An integrated automation system for design/build organizations

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Abstract: The construction of buildings is a complex process that is carried out by a large number of participants with conflicting objectives. This complexity and fragmentation makes the management of the process particularly difficult. This paper presents an integrated system called MITOS – multi-phase integrated automation system that has been designed primarily for design/build firms, i.e., firms or alliances of firms that do both design and construction. But the system can also be used by independent design firms and construction companies as long as they are cooperating on the same project. This integrated system allows designers as well as constructors to receive information about all aspects of the project (including clients, subcontractors, suppliers, human resources, time, design, materials, equipment, cost, communication, quality, and procurement) in the design and construction phases of the project and hence to manage the project effectively. The system makes use of a central component called ASDB – automation system for design/build and a set of satellite programs.

Keywords: design/build; architectural practices; construction companies; information systems; office automation; relational database; data warehouse; AEC firms.

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1 INTRODUCTION

An increase in the scale and complexity of building production requires a larger number of participants and more efficient communication among them. Because of the fragmented nature of the construction process, construction organisations have always searched for new ways to integrate both inter and intraorganisational functions [1]. Indeed, participants in the construction activity have always encouraged researchers to focus on integration issues with the hope that such research could eliminate the consequences of the currently existing fragmentation in the construction industry.

Attempts to deal with fragmentation can be carried out at three levels, namely (1) at the organisational level, including approaches such as partnering and design/build contracting, (2) at the process level, including methods such as lean production, supply chain management, just-in-time delivery, and (3) at the virtual level, including software and hardware packages aimed at integrating the activities of the parties such as the software package described in this paper.

At the virtual level, integration may be achieved in the horizontal or vertical direction. Horizontal integration refers to the organisation of the management-related functions within an organisation and is mostly based on intranet applications. Vertical integration, on the other hand, establishes relationships among the components of various information systems used by various participants in the different phases of the building production process.

Current information modeling for the A/E/C industry includes product, process, and project models [2]. Product models are conceptual structures used to organize and communicate building product information among project participants. They contain product information such as the properties of its parts, including geometry, topology, composition, material, behaviour, etc. [3]. Process models represent the important steps throughout a project's lifecycle. Project models provide a framework for system integration of product, process, and organisational aspects for A/E/C projects to provide richer semantics for project management. Froese [4] introduces several versions of core conceptual models (reference models) of construction processes from a variety of research projects associated with computer-integrated construction. Core models are intended to be high-level models that provide a unifying reference for more detailed application models and their role for A/E/C is to provide a unifying reference from which to construct application models for use within specific areas of project management. As integration capabilities continue to improve, the collected integrated systems reach a critical mass where they can form the primary mechanism or media used to develop, record, work with, and communicate the overall body of project information. These systems are called total project systems [5].

Fischer and Froese [6] note that electronic information sharing has not been highly successful, since this has not been a major goal of A/E/C computer applications. Rather these applications have focused on automating individual engineering tasks, creating islands of information. Successful computer-integrated construction requires a new emphasis on project information itself: that is, on project models. The authors also state that the logical extension of models that are shared across multiple applications is to develop standard project models and indeed, as the number and range of applications to be integrated grows, the possibility of all of the applications' developers working together to develop shared models diminishes, and the reliance on standards becomes a necessity.

There are many efforts underway to develop standards for product and process models. Since CAD systems were the central points for integration and thus for standardization initially, IFC – industry foundation classes has been one of the main areas in standardization efforts for defining standardized data structures for the exchange of intelligent A/E/C-related objects among CAD systems. ISO STEP (10303) – Standard for the exchange of product model data is another international data standardization effort and is being developed by the ISO TC184/SC4 committee.

In order to avoid the consequences of the currently existing fragmentation in the construction industry, research projects that focus on integration issues are encouraged by all participants in the construction activity, but integration is not the only conceptual tool for avoiding the effects of fragmentation. Another conceptual tool that can be used for this purpose is unification that involves combining the models used by individual participants into one universal model fulfilling the functions of all models combined.

Although, there are disadvantages to standards, e.g., because they are applied over large areas of applications, they can be a poor fit to specific uses and can inhibit advances and innovations, many researchers and practitioners believe they are important to enable significant advances in integration capabilities [6], unless these efforts are limited to conceptual models and so long as the reference models are converted into application models that can test and improve their efficiency. Application models can also solve the sort of problems stated above that stems from the standards by using customisation tools, e.g., providing the opportunities to chose one of the standard building product models or to allow user-defined code structures, etc., for various functions in an information system.

It can be said that defragmentation can be achieved in the construction industry by using project delivery systems such as design/build. Yet, since this type of solution is not applicable in all situations, other solutions that involve defragmentation via the integration of information systems used by the many project participants must be available as well. The efforts of defragmentation via information system models must consider the standardization, customisation, and unification possibilities at data, process, application, industry, and system levels.

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 systems are reported in the literature that attempt to solve the integration problem; examples include RATAS – infrastructure for computer integrated construction [7], SPACE – simultaneous prototyping for an integrated construction environment [8], I3CON – intelligent integration of information in construction [9], COMMIT – construction modeling and methodologies for intelligent information integration [10], ATLAS – architecture, methodology and tools for large scale engineering [11], COMBINE – computer models for the building industry in Europe [12], ASAP – automation system for architectural practices [13], and ASCC – automation system for construction companies [14].

