# Web-based integrated construction management solution

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ABSTRACT: Construction projects are becoming more and more sophisticated, as a result of increased client requirements, tighter budget and time frames, larger number of participants and more complex work processes. However, especially in the area of construction project management (CPM) these growing requirements are not yet sufficiently addressed by today's IT. Even though several systems integrating CAD, ERP and CPM tools have been developed and brought to market over the last years, there is still lack of efficient data and process interoperability for the purposes of CPM. Also, solutions are mostly proprietary, taking little account of established standards for the improvement of the quality of the product and the management processes.
In this paper we analyse CPM processes in terms of the needed applications and on the basis of generalised industry requirements. We describe the construction management life cycle model and suggest an IT framework for an integrated CPM system that can bring together design, ERP and CPM tools on the basis of standardised shared data (IFC) and standardised quality management procedures (ISO 9001). Reported is work that started at the Istanbul Technical University on more practical terms and is now continued, generalised and expanded at the TU Dresden in the frames of a PhD study.

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## 1 REQUIREMENTS TO INTEGRATED CPM

Today, it is generally believed that the integration of different types of software applications is a key instrument to improve the efficiency of the construction environment. However, even though several systems integrating CAD, ERP, and CPM tools have been developed and deployed, and the interoperability through connection of different types of products and CPM processes has led to considerable cost and time reductions, complete and generalized industry requirements based on standard models are not yet available. This significantly decreases flexibility, the information exchange between different systems, multi-stakeholder collaboration and, last but not the least, inter-enterprise cooperation and knowledge transfer. In spite of its potential, the upcoming common project model IFC of the International Alliance for Interoperability (IAI 2005) is practically not used for construction management purposes.

On the other hand increasing demands of quality in the AEC sector force construction companies to observe established guidelines for better quality management and product outcome. Accordingly, most companies have engaged with ISO quality management standards and established their process structure in accordance with (ISO 9001:2000). However, this trend is yet purely supported by CPM software.

A further issue that deserves consideration is the Internet. Collaboration through the Internet supports concurrent management of construction activities and enables achievement of better quality and shorter time to market. During the last decade established and new start-up companies continuously increased their use of the Internet for management applications. However, many business plans were not accepted as feasible because they were not grounded on a standard-based collaboration system.

In accordance with these briefly outlined issues, in the next sections we discuss major requirements to *web-based integrated management solutions* that are to be observed in order to foster successful application.

### 1.1 *Requirements from Concurrent Engineering*

Information technology has a decisive effect for the improvement of both the organizational and the technological infrastructure of construction projects so as to facilitate the effective application of concurrent and collaborative engineering practices.

Valuable steps for concurrent engineering in the AEC domain have been achieved in product model based integration (by ISO 10303 STEP, IAI/IFC and many European projects such as ToCEE, ATLAS, VEGA and others), in process modelling (by the CALS, IRMA and GPP initiatives, as well as by projects like eConstruct, OSMOS and ISTforCE), and in workflow developments and electronic document management - by the WfMC and several commercial and academic electronic document management systems (cf. Amor 1996, Scherer 2000, Katranuschkov 2001). Especially the industry driven IFC/IAI initiative can be identified as a major contribution to the standardization of concurrent model-based working processes.

However, in spite of all achievements for managing the process, product, documentation and communication, the organisational and information infrastructure in the AEC sector is still highly fragmented.

In particular, when the aspect of concurrent engineering is observed, the lack of standardized product and process models appears as a major handicap. Collaborative work heavily depends on parallel activities and information sharing during the design and construction processes. Accordingly, the specific characteristics of the construction environment have to be defined. Based on observations from (Amor et al. 1997), we can categorize these characteristics as follows:

1 Each major construction project is in fact an example of a virtual enterprise. It is quite common to have projects where the architects and engineers are from different countries, and the virtual product (i.e. the bid documents) of hundreds of hours of high-skilled labour exists as a complete package for the first time in the blue print shop. Also, in no other industry would a team of such breadth be routinely dissolved after executing only a single copy of the product.

