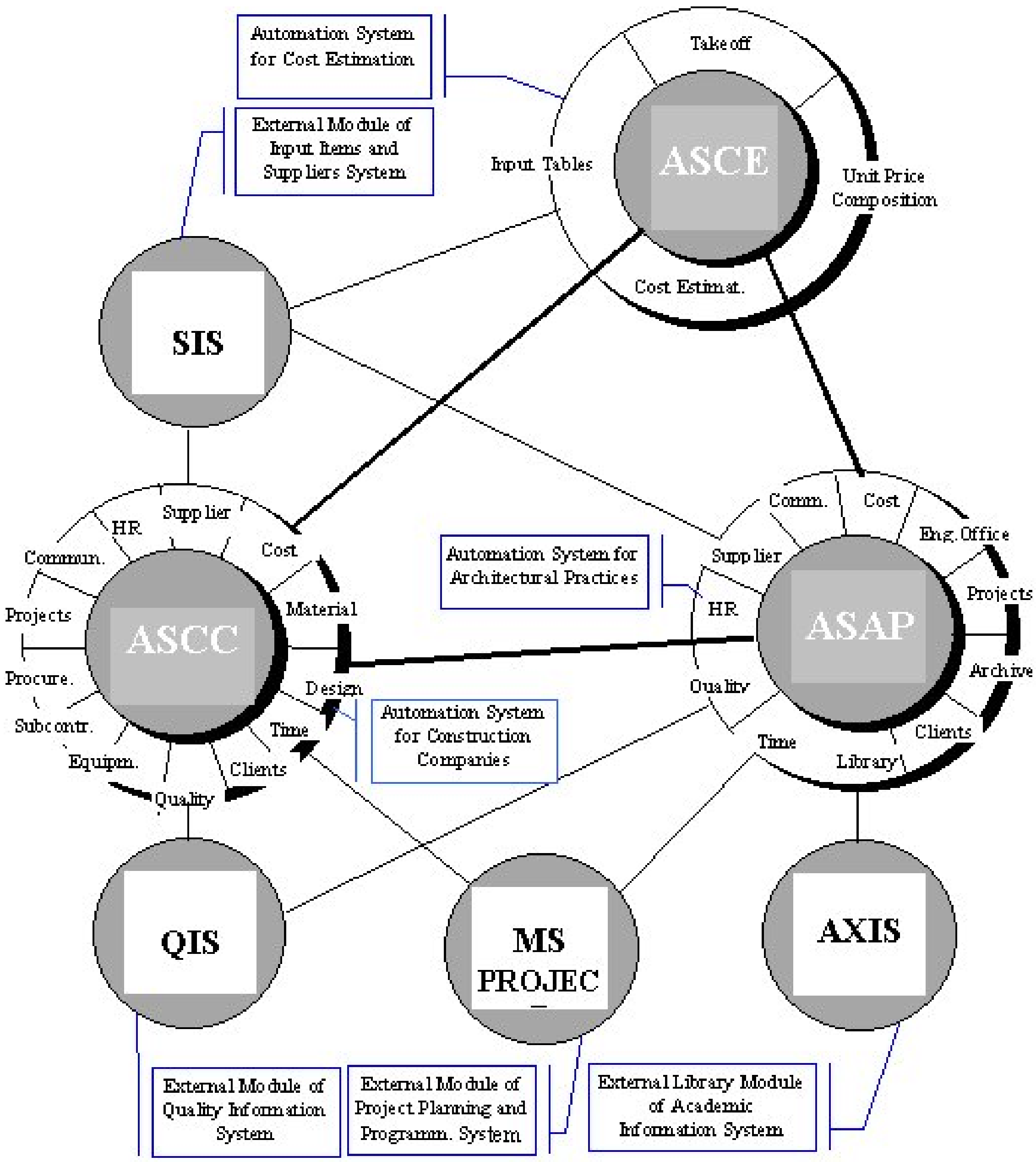

Figure 1 The conceptual structure of MITOS

Figure 2 MITOS start screen

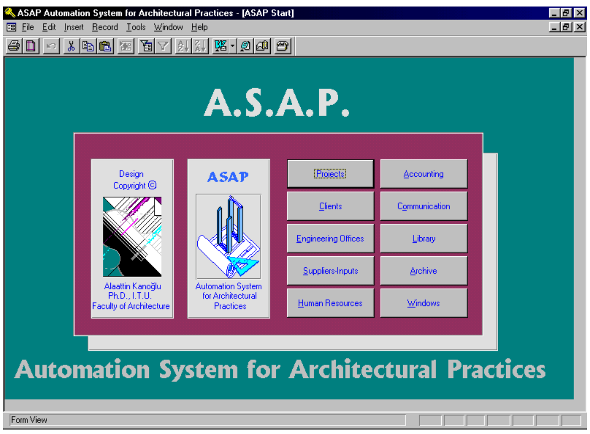

Figure 3 ASAP start screen

The models stated by Luiten and Tolman (1997), Froese (1996), Stumpf et al. (1996) and Rezgui et al. (1998) can be given as related examples. 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 (1996) and Mokhtar et al. (1998). However, any comprehensive conceptual model especially designed for architectural offices could not be located in the literature.

As for the commercial software packages in marketplace, it is possible to find some solutions for the architectural and engineering offices. *BillQuick, Portfolio, Semaphore* can be given as successful examples. Yet, these models do not seem to provide any management-related tools except for the standard operational level database functions. Only *Semaphore* provides an integration with *MS Project* software. They all can be qualified as mostly accounting oriented automation software for architectural practice and are not designed considering the whole design process functions and requirements in architectural offices.

Nevertheless, architects need some management-related tools to support them in making decisions and explain the leading motives of their decisions. Mostly, architects prepare the alternative solutions, expose the results of them and leave the decision to the customer. Thus, the customer is enlightened to select one of the solutions related to certain parts of design. It has been observed that commercially available software models for architectural practices