Although these are comprehensive studies in the area, most of the models developed in these studies are reference models and do not cover all aspects of management-related problems in the design or the construction process and constitute incomplete examples of horizontal integration; for example, ICON includes a bidding object model, a procurement system model and some activity models [4], whereas SPACE contains CAD, construction planning, specifications, virtual reality and estimating modules. Furthermore, none of these models combines the components of the individual systems into one universal system that could serve both designers and constructors all through the design and construction phases of a project, this way achieving full vertical integration; indeed, while COMBINE and ASAP focus on building design tasks, SPACE and

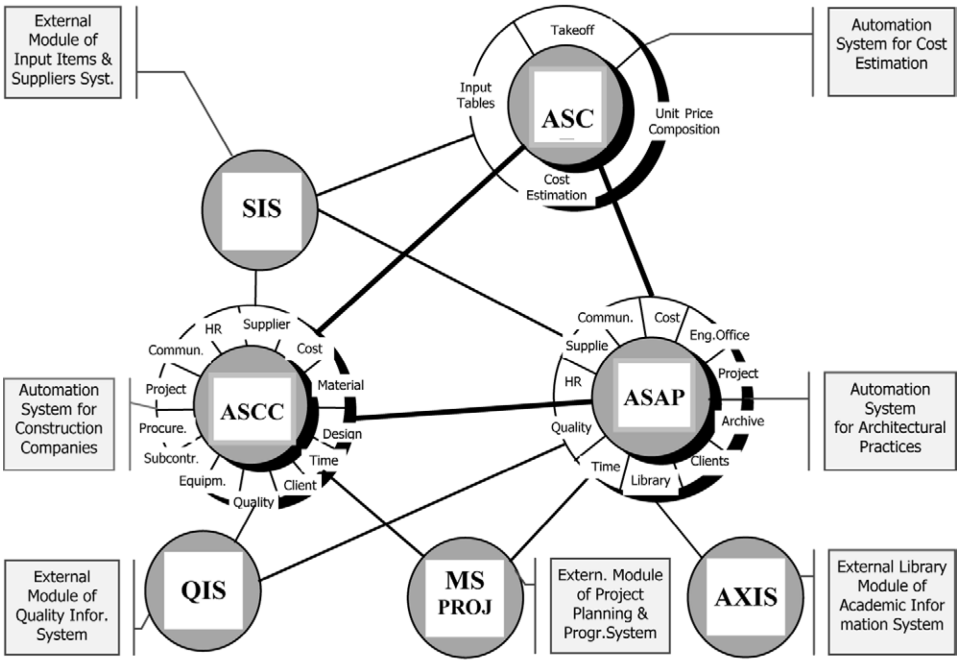

Figure 1 *Initial conceptual structure of model to automate design/build process*

ASCC emphasize the construction process portion of the project scope. These observations are of particular importance with respect to the design/build project delivery system.

Design/build contracts combine design and construction under a single entity. Design/build is sometimes conducted by a company that has design and construction capabilities under the same roof or by a joint venture between a design firm and a construction company. Design/build has gained the attention of the industry in the last decade and is expected to become the dominant project delivery system in the near future. In the last 10 years, the use of the design/build delivery system has increased from $18–$69 billion, representing nearly 25% of the construction volume in the US. This growth is justified by the reported benefits of the system, including faster delivery and lower cost. It is now time to have a management information system in place in design/build organisations that could facilitate the management of this delivery system. Such a system would facilitate the interactions of the members of the D/B team, but it would be particularly useful if the team members belong to different organisational cultures.

This paper describes efforts that are aimed at developing an integrated computerized automation environment called MITOS – multi-phase integrated automation system that is expected to increase the efficiency and productivity of design/build project delivery organisations as well as design firms and construction companies that make it a point to effectively cooperate within the framework of a partnering arrangement or in traditional design-bid-build projects.

2 MITOS: A MULTI-PHASE INTEGRATED AUTOMATION SYSTEM

The initial structure of the proposed model was designed around a distributed architecture that contained two separate and independent components, ASAP – automation system for architectural practices [13] and ASCC – automation system for construction companies [14] (Figure 1). The idea was that ASAP would serve the needs of designers and ASCC would serve the needs of constructors in the design/build firm, independently from each other, while making use of a common set of satellite programs that provide supplier information, quality standards, academic reference services, and cost estimating and scheduling functions. But it was later noted that ASAP and ASCC make use of almost the same internal modules with few variations. So all modules used by ASAP and ASCC were consolidated into one universal model called ASDB – automation system for design/build with some differences and additions in detail. Unification of the information systems of these different organisations, i.e., architectural offices and contractor companies, is one of the main challenges to be overcome by the model.

