

A Unified Construction Project Management Arena

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ABSTRACT: To address the severe problem of information fragmentation in the construction industry, significant effort has gone into developing information interoperability techniques based on shared project data models. As a result, a wide range of software applications are able to exchange project information, resulting in significant efficiency and coordination improvements. Here, we extend this trend further, exploring the role of an information integrator system that allows users to work directly with the combined set of project information. An information integrator would work in conjunction with traditional applications, allowing users to create user-defined, multi-dimensional data views from the combined project data model, tailored to suit the needs of specific work tasks. In this way, users can maximize the benefit of the combined data model and enhance their ability to deal with the data interdependencies. This paper presents a technical framework for an information integrator for construction project management. It describes the requirements and technical solutions to achieve the necessary integration and flexibility at three layers of system architecture: the data layer, the application logic layer, and the presentation layer. Finally, it describes a prototype information integrator system called the Unified Construction Project Management Arena.

1 INTRODUCTION

Construction lags behind other major industries in the adoption of information technologies due, in large part, to the highly fragmented nature of the industry. Over a short time span, each project brings together many different users from many different companies carrying out different tasks using different software tools that each adopt a different information perspective (data models or data views), yet all of these are collaborating on the same project and all of them are working with data that describes the same building. A major trend in construction information technology has been the development of information interoperability through shared data models of construction projects, or Building Information Models (BIM). With shared BIM-based models, and the Industry Foundation Classes (IFC) data standard in particular (buildingSMART, 2009), the potential for a high degree of information interoperability has been reached. However, we argue the need for an additional level of integration beyond interoperability.

With interoperability, each user still completes their separate tasks using their separate (largely traditional) tools, adopting their own perspective of the project information. The advantage of data exchange and interoperability has been achieved (with

its major efficiencies and information coordination benefits), but there is still no way for users to work with the entire data set as a whole, and there is no significant improvement toward having all users sharing a common view of the project, which would improve coordination and collaboration of the fragmented work tasks. We suggest that this calls for a new class of software tool that we call an information integrator.

An information integrator would work alongside traditional software applications to aggregate all of the project information into a single project data set, and allow users to explore all of the project data (particularly the interrelationships between different data views) in support of specific work tasks through user-configurable views of the integrated project data. This paper presents a technical framework (conceptual design) for an information integrator for project management information, call the Unified Construction Project Management Arena (UCPMA). The approach addresses integration at three layers of system architecture: the data layer, the application logic layer, and the presentation layer. In addition to the technical approaches, the prototype of the UCPMA system has described.

2 INFORMATION INTEGRATOR

An information integrator system would work in conjunction with traditional software applications, which would continue to excel at supporting individual tasks and to generate project-related data sets. In contrast, the information integrator would excel at allowing users to explore the interrelationships among the data by combining all of the available project information into a single integrated data model and allowing users to work with the integrated data model directly by defining ad-hoc, multi-dimensional views of the project information.

For example, in a scenario where a project manager is evaluating the impact of a proposed change order, he or she will want to consider the schedule, cost, scope, resource, reference documentation, and other information relating to the change. Each of these datasets is developed using an appropriate software application, but it is traditionally left to the user to manually identify each relevant data set and to understand the interdependencies between them. An information integrator would collect the data from each application and present it to the user in an integrated form that has been custom tailored (by the user) to support the change order evaluation task.

This research has not developed the concept of the information integrator, but rather adopts the idea from previous work. For example, Froese & Staub-French (2003) proposed a unified approach to project management, O'Brien et al. proposed a configurable environments approach (O'Brien et al., 2003), and (Songer et al., 2004) explored various visualization strategies appropriate for different types of project information.

The concept of the information integrator can be compared with other types of software systems used in construction. Some applications that traditionally support a specific work task and associated data view have expanded to incorporate a wider range of tasks and data, e.g., CAD systems or project planning and scheduling applications. While these systems are becoming increasingly integrated, they are far from supporting the entire integrated project data model or providing unlimited user-configurable views of the data. Some newer systems are designed from the ground up to be integrated systems spanning a broad range of tasks and data views, such as VICO project management software, but these systems again fall well short of providing fully user-configured access to the entire project data set. Other systems, such as Navis Works, can bring together project data from many different applications and allow the user to explore the information in a very flexible way, but it is restricted primarily to the project's 3D geometric data. Thus, while many systems provide increasing levels of integration and flexibility, none approach the concept of the information integrator.

This paper reports on research to develop a technical framework for the UCPMA, an information integrator to support construction project management. The basic approach recognizes that such a system requires extensive integration and flexibility at three different levels of system architecture: the data layer, the application logic layer, and the presentation layer. The following sections describe the challenges and the proposed technical solutions at each of these three layers.