do not have a comprehensive approach covering all the required database and management-related functions. They seem to be designed for accounting-oriented transactions and handling basic database purposes in a limited scope. ASAP (**A**utomation **S**ystem for **A**rchitectural **P**ractice) was developed for solving the information handling and management-related problems by taking into consideration the design process in architectural offices with a holistic look (Figure 3).

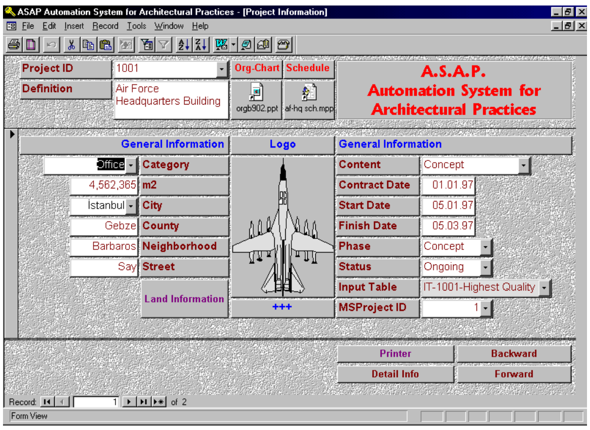

Figure 4 Project information

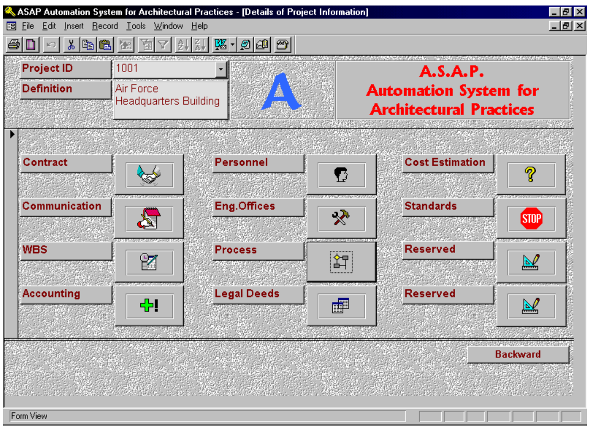

Figure 5 Details of project information

Information related to the drawing sheets, approvals of local authorities, required legal documents for projects are defined. Work hours of personnel, income-expense values and payment plans related to clients and engineering offices are defined for each project in related modules. Messages and meeting minutes recorded for each project can be accessed from the Projects Module. Engineering offices can be assigned to perform the design of subsystems and contracts/specifications can be defined. All the information is organized in the modules stated below. The details of the components will not be given due to the scope of the paper.

- Projects Management Module,
- Clients Management Module,
- Engineering Offices Manag. Module,
- Suppliers Management Module,
- Human Resources Manag. Module,
- Archive Management Module,
- Time Management Module,
- Design Management Module,
- Cost Management Module,
- Communication Manag. Module,
- Quality Management Module,
- Library Management Module.