The conceptual structure of MITOS – multi-phase integrated automation system for the construction industry is presented in Figure 2. The central component of MITOS is ASDB – automation system for design/build, which interfaces with the same external satellite programs used by ASAP and ASCC, with the exception of an additional CAD program. These satellite programs can be used independently of MITOS if desired. They include:

- SIS (suppliers information system)
- ASCE (automation system for cost estimation)
- MS project (project planning and programming software)
- Nemetschek (CAD software)
- QIS (quality information system)
- AXIS (academic information system)

The same databases are used in ASDB to save the same type of information for design (ASAP) and construction (ASCC)

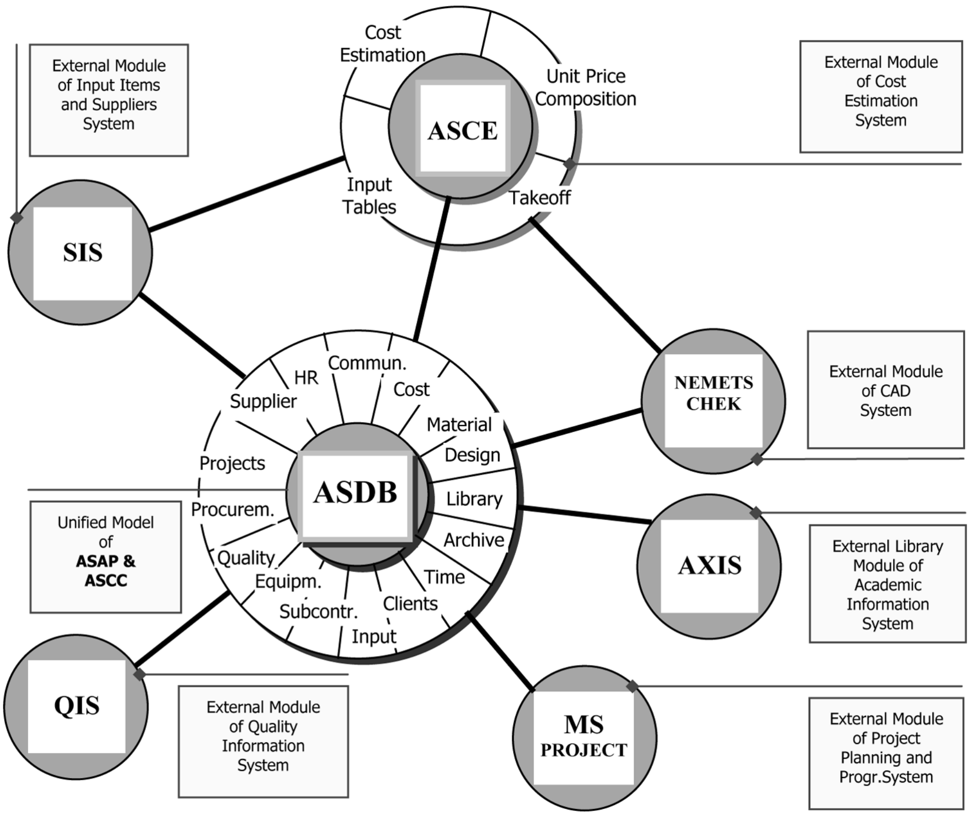

Figure 2 *Conceptual structure of MITOS*

related functions, with some exceptions. For example, the information related to normal and overtime work hours of design personnel must be recorded in reference to the drawings produced in the design process whereas the same type of information will be recorded in reference to construction activities in the construction process. Although this sort of exception makes it difficult to use the same database to represent events in both the design and construction processes, many of the modules that exist in ASAP and ASCC match each other. For example, ASAP contains the engineering offices module that organizes the information related to consulting firms that undertake the design of various subsystems of the projects. As for ASCC, the subcontractor module is one of the basic modules of the model. These two modules are identical since the type of information that the system needs to store about consulting firms used in the design process is the same as the information one needs about subcontractors whose services are engaged in the construction process.

After the conceptual model was formulated, it was converted into a relational database software called MITOS (Figure 3). The database file was developed in MS access 2000 and the help and content files were prepared by using MS access help workshop. Finally, all the files were compiled and prepared for an automatic set-up process using MS access developer toolkit. The software requires approximately 50 Mbytes of memory space and contains 95 tables, 218 queries, 87 reports, 373 forms and 400 macros. The software provides multi-user architecture. The users and their access rights to the database objects can be arranged by the system administrator.

MITOS was designed as an intranet application but it can easily be expanded for use as a web-based management tool. MITOS was not designed for operational level transactions but as a data warehouse to be used for providing information and decision support at the enterprise level. All transactions at operational level are carried out by external software packages but the documents including the detailed information are linked as OLE objects to the records that contain summarized data in the related modules of the model.

Although a simple combination of two models (ASAP and ASCC) provides facilities of electronic data flow and exchange, it carries the fragmented structure of the construction industry to the information system. This type of solution is not desirable because users of the information system will have to deal with hundreds of screens caused by unnecessary duplication. With a fully integrated model such as MITOS, it was possible to reduce the number of screens by half and eliminate user resistance caused in response to the complexity of the combined (ASAP + ASCC) information system and the large number of procedures to be learned in the combined system. Furthermore, the architecture of the integrated model minimizes the number of interfaces and simplifies the transitions among them. MITOS achieves this simplification by making use of a tree structure for the transitions that is very simple to learn and impossible to misuse. The structure and principles of these transitions are presented in Figure 4.