2 Through the increased use of IT in the last years, architecture and engineering have become typical information based professions, requiring - because of the nature of their work - highly decentralized data management solutions. However, communication and data exchange in a project happen often between different organizations, operating within different domains of AEC. A large variety of heterogeneous IT tools and a wide range of technologies are being used, and hence the needs of sending and receiving applications are not a priori predictable.

In this context, to manage a building project in collaborative way requires to establish adequate software support, a general process methodology and an overall architecture for the technical work in the area of the design of buildings, construction process planning and project management. To fulfil these requirements, a conceptual framework which allows different partners to use the common processes and interrelated interoperable models need to be defined, and a web-based integrated management system using ISO quality management standards supported by CAD, ERP and CPM has to be realised.

### 1.2 *Requirements for Interoperability*

In the envisaged interoperability framework the activities and information flows should ideally cover the whole life cycle of a building. The product, the document and the information flow have to be defined under accepted processes. In this context, a feasible methodology for interoperability should deal with:

1 *The IFC model of the IAI initiative* (IAI 2005) (for a hierarchically structured product model).

2 *The ISO Quality Management System* (ISO 9001) (for the existing real-world process specification for managing the quality requirements of outcome)

3 *Web-based integrated methods*, encompassing the product and process information exchange within the CAD and CPM systems that support the IFCs.[*)]

## 2 THE CONSTRUCTION MANAGEMENT WHOLE LIFE-CYCLE MODEL

The specific requirements and the highly distributed nature of the construction industry, and the independently used systems for management processes provide the rationale for setting up the basic principles of the proposed system.

In this context the construction management whole lifecycle and the operational ICT framework can be defined. Their major characteristics are outlined in the following sections. The whole lifecycle model is shown on the high level in figure 1 below.

Generally, a construction project proceeds through the following stages: (1) feasibility & design, (2) preliminary preparations (measurement, bill of quantities, budget etc.), (3) planning & execution, (4) realization, and (5) evaluation of the outcome. These stages vary for different countries, but the basic principles are the same. In all stages specific databases and algorithms are used. All these databases must keep the information about their function and content in suitable structures and algorithms so that they can be further reused by the other stages whenever required.

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*) Whilst not yet deployed in practice, examples for such methods are provided by the Eurostep Model Server (Eurostep 2003), the SABLE project (Houbaux et al. 2005), and in the work of Weise et al. (2004).