3.2 ASCC: Automation system for construction companies

The model (Figure 6) is the output of a research project (Kanoglu, 1999) supported by TUBITAK (Turkish Scientific Research Council). The aim of the project was to develop a software model, i.e., management information system for constructor firms. The model (ASCC), contains the basic components stated below.

- Projects Management Module,
- Clients Management Module,
- Subcontractors Manag. Module,
- Suppliers Management Module,
- Human Resources Manag. Module,
- Time Management Module,
- Design Management Module,
- Materials Management Module,
- Equipment Management Module,
- Cost Management Module,
- Communication Manag. Module,
- Quality Management Module,
- Procurement Management Module,
- Input Management Module.

The Teams and Productivity Submodule in HR Management Module of ASCC allows the user to define project-based team categories and teams. Composition and standard production values of each team can be defined in this submodule (Figure 7). The default value (1.00) for project, team category and team level productivity coefficients is assigned automatically to each parameter, i.e., project, team categories, and teams (Figure 8). When assigned the user-defined coefficients at start and the revised coefficients calculated from the progress of construction later on to each field, the revised productivity values for each team are automatically updated. In *Time Management Module*, the activities of projects are retrieved from the takeoff list defined in *Cost Estimation System* and the teams defined in *Teams and Productivity Submodule* are assigned to these activities and the duration of activities is automatically calculated and updated (Figure 9). The conceptual structure of the approach is given in Figure 10 as the part of the integrated performance-based cost and duration estimating system.

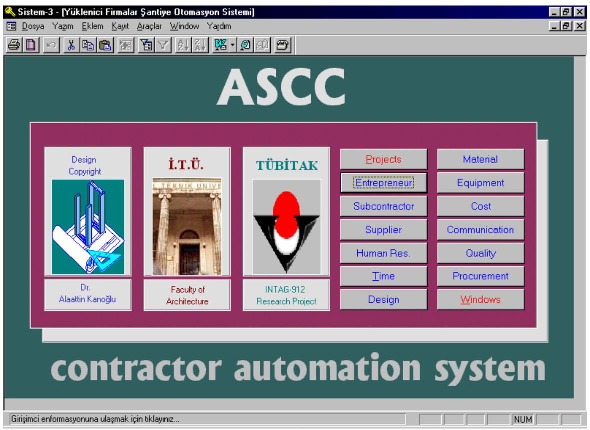

Figure 6 ASCC basic modules

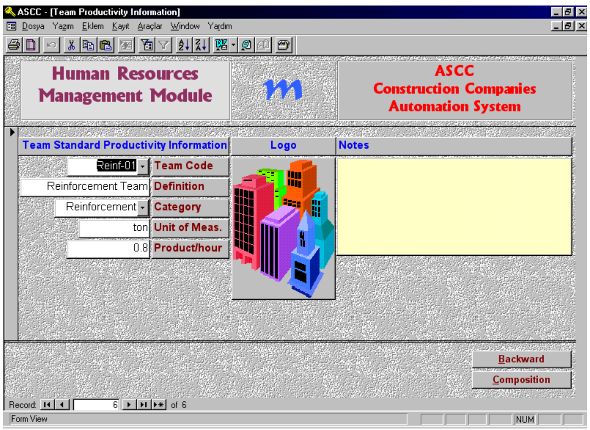

Figure 7 Team standard performances

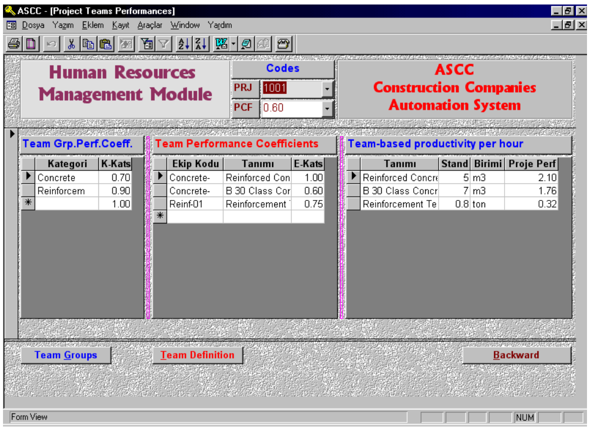

Figure 8 Assignment of coefficients and calculation of revised productivity values