Figure 3 *Basic modules of MITOS*

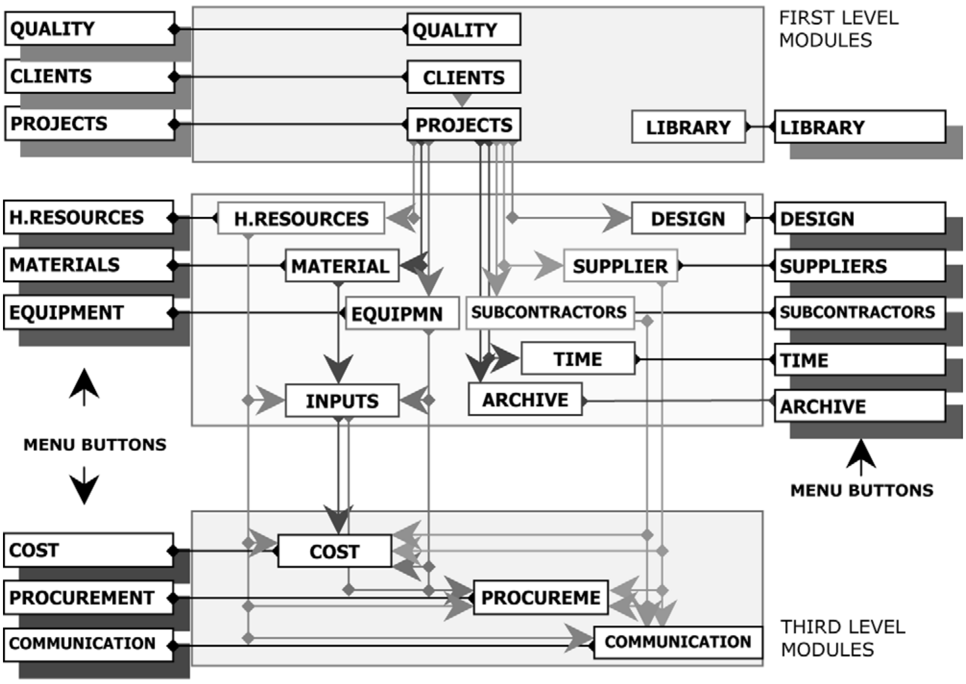

Figure 4 *Levels of and access to the modules*

As it can be seen in Figure 4, the modules are grouped in three sequential levels. The modules at the third level, i.e., the cost, procurement, and communications management modules, can be accessed in one (direct access), two, or a maximum of three steps. The second level modules, i.e., the human resources, materials, equipment, design, suppliers, subcontractors, time, and archive management modules are reached in one (direct access) or a maximum of two steps. The first level modules, i.e., the quality, clients, projects, and library management modules, can be accessed directly in one step. In each transition, selected entities such as project, personnel, equipment, material, supplier, subcontractor, etc., and their unique IDs are transmitted automatically to the succeeding modules as filter parameters. The same forward and backward paths are used, as this is the simplest map for users.

3 BASIC COMPONENTS OF MITOS

ASDB: Automation System for Design/Build. Since a considerable part of the revenues in the construction market are shared by constructors, the problems associated with the construction phase are thought to be important and occupy a large portion of the research agenda. The problems associated with the other stakeholders such as designers are often ignored. Indeed, there are only few conceptual studies [15–18] and prototype models that were developed as a response to the specific needs in the design stage [19,20]. As for the commercial software packages on the marketplace, it is possible to find some solutions for architectural and engineering offices such as billquick, portfolio, and semaphore that provide standard operational level database functions but no management-related tools. Only semaphore provides integration with MS project, a project management software. They can all be classified mostly as accounting oriented automation software for architectural practices and are not designed considering the design process, functions, and requirements in their entirety. Yet, architects need not only management information systems but also decision support systems to make and explain healthy decisions. Mostly, architects prepare alternative solutions, present them to the client and leave the final decision to the client. ASAP – automation system for architectural practices was developed as a response to the information handling and management-related problems in architectural offices by taking a holistic look at the entire design process [21].

As for the construction companies, they are in need of comprehensive information systems to cope with the management-related problems at both project and corporate levels. The majority of the research studies conducted, the models published and the software developed in the construction industry were related to these issues until integration of the building production process started to occupy the agenda. The studies conducted by Sanvido and Paulson [22], Abudayyeh and Rasdorf [23] and Zapalac *et al.* [24] can be given as examples. ASCC – automation system for construction companies is the output of another research project [14] where a management information system was developed for contracting organisations using much the same principles used in developing ASAP. Although ASCC was initially planned to address project level (site-based) information management problems, the scope of the project was revised to accommodate the information requirements of most construction companies. An analysis showed that the primary expectation of the top management was to obtain and exploit enough reliable information in order to enhance their competitive advantage in the industry. That is why the model was designed as a data warehouse providing summarized site-related data for use by decision support systems instead of dealing with operational level transactions.

ASDB makes use of the principles used in developing ASAP and ASCC. All information in ASDB is organized in the following modules. These modules are borrowed in full or in part from ASAP and ASCC since both models use the same database objects, i.e., tables, queries, forms, etc. with minor variations.

- projects management module
- clients management module
- subcontractors/consultants management module
- cost management module
- equipment management module
- human resources management module
- materials management module
- time management module
- design management module
- communication management module
- procurement management module
- suppliers management module
- input management module
- quality management module
- library management module
- archive management module

In the projects management module, every project is defined with a unique project ID. The phase of project is defined either as ‘design’ or as ‘construction’ (Figure 5) since some of the embedded forms are different for each phase of the project. Each module can be reached directly and information in the selected module is accessed regardless of the project to which it belongs. But, if a certain project is selected before accessing any module, only the information related to the selected project is accessed. Information recorded in the other modules is organized and can be filtered by project ID.

The clients of projects are defined in the clients management module. Architectural firms, construction companies, or design/build firms may work for the same client in various projects. The projects awarded by the same client can be filtered by this module and information about any project(s) undertaken for the same client can be accessed from this module. If any module is reached by specifying the client first, only the information related to the project(s) undertaken for the selected client is filtered.