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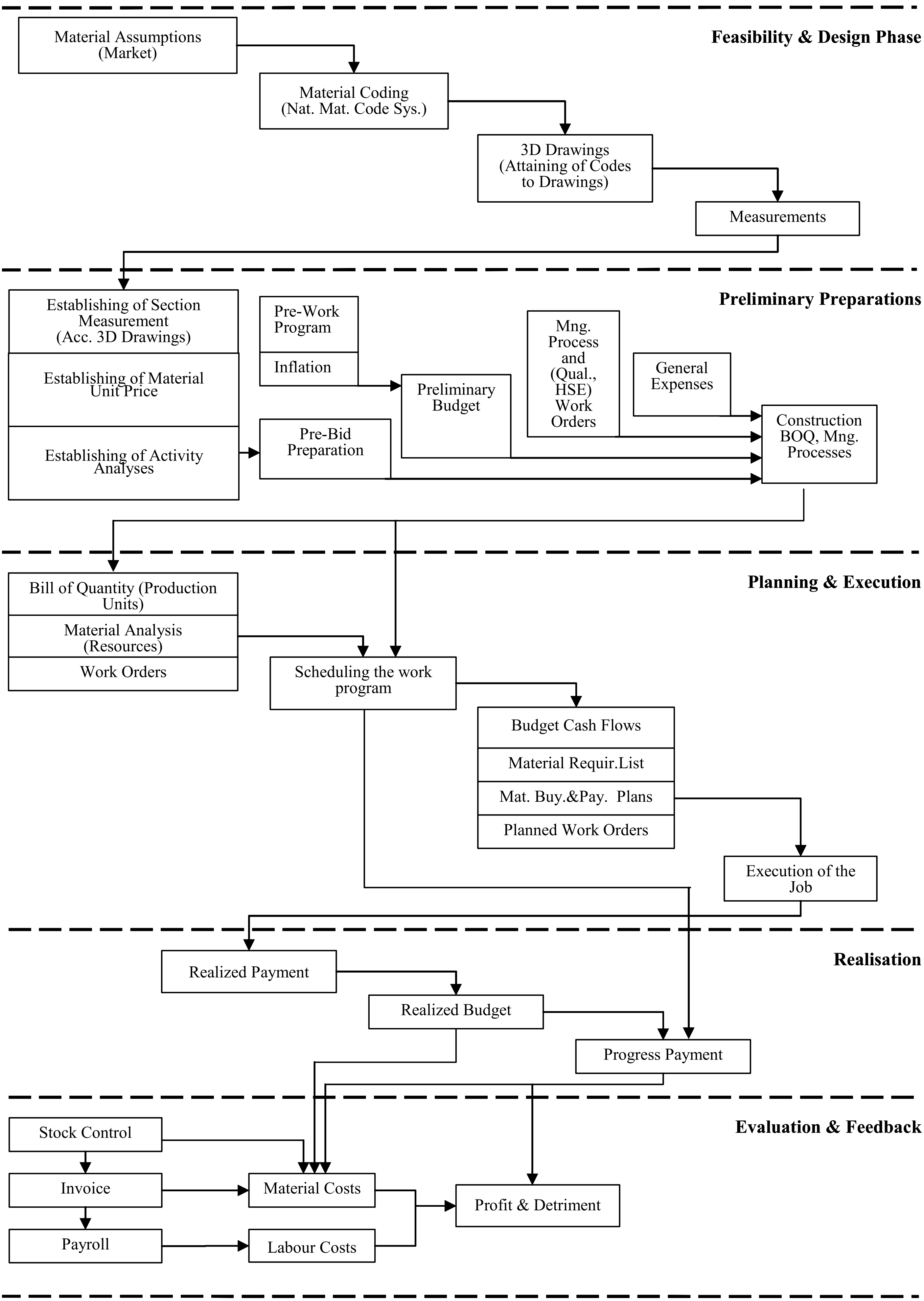


Figure 1: The Construction Management Whole Life-Cycle Model.

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In the *Feasibility & Design Phase*, the architectural and structural drawings, and the installation schemes of electricity and plumbing provide the database of the initial processes of the project. These schemes and drawings are the inputs for the technical applications defining the construction details, the measurements and the section lists. 3D drawing models with their identities can be established with the assistance of other databases. For example, door, window, decoration objects or other technical drawings are taken from the software object libraries of the design software (such as Nemetschek's Allplan or Autodesk's AutoCAD), the material codes can be taken from national/international code systems or from special databases etc. Combining these outcomes allows to visualize a project three dimensionally, and – more importantly - to report and export the *quantity surveying and the section analysis* in a desired format that can be used in other stages of the CPM process.

In the *Preliminary Preparations Phase,* after the quantity surveying is finished, cost estimates can be established. These estimates, typically prepared on the basis of the construction diagrams and the technical specifications, are actually the pre-budget in terms of quantity and finance.

In this context a proposal should be prepared based on the cost estimation and conforming to the owner's requirements. Measurements should be checked, recalculated and classified. Based on the production analysis, unit prices are calculated, and market values are checked. At the same time, with a speculative work schedule, the effect of inflation, the budget and cash flow tables have to be done. This requires collective work in the company. One group performs the quantity surveying and creates the measurement database, another one does the market research and creates the unit price database, a third one makes the construction cost analysis with respect to the company standards, and a fourth one prepares the work schedule and creates the budget and cash flow tables. These databases have to be inter-related. Each data produced in one group is needed by another group, i.e. highly cooperative work is required. Hence, an approach of integrated construction management tools is required that can support reliable bi-directional information exchange between the CAD and the CPM applications.