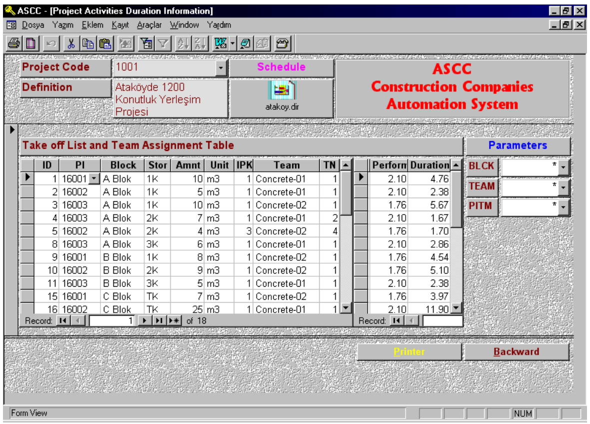

Figure 9 Assignment of teams to project activities and calculation of duration

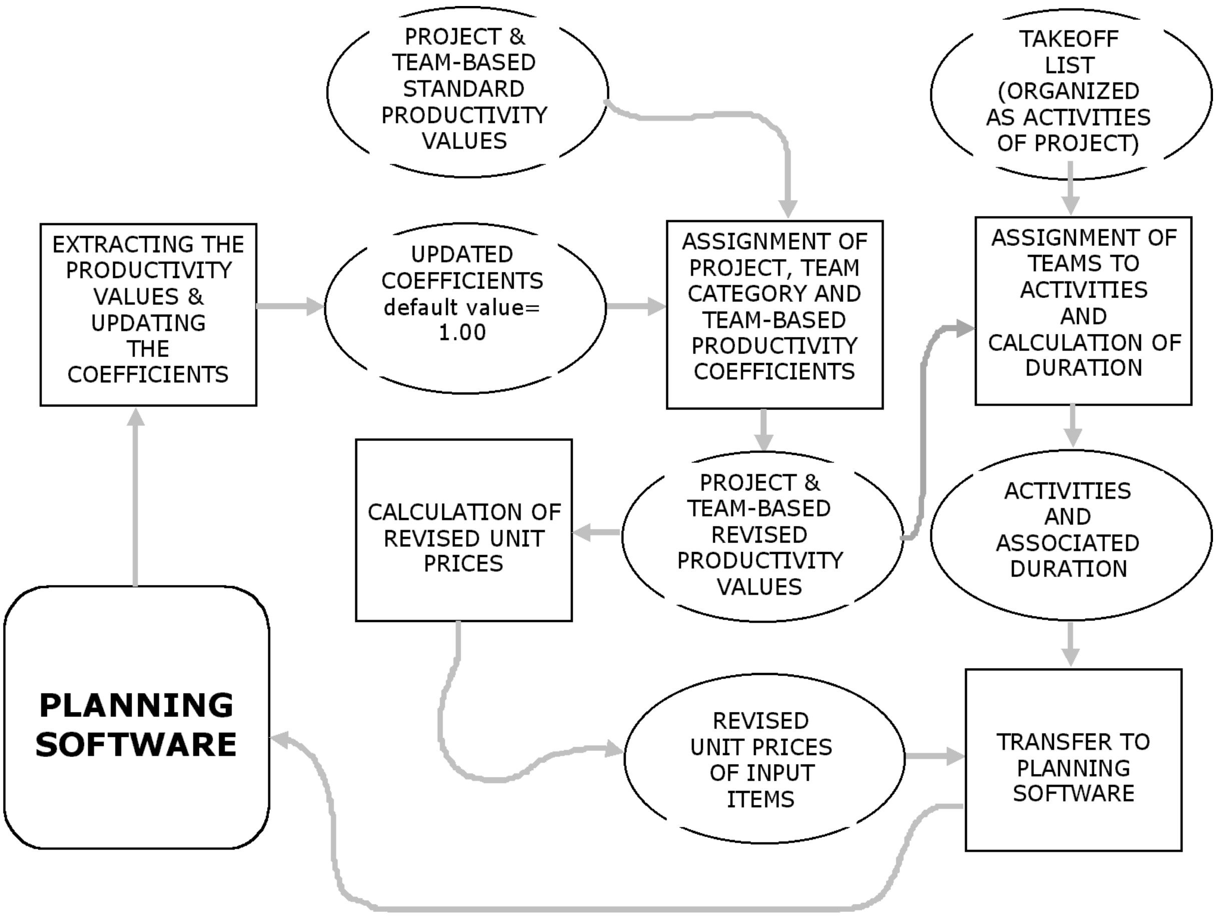

Figure 10 Conceptual structure for the integration of suggested performance-based cost and duration estimating systems