The subcontractors/consultants management module stores and manages information concerning the subcontractors engaged by construction companies to perform specialized work on the construction site (e.g., HVAC subcontractor) and the consultants hired by architectural firms to design specialized functions (e.g., structural engineering consultant). Subcontractors and consultants are defined by an ID and name. Information related to work packages awarded to these subcontractors/consultants; the progress in work items undertaken; earned values and progress payments are recorded and monitored in this module. Projects delivered to these offices, meeting minutes, payment conditions, and expense records are stored and can be accessed to monitor the relationship between the architect’s office and each and every engineering office or the construction company and each and every specialty subcontractor that is listed in the subcontractors/consultants management module.

The cost management module is composed of four different submodules, namely estimation, finance, progress payments, and accounting. The estimation submodule communicates with ASCE, an external module that carries out the estimating function. The progress payments submodule compiles information according to the path followed by the user. For example, if the user accesses this submodule by specifying project and subcontractor names, the progress

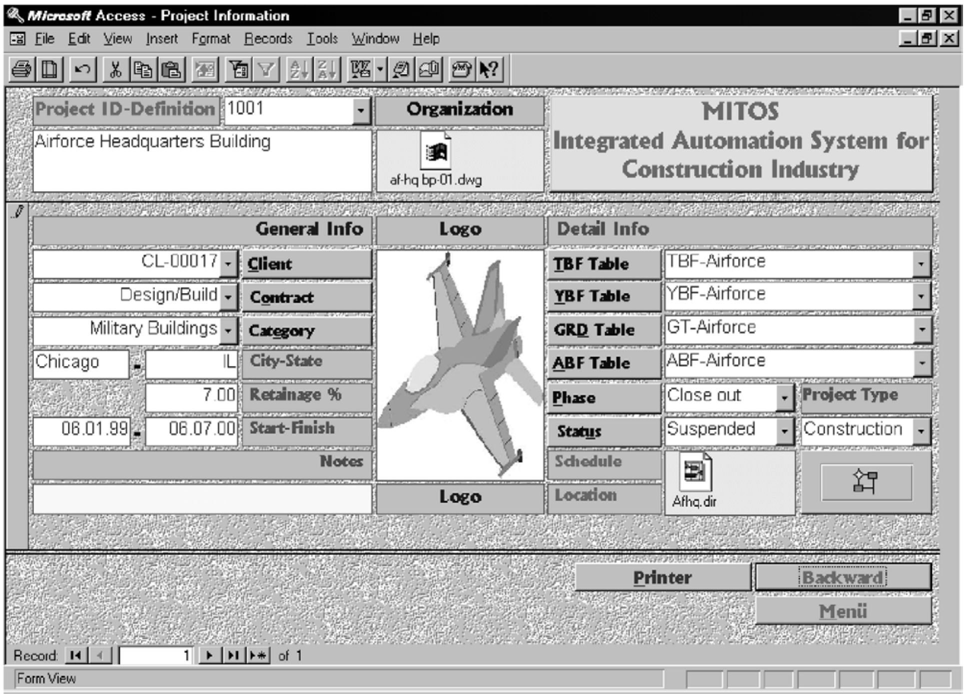

Figure 5 *Project ID information*

payments related to only the specified subcontractor in the specified project are accessed. If an alternative path is followed, for example if the module is reached from the projects management and then the human resources management modules, payroll values for work done by selected labour are reported for the specified project. The finance and accounting submodules allow the use of a user-defined cost structure, which in turn allows the user to generate flexible and customisable reports.

The equipment management module deals with equipment used in construction sites. All information related to equipment including ownership and operation costs, maintenance schedules, and productivity analyses are organized in this module for each equipment individually. Equipment can also be monitored not only individually but also by category (e.g., only crawler tractors) by specifying it in the input management module of SIS – suppliers information system. While constructors need this information for estimating purposes and effective equipment management practices, designers also need this information for producing accurate and reliable cost estimates particularly since they can access equipment information by category.

In the human resources management module, two different types of human resources (office personnel and labour) are defined by their ID and name. The hours that an employee works are recorded by project ID and project phase. The fees are calculated according to normal and overtime rates, whichever applies. Payment records can be accessed either in graphic or text format. The information related to normal and overtime work hours of design personnel is recorded by reference to the drawing sheets in architectural offices. The counterpart information in construction companies is recorded by reference the work items defined in the bill of quantities. That is why, different subforms are embedded into the system and can be accessed as the user specifies the phase of the project (i.e., design or construction). The teams and productivity submodule of the human resources management module allows the user to define project-based team categories and teams. The composition and the standard production performance of each team can be defined in this submodule. As a project progresses, the productivity performance values for each team are automatically updated. The system supports an infinite number of teams, so the user can add as many teams as necessary in the project. The system can supply information related to which teams are used in which projects, which teams perform which activities, and what the performance rates of the individual teams are. Given the quantities involved in an activity and the performance rate calculated by the module, the system can calculate the duration for that activity and export it to the scheduling program (MS project). This is a major contribution to integration.

The materials management module retrieves cost and availability information about building construction materials from SIS – suppliers information system. Whereas, labor and equipment are inputs that can be monitored both individually and by category, materials can be monitored only by category. Because of this, the materials management module interfaces closely with the input management module of SIS where the user specifies the category of the material in question (e.g., concrete).