In the *Planning & Execution Phase* the planning of the activities or designation of the work order (pursuing of work order), identification and assignment of the appropriate labour and material resources, determination of the pre-budget and determination of the real-budget for the progress payment is done. For managing of the execution processes at the jobsite the quality management, technical inspection, contract and HSE management procedures should be followed.

Construction planning systems (such as Primavera, Suretrak, Artemis etc.) have the ability to schedule and report the allocation of the resources. To achieve that, activities should be defined with

- the quantities of their resources, and
- the monetary values of these resources.

These items can be tackled in the *preliminary preparation phase.* They can be re-used within these two phases if adequate information exchange can be established.

It is important to have a decision about material purchasing. It should be known which material is going to be used when and in what amount. The material requirement list with the amount and work program received from CPM helps to take material purchase decisions so that a payment plan can be easily created. Pre-budget can be estimated based upon the income and expenses which were already determined in the proposal, according to the values of a CPM solution. The income is related to the production and the sales price of the production at some future period. The distribution of the production over time is determined in the work schedule. The material requirement which is also determined in the work schedule is the budget expense and can be retrieved and reported periodically. To calculate the pre-budget and the real budget the resource costs of the activities, the estimation of the inflation, and the sales prices of the productions are required.

The above data is found in the *unit price and analysis* databases. The ***"****Pre-budget" and "Real budget****"*** reports are created using the data received from these databases and the CPM software.

In construction practice, most projects are easily managed according to a CPM program by continuously consulting the work orders. Such work orders can be reported automatically every morning. They provide the list of tasks to be performed during the day or week by any unit or technical personnel, and they can be reported and received easily.

*Project, cost* and *period* have the dimensions of quantity, time and money and should be examined by data evaluation programs based on arithmetical algorithms. These concepts should be considered under the title "*management and planning*". The related processes depend on people's ability to manage, software and tools that are used, and the direction of management decisions.

Concepts of *quality, agreement* and *HSE* should be considered under the title '*supervision*'. They are not limited by the 'talents' of the manager. Rather, they are the objectives that are determined by agreements, standards, and contracts. There are no formal arithmetical algorithms for their determination, but they are conforming to heuristic rules, methods and standards. Related to this approach is the '*management process layer*'. It will be discussed in the following sections.

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In the *Realization Phase* actual payments, realized budget and progress payments have to be considered. During the calculation of the planned budget, purchase decisions are taken, payment plans are formed and the resulting cash flow is foreseen.

Real payment is something different. On the construction site, the necessary purchase decisions are taken and a budget is estimated. However, the real budget is calculated not based upon the demand from the construction site but also the demands from the headquarters. From headquarters viewpoint all projects are considered as a whole, and the payment plan is arranged depending on the degree of importance. In other words, real payments are made according to the possibilities decided at the headquarters, not according to what is required at the construction site. At that point, the *"Real Budget"* is formed. However, it cannot be certain that the central management takes the right decisions, and it is hardly possible to compare the planned budget, the required budget and the real budget and to inform the management about the ratio of the realized portion of the work to the planned. Therefore, ad-hoc co-operation forms should be set up so that all participants in the project can reach their own project data and can easily share this with the other units.

On the other hand, progress payment is a partial payment paid by the owner, verifying that portions of the work have been accomplished. Basically, it is an invoice showing the quantity of the realized construction, the unit prices of the construction items and the cost of the realized construction. The conditions, payment intervals and the format of this invoice are defined in the agreement.

Related with this, if the work schedule is appropriately followed, all work orders can be given by the software, and all changes related to the activities can be updated daily. Thereby, the work schedule can be also the source database of the progress payment reports.