3.3 ASCE: Automation system for cost estimation

The conceptual model already mentioned above for the estimation of duration of activities on a performance-based approach was applied in the software, MITOS. The basic rules of the approach in estimating the duration of activities are considered to be applied to cost estimating problem and the integration of these two systems is suggested (Figure 10).

The model obtains the unit price information from the *Suppliers and Input Items Information System*. The database in this system provides supplier-based up to date information. *The Cost Estimation System* allows the user to compose unlimited sets of alternative input tables. Thus, the cost information used in estimation is based on real values. In this situation, probable variations in estimation may only stem from the project and team-based variations of performances due to the unforeseen factors. As already stated, any model should take into consideration the construction phase parameters in addition to design characteristics for more accurate estimating in design stage. Ignoring one of these sets of parameters will result in inaccurate and unreliable project estimate costs. The model suggests to use the revised productivity information obtained from the project and team-based performances of selected projects already constructed.

The cost estimation system is one of the independent components integrated to ASAP and ASCC. If desired, it can be used independently. It requires the Suppliers and Input Items Information System (SIS) explained above for the associated rates of input items supplied by specific companies. This module is also used by ASAP directly for various database purposes (reporting the specifications of input items, etc.,) and by ASCE for cost estimating function.

The module allows the user to define project takeoff items at different stages of design. At the conceptual design stage takeoff items can be defined in terms of amounts of building components. After completing detailed design, it is possible to define takeoff items in terms of production items if desired. The user can choose one of these methods. Users can define unlimited number of *input tables* each composed of the same or different material, labor, and equipment items provided by different suppliers with various associated rates. The items are chosen from the periodically updated database in *The Supplier Module* that includes the data related to supplier companies and the input items provided by them. Thus, it is possible to make up alternative input sets within different *input tables.* By assigning alternative *input tables* to the current project consecutively, the client can be informed about the impacts of alternative input sets on project costs. The user can also define unlimited number of *production item/building component* (according to preferred estimation method) for calculating their unit prices by assigning input items and their quantities. Thus, the unit prices of the *production items/building components* are automatically calculated based on the *input table* assigned to the project. When the user defines production items and their quantities in the project, after defining an item and its amount, the price of the item is automatically calculated and total cost of the project is updated in cost estimation table instantaneously. The expectations stated above has affected the design of the model in conceptual dimension. Two different cost estimation methods are included within the model for responding the cost estimating problems in different stages of building production process:

- **Method 1:** The cost estimation method that is based on *building components,*
- **Method 2:** The cost estimation method that is based on *trades (production items).*