3 DATA LAYER

3.1 *Integration at the Data Layer and the IFCs for Project Management*

The first of the three architectural system layers is the data layer. At this layer, the challenge is to gain access to all of the relevant project information that exists throughout the range of software applications used by the project actors, by combining it into a common project data model. The common model approach has been at the center of most research aimed at systems integration and interoperability within the AEC industry, and a great deal of work has been done, resulting in BIM technology in general, and the IFC data standard in particular.

The IFCs have been widely used to exchange building product information between different design systems within the AEC industry, for example, from one CAD system to another, or from the CAD design system into downstream applications such as energy analysis or quantity takeoff. However, the scope of the IFCs includes not only building product information, but also a wide range of project management data, such as actors, processes, schedules, cost estimates, reference documents, etc. Furthermore, although the purpose of the IFC schema is to support data exchange between systems (interoperability), the model is also suitable to be used as the schema for an integrated database system capable of housing complete project data models.

A technical solution for the data layer of a project management information integrator system, then, is largely pre-existing in the current IFC model. The challenge remains, however, that the project management portions of the IFC model have received very little research and development attention, and their suitability for supporting project management integration is largely untested. Therefore, at the data layer, the goal for this research was to establish the data requirements needed to support project management integration, to evaluate the IFC model against these requirements, and to suggest possible extensions to the IFC model if necessary.

3.2 Data requirements for integrated project management

In order to establish the data requirements for project management, a number of references on general frameworks for project management were reviewed (e.g., Wideman 2003, Project Management Institute 2000, Russell 2004, GloblePM 2003), and a common set of project management functions was identified, as follows:

- Scope Management,
- Cost Management,
- Schedule Management,
- Resource management,
- Quality Management,
- Risk Management,
- Organization Management, and
- Information Management.

Each of these project management functions was evaluated to determine the associated information elements. For example, the resource management function was found to involve the following information elements:

- Team (e.g. stakeholders in various disciplines, roles, project manager, etc.)
- Material
- Equipment
- Resource procurement schedule (tracking, book-keeping, project lifecycle, etc.)
- Process
- Work breakdown structure
- Organization
- Financial (payment, funding, etc.)
- Performance measurement, and
- Documentation of resource management

Next, the IFCs were evaluated against these information requirements, and appropriate IFC classes were selected to form a data schema for each of the project management functions. The conclusions of this assessment were that the IFCs provided very comprehensive coverage of the data required to support integrated project management functions. A few necessary information elements were found to be missing in the IFCs. Although these data structures were not developed in detail within this research, the following classes were identified as possible areas for extension of the IFCs:

- Specification,
- Phase,
- Performance Metric,
- Event,
- Transition,
- Quality Control,
- Quality Compliance Notice,
- Risk,
- Risk Trigger,
- Risk Response,
- Communication Channel,
- Meeting,

- Responsibility,
- Trade, and
- Procurement Process

In summary, the IFC classes selected through this process, along with the proposed extensions, comprise the schema of the central data model for the proposed UCPMA project management information integrator system.

4 APPLICATION LOGIC LAYER

4.1 Requirements for integration at the data logic layer

The data layer combines all of the project data into an integrated database. However, no single application or task can work with the entire data set as a whole, each must extract a subset or data view from the overall dataset to meet the data needs of the individual application. Typically, this is done by carefully mapping the application's data needs to the integrated database and developing custom data import/export software. Recently, much effort has gone into developing techniques for defining standardized data views of the IFC model to support specific data exchange scenarios (e.g., the model view definition work, Hietanen, 2009). However, both the traditional techniques for mapping application data into the integrated data base, and the recent view definition work, develop the data views at the time that software applications are designed—neither is capable of supporting a process for the user to define any data view as part of a run-time, system-configuration process.

In contrast to techniques that define application data views at software design time, general query language techniques (e.g., SQL) could be used to allow end users to define their own data views and extract the relevant information from the integrated database. However, given the complexity of the full IFC model, it is a difficult and highly technical task to define query statements to extract data views, well beyond the capability of typical end users.

In order to support the requirements of a project management information integrator, then, the technology used at the application logic layer should support end user configuration of data views, but should take advantage of as much pre-defined knowledge of project management information as possible in order to simplify and structure the users' data view configuration task. Online analytical processing (OLAP) technology was found to provide a suitable solution to these requirements.