In the work schedule, we can easily follow when and in what amount production will be or has been made, i.e. the portion of the construction completed within a certain period can easily be figured out using the work schedule. The evaluation of this quantity data with the prices in the analysis or unit price database provides the content of the invoices *"progress payment"*.

In the *Evaluation & Feedback Phase* the cost of each construction item is defined and it can be tracked which invoice was issued for what construction item. A database can be established to reflect that simple relationship. Tallying can also be processed in the same database, i.e. which worker worked for what construction item on which day. The construction item costs and the labour costs can also be processed in the same database to calculate the "*real construction costs*" and the *"real labour costs*". Also, the actual costs of all resources during the realization phase of the project have to be determined (for example, material and labour costs are determined from the stock records and the tally lists).

The analysis of each construction item can be compared within the proposal to provide the values 'as estimated' and 'as realized'. This comparison clearly reveals the profit or loss during the construction of each item. Another advantage of making the comparison is that the stocks are continuously kept under control. Following the real stock movements enables to determine the material costs in those analyses better, and to follow the purchases and excess material amount more consciously.

The information required for these purposes must be entered in the system and reported in different formats. Otherwise, this knowledge gained by experience is going to be forgotten. At the completion of each project, recording the experience in the firm analysis and the firm unit price database ensures a strong basis for future proposals and decisions of the company.

Such a database represents the so called "*firm memory*". It enables the users to conveniently access various types of important information such as:

- construction analyses,
- unit prices and market values,
- technical specifications,
- planning of execution,
- budget, stock, payroll, profit and loss records,

and re-evaluate the work of a finished project.

According to the whole life cycle model shown in figure 1, the activities and information flows to be supported in the targeted integrated CPM solution should cover most the whole life cycle model of a building. In this broad scope, various types of information entities have to be considered in their inter-relationship: (1) the information about the constructed facilities, including construction products, processes, documents, regulations, contractual requirements etc. (2) the information about the model itself including the information representation (files, databases), the information processes and the components of the environment such as servers, clients, users, applications etc., and (3) the information about the information, including concepts like ownership, access control and versioning.

Therefore integration of the inter-related information aspects of a building project into a consistent conceptual framework is of primary importance. These aspects are: the product, the document, the information flow and the process models.

## 3 SUGGESTED OPERATIONAL FRAMEWORK

The operational framework has to be established according to a coherent process and information exchange paradigm. We suggest a layered structure,

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comprised of 4 clearly defined layers: (1) Application Layer, (2) TSD Layer, (3) Management Process Layer, and (4) WPA Layer. They are described in more detail in the following sections.