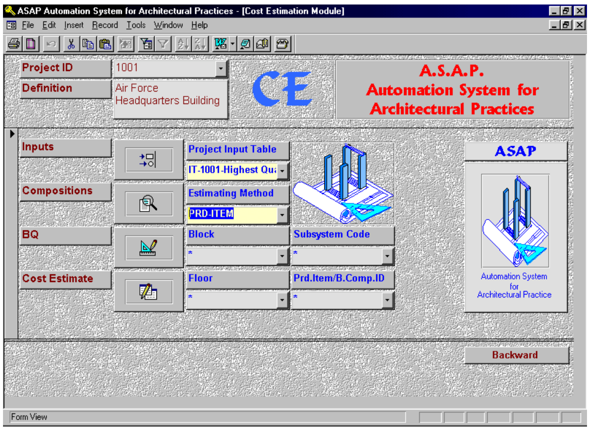

Figure 11 ASCE the cost estimating system

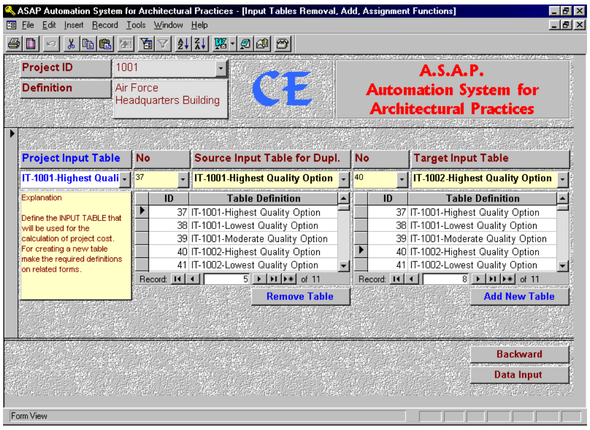

Figure 12 Assignment of input tables

One of these methods that suits the limitations of current stage of design and requirements of the architect and the client must be chosen before proceeding for cost estimation. The cost estimation system (ASCE) comprises four modules, i.e., input table composition, PI/BC unit price composition, takeoff and cost estimation modules (Figure 11). The user can compose unlimited number of input tables including specific input items linked to products and rates supplied by real world companies. Thus, supplier-based unit prices are used in estimating.

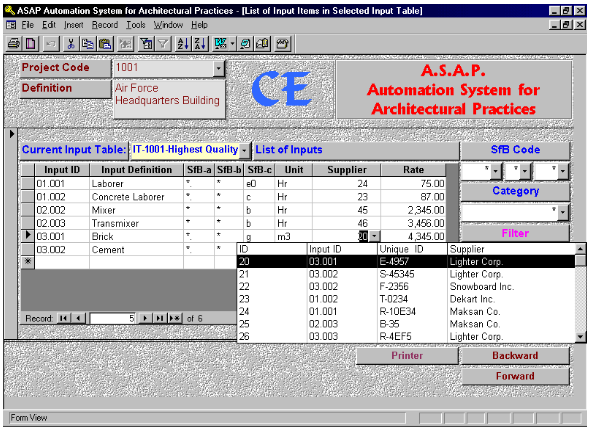

Figure 13 The content of an input table

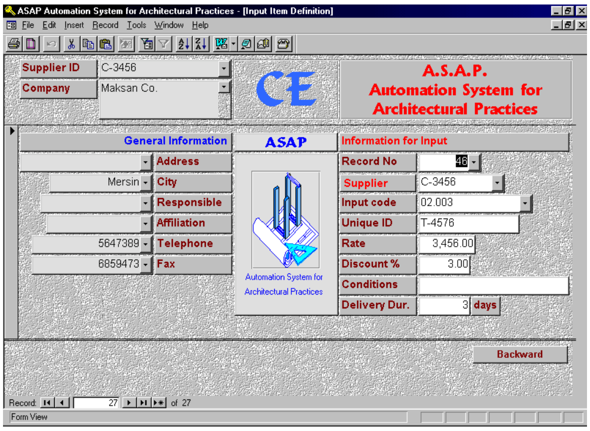

Figure 14 Supplier-based input items

New companies, their products and rates of products can be defined and the database is updated periodically (Figure 14). After finishing all definitions related with input tables, these tables are assigned to the specified project consecutively and after every assignment recalculated building cost estimation is obtained. The composition of unit prices for production items/building components is given in Figure 15 and Figure 16.

As already mentioned, in building production process different cost estimation methods are needed in different phases. The user can choose one of the methods that fits to the purpose of estimating function. Selection of the cost estimation method is the first step of creating the unit price compositions for both *production items and building components*. The logic is the same for both methods. A unique code is assigned for PI/BC and then the input items are defined.