The time management module automatically calculates activity durations. It retrieves information about project activities from the cost management module, which includes the takeoff generated by ASCE – automation system for cost estimation. The time management module also makes use of information about the teams that are assigned to these activities and that are defined in the teams and productivity submodule of the human resources management module. The durations of activities are automatically calculated and updated (Figure 6). Two additional parameters are used in the calculation of activity durations, namely the number of the teams assigned to perform the activity and performance coefficients based on past production data. The conceptual structure of the approach is presented in Figure 7. Details about this module and its integration with the other modules are explained elsewhere [25].

Documents such as CAD files, photographs, and videos that are related to design are organized in the design management module. A coding system allows filtering the records containing different types of design objects that belong to different stages of design. All the objects are linked to the related records and can easily be accessed when desired. This module allows designers to manage their design production by streamlining the design process and enhancing design efficiency. The design management module also serves constructors to organize revised or as-built drawings during the construction stage or to access design information generated by designers. The function of the design management module is simply to store design-related documents in a systematic way. It does not interfere with designers' creativeness or initiatives. The great advantage that this module offers is that parties (designer or constructor) can access this information any time they like and very rapidly (compared to calling the other party and having the drawing mailed). Consequently, it can be argued that since access to information is very fast (almost instantaneous), designers should have more time left to devote on their creative activities and constructors should have plenty of time to spend on their construction management activities.

All messages and meeting minutes are recorded and stored in the communication management module. The message files including electronic, fax or voice messages are linked to related OLE object fields. Designers and constructors will eventually give up traditional paper-based communication tools and adopt modern means of electronic media. Designers and constructors work often concurrently sometimes on a number of different projects and have to effectively communicate with each other and with interior (office personnel) and exterior (engineering offices, local authorities, clients, etc.) participants.

The procurement management module is composed of five submodules, namely demands, orders, inventory, contracts, and specifications. Any input item such as materials, equipment and labour required by project personnel in an architectural office or construction site, is recorded and organized by type of input item in the demands submodule. This information is used by the orders submodule to issue purchase orders to procure materials, equipment, or labour. Input items inspected/accepted and their quantities in stock are monitored by the inventory submodule. The contracts submodule contains the contract documents; these documents are organized by project ID and by participant, i.e., suppliers, subcontractors, etc. The technical and administrative specifications are organized in the specifications submodule by project, related building component, material, equipment, and labour; they are automatically attached to purchase orders in the procurement process.

The function of the quality management module is related to purchase orders. The quality management module contains the required interfaces to communicate with the satellite program QIS – quality information system that organizes the quality information by means of three submodules, namely codes and regulations, construction specifications, and standards.

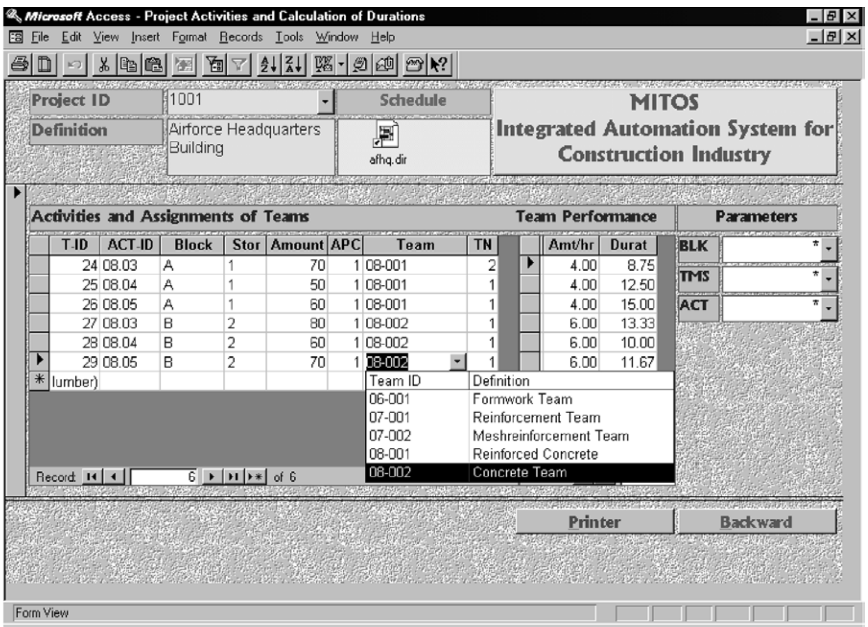

Figure 6 *Assignment of teams to project activities and calculation of duration of activities*