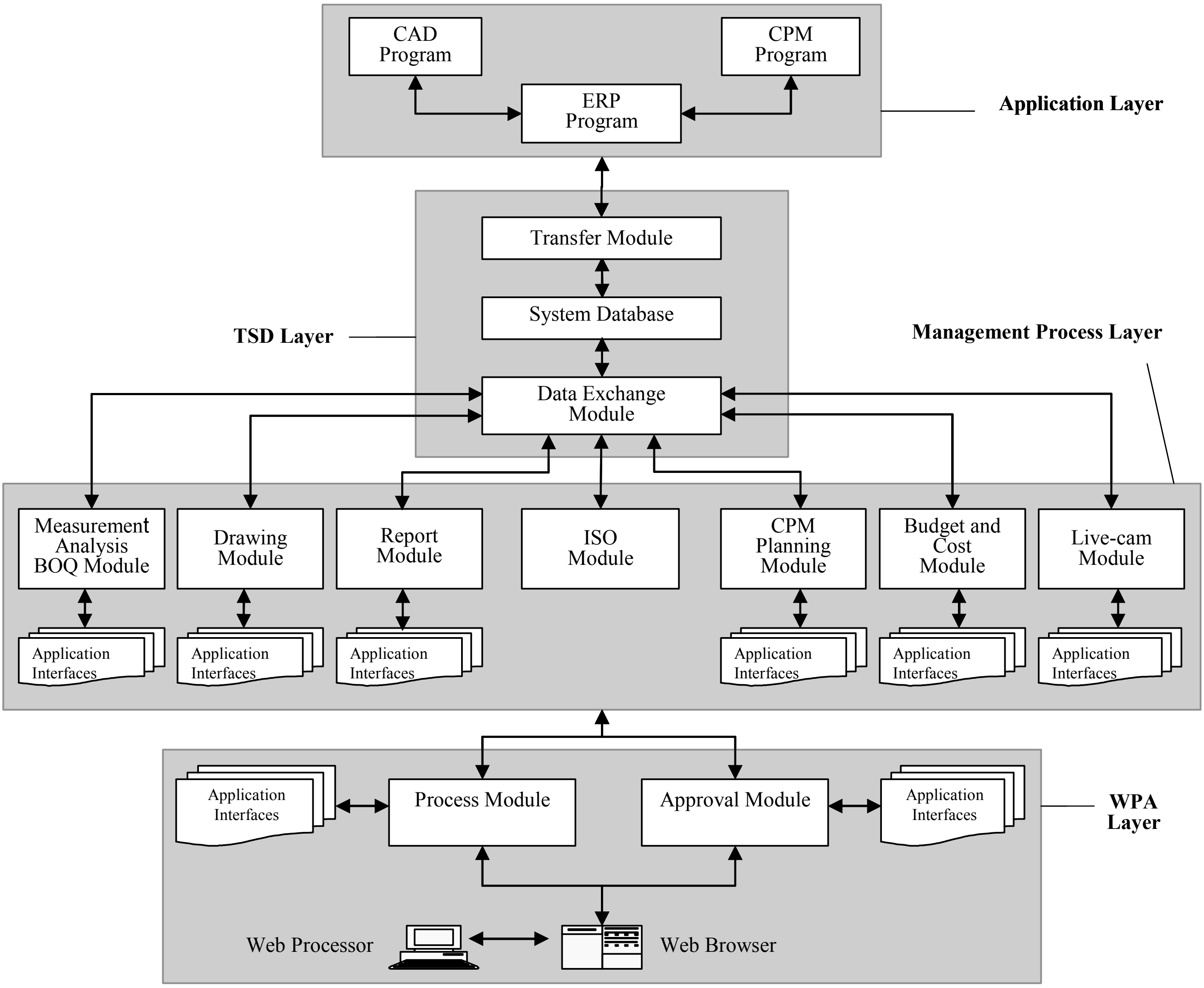


Figure 2: Web-based integrated CPM solution supported by quality management, design, ERP and planning Systems.

### 3.1 *Application Layer*

The purpose of this layer is to support different types of project activities, performed with the help of CAD, ERP and CPM programs. The main target is to combine the construction site and project partners' databases, thereby allowing improved project/cost control, increased work efficiency and fast response to changes within the construction environment. The layer is structured and established in accordance with the interoperable CAD-ERP-CPM environment outlined in figure 3.

On the basis of experience gained from studying a number of state-of-the-art systems, the method of establishing a collaborative work environment that is grounded on an interoperable system should fulfil the following objectives:

1 Generalize and formally describe construction project management processes comprising the whole construction management lifecycle in order to support interoperability over a broad spectrum of applications,
2 Provide a common information model for construction project management based on the data schemas of the IFC standard, thereby ensuring the needed integration of product, process, cost and management data,
3 Provide interoperability methods to integrate legacy systems,
4 Provide algorithms for completeness check and an assistance system based on context analysis to interactively establish completeness.

The approach is based on using and appropriately combining methods for requirement analysis (quality function deployment, critical success factors, use case analysis), process modelling (IDEF0, UML), and STEP-based product modelling (EXPRESS) - to identify and formally define *necessary IFC extensions*. System APIs are conceptualised using the

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object-oriented modelling method, and the system itself is established as a client-server environment, integrating the component tools as services via a common GUI implementing the Web Services concept (Vasudevan 2001).