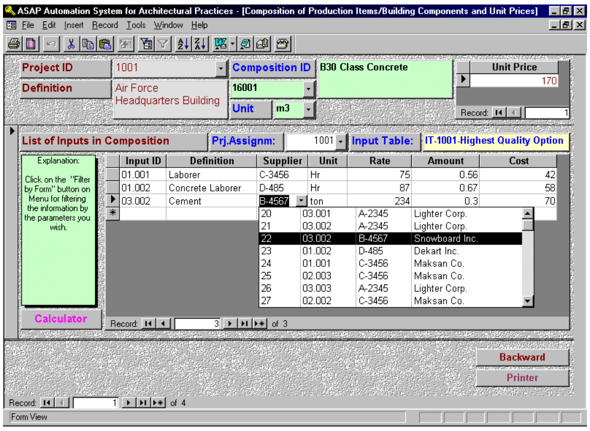

Figure 15 The composition of unit price

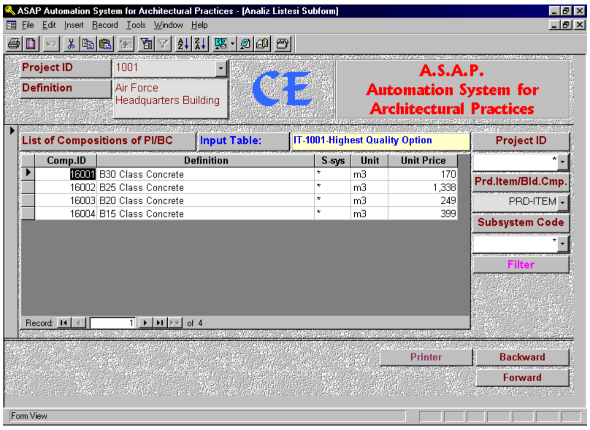

Figure 16 Calculated unit prices

It is possible to use the two separate methods in different stages for cost estimation for a specified project. All takeoff data is recorded in the same table of the database since the structure of the records for different methods are the same. The module only displays the PI/BC's in the specified project by retrieving data from takeoff list, their unit costs and calculated cost values and total project cost (Figure 18).

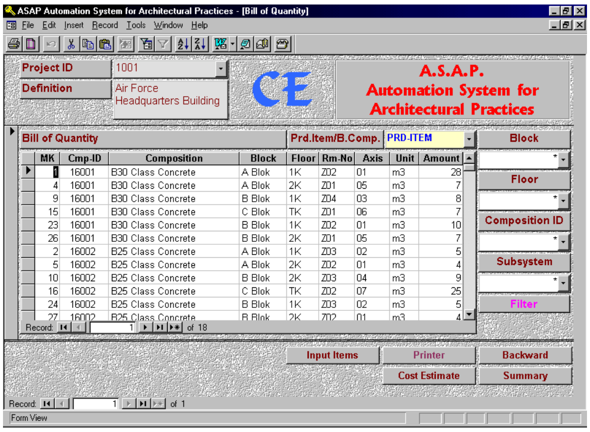

Figure 17 Takeoff

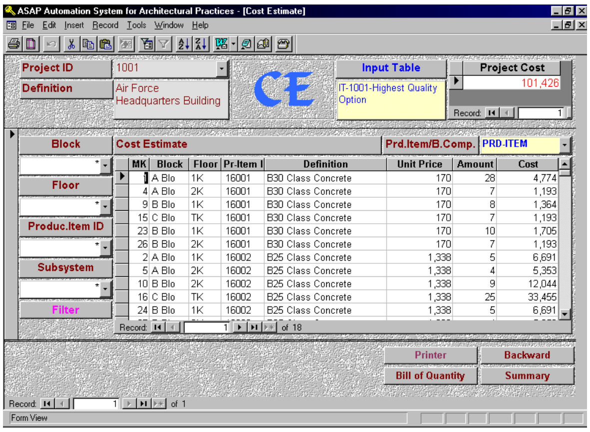

Figure 18 Project estimate

3.4 The shared components

The Suppliers and Input Items System is not an optional component and needed by and linked to all the three models ASAP, ASCC, and ASCE. The supplier companies are defined by ID and name and they are classified according to the input (labor, material, equipment) they deal in. International standards (SfB) for coding inputs are used in this module. A list of inputs supplied by individual companies and the rates and specifications of these input items or a list of companies that supply specific inputs can be produced using filter options by defining filter parameters such as supplier, material, 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 are used one by one in order to calculate the alternative project costs. The other systems, i.e., *Quality Information Systems* (QIS), *Project Planning and Programming System* (MS Project'98), *The Library Module of Academic Information System* (AXIS), (Kanoglu, 1999) are the optional components of the model.

4. CONCLUSIONS

As it can be seen, the dynamic structure allows the users to make their own definitions and to see the impacts of changes in decisions instantaneously, and to use one of the cost estimation methods that may be suitable for different stages of building design. Another point of the cost estimation model is the flexibility of its structure that allows the user to use it separately or integrated to the specific models such as ASAP (Automation System for Architectural Practices) and ASCC (Automation System for Construction Companies). Thus, beyond the design stage, cost estimation information can be used at tender and construction stages. The Cost Estimation System (ASCE) can be used as an independent cost estimating tool but it is possible to make an integrated use of both separate software (ASAP, and ASCC) to avoid repetitive information handling actions for cost estimation purposes.

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