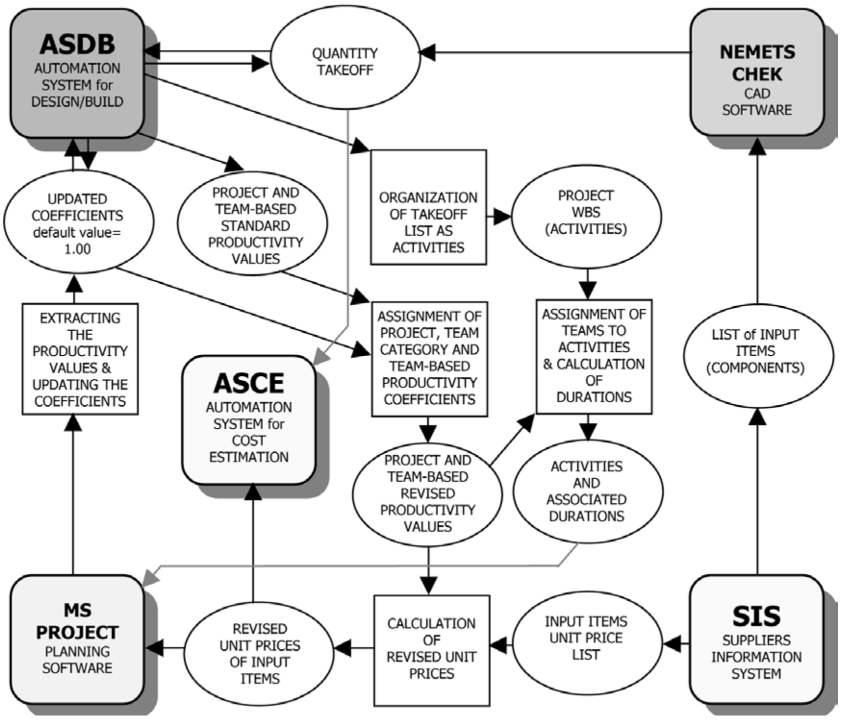

Figure 7 *Conceptual structure for the unified performance-based duration and cost estimating system*

Input items, i.e., materials, equipment, and labour are defined by unique IDs and CI/SfB codes in the satellite program SIS – suppliers information system. The input management module contains the required interfaces to communicate with this satellite program. The information generated by this module is used by other modules of ASDB such as materials, equipment, and human resources management modules and by other satellite programs such as the estimating package (ASCE).

The library management module contains the required interfaces to communicate with the satellite program AXIS – academic information system. Information about books and periodicals on the database can be searched by user-defined keywords and other parameters such as author, date, periodical code, publishing company, etc.

After a project is completed, all the documents, minutes, legal deeds, drawings, etc. related to the project are archived. The original hardcopies of the documents can be kept in good order, but copies can also be stored electronically, in which case they can be more easily accessible when needed. The archive management module contains electronic copies of the archival information for project documents including contracts, maps, urban plans, drawings and specifications that were used all through the project. Information about documents can be accessed on a dedicated screen and a search can be conducted by category and subject.

SIS: Suppliers Information System. The suppliers information system (SIS) is not an optional component of MITOS; as seen in Figure 2, it is needed by and is linked to ASDB and ASCE. The supplier companies are defined by ID and name in this external module and they are classified according to input type (labour, material, equipment) they deal in. International standards (CI/SfB) are used in this module for coding input items. A list of inputs supplied by individual companies or a list of companies that supply specific inputs can be produced using filter options. The inputs, i.e., materials, equipment, and labour supplied by different companies and their unit prices are used by the cost management module to create alternative input tables. Personnel and equipment are two inputs that can be monitored both individually and by category, but materials can only be monitored by category. These tables are used to calculate alternative project estimates. The unit prices must be updated periodically and the model allows the related databases to be updated by the users of the system or by the software vendor of MITOS.

ASCE: Automation System for Cost Estimation. The basic characteristics and purpose of the cost estimating function in the various phases of the building production process are different from each other. Therefore, the outputs of the estimating activity performed by different professionals in the different phases of a project mostly vary from each other. The variations may sometimes be very large due to the effects of unforeseeable factors related to the basic parameters of design (e.g., buildability) or construction (e.g., location of project), weather conditions and their effect on productivity, problems associated with procurement or availability of materials, labour and equipment, etc. ASCE takes into consideration the construction phase parameters in addition to design characteristics for more accurate estimating in the design phase. Therefore, the cost estimate made in the design phase of a project will have little or no variation from the cost estimate made in the construction phase. Because cost estimates have thus become more reliable, it is now proposed that activity durations be derived from this information. The conceptual structure of MITOS's performance-based duration and cost estimating system is presented in Figure 7. ASCE and its integration with the other modules are explained in detail elsewhere [25]. As it can be seen from the figure, both the duration estimation and cost estimation functions, use the outputs of a unified process of calculating the performance values of similar past projects. This can be stated as an example of process level standardization in the model.

ASCE obtains unit prices from the suppliers information system (SIS), which provides up-to-date supplier-based information. ASCE allows the user to compose unlimited sets of alternative input tables. Thus, the cost information used in estimating the cost of a component or a project is based on real values. In this situation, probable variations in estimates may only stem from unforeseen project- and team-based performance variations. ASCE allows the user to define project takeoff items manually or to retrieve them from a CAD system at different stages of the design. At the conceptual design stage, takeoff items can be defined in terms 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.

MS Project: Planning and Programming System. The time management tools used for planning and scheduling on-site activities in the construction phase can also be used for planning and scheduling design activities in the design phase of a project [26]. MITOS encourages users to make use of MS project in the design and construction phases. Furthermore, it is not only ASDB that calls on MS project for project planning and scheduling purposes; ASCE too calls on as-built project and team performance data generated by MS project to conduct cost estimating activities. As observed in Figure 2, ASCE has no direct link to planning and programming system; it obtains this information indirectly through ASDB.

Integrating a commercially available software is a more reasonable solution than developing a similar system from scratch, particularly since MS project provides all the facilities required in this instance. The reasons and enabling technologies for using such packages are explained clearly by Rao *et al*. [27]. There are also comprehensive models that define the architecture of construction-related software integration [28,29].