In preparation to the actual realisation work an extensive study of existing systems, earlier standardisation efforts and applicable integration and interoperability methods are being performed.

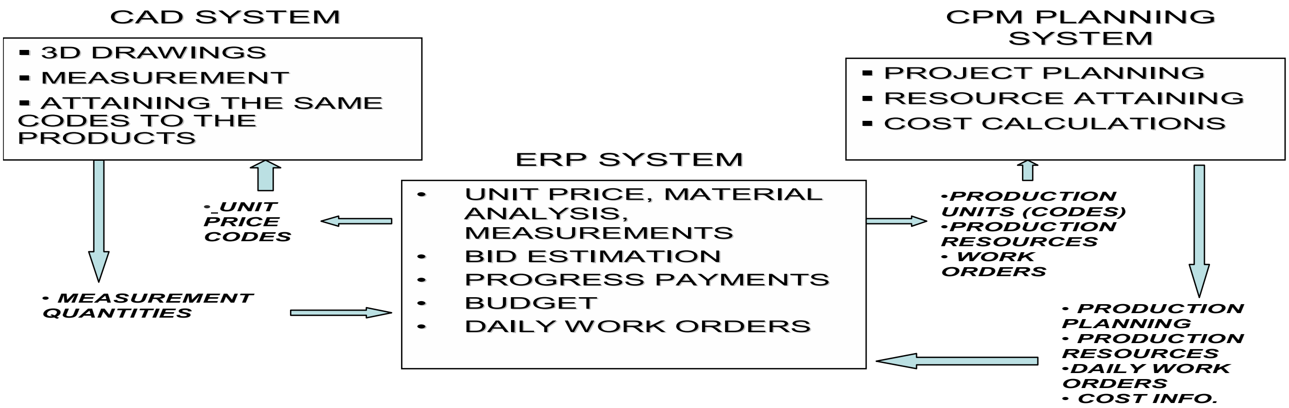

Figure 3: Integrated client-server architecture of the Application Layer.

### 3.2 *TSD Layer*

This layer consists of a Transfer Module, a System Database and a Data Exchange Module. The information that can be obtained from the application layer is stored in the *System Database*. This information should cover the identified needed outcomes of the CAD, ERP and CPM programs. The *Transfer Module* supports the data exchange between the *Application Layer* and the *System Database*. Assuming that IFC data can be exported by the involved applications, this can be done with the help of a general-purpose API in a convenient format (using ISO 10303-21 files and/or ifcXML). Information is transferred to the *Data Exchange Module* which is the coordination module for the below layers, ensuring synchronous and asynchronous information flows in a standardised, regular way.

### 3.3 *Management Process Layer*

The Management Process Layer consists of 7 different modules that can perform and be managed separately. Five of them, namely the *Measurement/BOQ Analysis Module,* the *Drawing Module,* the *Report Module,* the *CPM Planning Module,* and the *Budget and Cost Module* include and further process the data obtained from the *TSD layer.* Additionally, a *Live-Cam Module* can be provided to track execution on the jobsite, and an *ISO Module* can be included for process support in accordance to *ISO Quality Management* procedures. This module would also allow to observe the approval process within the partner organisations and within the applications.

### 3.4 *WPA Layer*

The WPA Layer provides the facilities for (1) execution of the management processes and the related applications via the Internet, and (2) presentation of the obtained results to all stakeholders via a common Web Browser. The process workflows can be carried out using a standard based schema, and on every step the information can be checked and approved by the responsible persons who are attained by the project organization.

### 3.5 *Prototype Implementation*

The suggested framework is prototyped in the frames of a PhD thesis '*Web based Integrated Construction Management System for ITU Campus Construction Sites',* carried out under the supervision of Prof. Dikbas (cf. Yitmen 2001). The implementation is based on proprietary interfaces. Planned further work involves realisation of IFC support for the data exchange and ISO 9001 support for process. Figure 4 below illustrates the workflows within the system and provides example screenshots from its use.