MS project for Windows 98, a low-end project management software, was integrated into MITOS for management functions related to time, cost and resources in design offices as well as in construction sites. The relational database file created by MS project consists of several tables. Four of them that are essential for the integration are:

- project information (data related to projects)
- task information (data related to activities)
- resource information (data related to resources)
- resource assignment information (data related to assignments of resources to tasks)

Planning and programming system allows these files to be converted into MS access database format (and saved as MS projects.mdb files in MITOS). MS access 2000, the database development software that was used in developing MITOS, allows the developer to establish relationships with external applications in three ways: object linking, object embedding, dynamic data exchange. The four tables in this file are linked to the Mitos.mdb file. Thus, the project information is updated externally by MS project and not by MITOS. Matching the related project ID fields in the Mitos.mdb file and the projects.mdb file is the next step. The only action that should be taken by the user is to save the project files in projects.mdb file by using the 'save as' option in the MS project menu after updating the project information and then to assign the ID of the project in MS project to the project ID field in the project information screen.

Nemetschek: CAD system. The Nemetschek CAD software was integrated into MITOS to facilitate the performance of the cost estimating functions of ASCE. The software provides the required facilities to extract the quantities of building components from the design and export these values in a format that can be recognized by ASCE (Figure 2). The software works with 'smart objects' corresponding to building components such as walls, windows, etc., that can be defined by the user prior to design. At any point of the design process, the quantities associated with components can be extracted from the design automatically. The software imports the coding structure defined by the user for building components in ASDB, assigns these codes to smart objects, produces takeoff lists in the desired format, and finally exports the output table to ASDB.

The complementary components. The remaining two external modules, namely the quality information system (QIS), and the academic information system (AXIS) are the optional components of MITOS.

Since information about regulations, standards, and specifications is required by both design and construction organisations, the quality information system (QIS) that deals with this information is designed as an external component that can be accessed by ASDB. The quality of the constructed facility is planned at the design stage. Designers have to make decisions concerning the subsystems, components and materials such that these are compatible with the scope of the project. In order to make timely decisions, information about these items must be available, easily reachable, efficiently filtered and quickly retrievable. An information system including published standards and specifications can provide this kind of information. All the general and local codes and regulations, construction specifications, and standards related to construction are organized in QIS. This module can be expanded to include specifications published by ASTM, AIA, ASHRAE, etc.

Reference books and scholarly and trade journals are of great importance to designers as well as constructors. Academic information system (AXIS) is a reference system that stores this kind of library information. It was developed as an external module of MITOS as part of another project [30]. It interfaces with ASDB through ASDB's library management module.

4 CONCLUSION

This paper presents an application model called MITOS that is a relational database model attempting to achieve unification of all the models used by individual participants into one universal model fulfilling the functions of all models combined, along with horizontal and vertical integration in the management of the building construction process. If the architecture of an IS model allows to achieve unification of information across all systems used by different organisations in a fragmented industry such as construction, then it would support and serve the standardization efforts in the industry. MITOS proves that in a relational database environment, unification of the information systems of different organisations, such as design offices and contractor firms is possible beyond the integration of the existing IS models.

The models developed for these organisations seem to be different at first sight relative to their basic functions, i.e., design and construction. However, combining these models makes sense because when the management-related functions in both types of organisation and at both project and corporate levels, are explored, they are found to be extremely similar to each other with some minor exceptions. Integrating and unifying the many information and management systems being currently used by the many participants in the construction activity and formulating a special architecture for an automation system may be preferable in certain project delivery systems such as design/build. Integrating the various components used by the parties is a common solution. What is new here is not the integration but the unification of the many systems, i.e., the combination of the components into a universal model. Thus, the same sort of information can be recorded in one relational database object (table) instead of two, and can be shared both by design and construction projects.

The management-related functions of the organisation, i.e., human resources management, subcontractor management, etc., at project level have horizontal (between departments) and vertical (between design and construction phases) relationships. In some project delivery systems such as design/build, design and construction are performed by the same organisation. In other words, these functions are undertaken by separate departments within one firm or by a joint venture of a design firm and a construction company. This type of organisational pattern can also be observed in partnering approaches. The model presented in this paper (MITOS) proves that integrating and unifying the many systems across design and construction can be achieved in both conceptual and practical dimensions.

MITOS is a system that provides information and establishes interfaces among all management-related functions in the design and the construction processes; it can effectively be used by designers as well as constructors as a decision support system. It is particularly suited for use by design/build firms and has obvious advantages in partnering arrangements. The current version of MITOS is an intranet application but it can easily be modified to become a web-based system and it can easily be expanded into a more comprehensive system that could make extensive use of data-mining tools to exploit the information stored in its many databases.

The system is composed of a central component called ASDB that is in turn composed of 16 modules. It serves designers and constructors by helping them manage their work as well as conduct their relationship with each other in harmony. These modules have passed the test of time as they were used extensively within the context of ASAP and ASCC, which are operational systems currently in use by architectural design firms and construction contractors, respectively. The lessons learned in the development of ASAP and ASCC played an invaluable role in the development of ASDB.

MITOS is fully operational and has been tested. No user resistance was encountered. It produces all desired reports as long as the required data are available. It can however be further improved by adding sophisticated data mining tools such as statistical analysis packages, decision tree classifiers, and neural network prediction tools that can derive trends and other useful information from the vast quantities of data warehoused in the system. With automation systems like MITOS, decisions in all phases of the traditional design-bid-build delivery and particularly in design/build environments are expected to be made faster and to become more reliable.

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