## 4 CONCLUSION AND OUTLOOK

In this paper we suggested a general framework for integrated construction project management, which is based on clearly defined collaboration between project partners. We described the developed construction management whole life-cycle model related to the general workflow schema of the processes, and outlined a conceptual client-server environment architecture that can fulfil the identified requirements.

The goal of the system, currently under development, is to handle various types of information coherently, including product, process, and management data, and to provide seamless information exchange between the actors and tools in the process.

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This development is not done from scratch. Related with the suggested approach is the ProIT project which also addressed development of product model based process and modelling its data exchange. ProIT compiles design guidelines needed in product modelling and establishes model structures for the re-use of product libraries (cf. ProIT 2004). It can provide valuable input to our further work.

Another effort that calls for close consideration is the SABLE project which has developed a set of APIs to access IFC model data in a client-server environment (Houbaux et al. 2005). Along with emerging IFC import/export functionality in legacy applications this establishes a good foundation for coherent IFC-based implementation of the outlined conceptual framework.

Thus, further development need is seen especially in the novel formalisation of ISO 9001 procedures, their realisation within the system and integration with the product data.

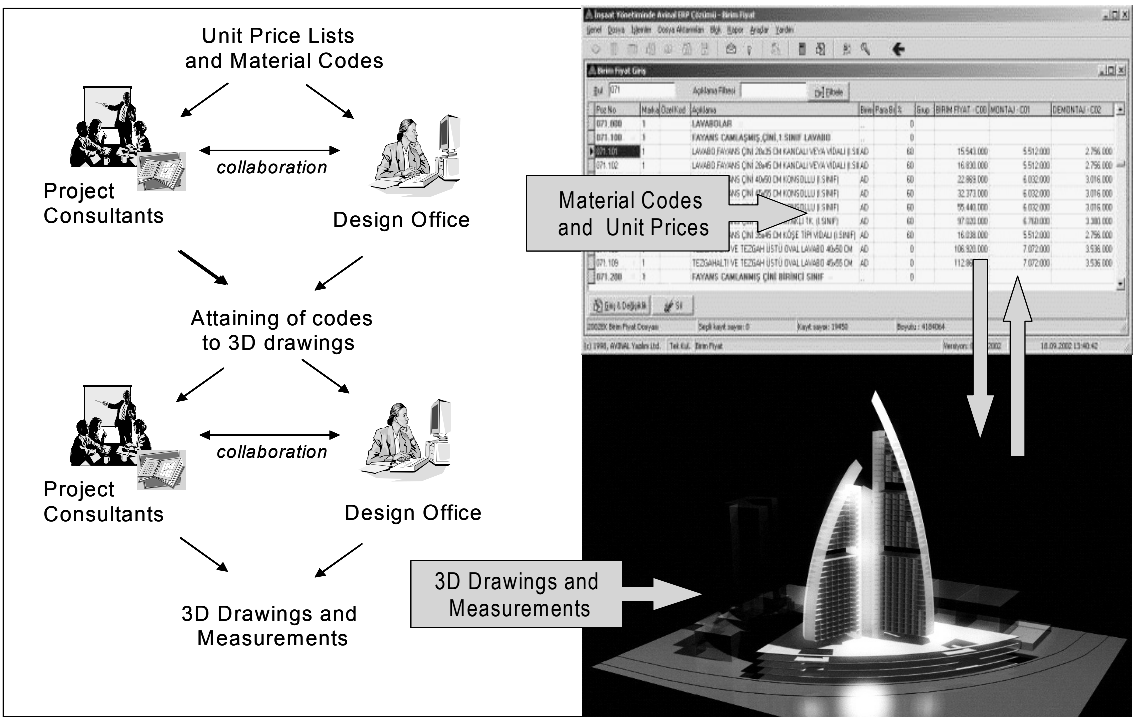


Figure 4: Schematic presentation of the workflows in the prototyped integrated CPM system.

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