4.2 *Online analytical processing*

OLAP is an approach to answer multi-dimensional queries from databases in support of users' exploration and analysis of large data sets, for example, in business intelligence or data mining scenarios (in contrast to more common database operations aimed at high efficiency in performing a pre-defined set of transactions against the database). While there have been a few previous applications of OLAP to the construction domain (Chau et al., 2002) and (Nie, et al., 2007), the project management information integrator is not a typical application of OLAP techniques, since it involves a more complex, object-oriented, engineering data model and fewer numerical operations than would normally be involved in OLAP applications. However, OLAP's ability to support flexible, user-defined queries against complex multi-dimensional data sets is a good fit with the information integrator's requirements, and OLAP's techniques for defining multilevel data dimensions, linking these in data cubes, supporting hierarchical data navigation, and applying appropriate data operations are all relevant for achieving project management information integration.

The goal of this research at the application logic layer, then, was to apply OLAP techniques as appropriate to allow end users to effectively define queries to extract specific data views from the underlying common data model. Within the UCPMA, this component was called the Data Winnow.

4.3 *Applying OLAP in the Data Winnow*

Within the data layer, the central data model is based on the object-oriented data-modeling constructs of classes, attributes, and relationships. In the application logic layer, this data is mapped into the OLAP data modeling constructs of dimensions (which represent an individual topic such as construction processes), levels (which represent specific layers within each dimensions' breakdown hierarchy, such as the process levels of project, phase, activity, etc.), members (which represent individual data items within each level), properties (which represent the attributes of the data members), and measures (which represent the data types of properties). Different dimensions can be linked together to form data cubes (integrated, multi-dimensional datasets), and the data from specific dimensions within one or more cubes that relate to a specific issue can be specified as a defined data view.

For the UCPMA, the project management functions identified earlier were evaluated to identify the main information elements common throughout project management, and these were mapped into data dimensions along with their corresponding levels, members, etc. These data dimensions, shown as fol-

lows, were further linked together to define a project management data cube:

- Product dimension,
- Process dimension,
- Cost dimension,
- Resource dimension,
- Actor dimension,
- Document dimension, and
- Time dimension.

4.4 *Defining common and custom data views*

The definition of views to support specific project management tasks raises an issue identified in Froese & Staub-French (2003). Each user and task's data needs are different, so each should be able to define their own data views to meet their own requirements. However, if all project actors work with their own unique data views of the project, this will work against the objective of all the actors sharing a common understanding of the project and will add to information fragmentation. Our proposed solution is to define a small set of data views that are generally relevant to many actors and many tasks. These are the common views that can be widely used, and can promote the unified understanding of the project. In addition to these shared common views, all actors can define their own custom views to support their individual tasks. Part of the work of the UCPMA, then, was to define these broadly applicable common views. From again reviewing the information requirements for project management tasks, a set of common views was defined as follows:

- Plan view, focusing on processes and tasks,
- Effect view, focusing on the physical products,
- Supply view, focusing on resources,
- Reference view, focusing on related documents and similar supporting information, and
- Context view, focusing on other information that positions tasks within the larger project context.

Through the application of the OLAP techniques and their mapping to the underlying data layer, full data schema were developed for each of these common data views, as well as the ability for end users to construct their own custom views.

5 PRESENTATION LAYER

The data winnow component in the application logical layer allows users to extract data views from the central data model to support individual project management tasks. Yet the raw data alone is of little use, it must be made available to the user through appropriate presentation and visualization interfaces. The software applications that are well established within project management, such as scheduling, estimating, cost control, or CAD, have developed their interfaces through many software generations.

These interfaces have become very effective at supporting their target project management tasks, and we do not expect to improve upon them within this research. However, none of these interfaces have been developed with the goal of the supporting arbitrary, user-configured, multi-dimensional datasets, and they cannot provide a general solution for the requirements of the project management information integrator.

On the other hand, many generic information presentation and visualization techniques are widely available, such as the tabular and charting capabilities available within spreadsheet applications. While these are, in general, the types of techniques that will be appropriate for presenting the information integrator information, they cannot provide a complete solution since additional elements are required to assist the user in mapping the information elements in the data views to appropriate visualization elements. The research goal of this work at the presentation layer, then, was to evaluate a full range of data presentation and visualization techniques, and to develop a cohesive approach for presenting the information from the data winnow to end users. This work, called the Visualization Configuration Model (VCM), was informed by previous data visualization research such as Songer et al (2004), but was developed to meet the specific requirements of the UCPMA information integrator.

In surveying a broad range of technical issues relating to information visualization, it was found that graphic elements and issues can be arranged into layers that come together in a concentric structure. This structure is reminiscent of the way that natural flowers contain simpler elements of sepals and petals in different sizes, shapes, colors, and layers, which come together into diverse configurations to form complex and naturally brilliant patterns. These concentric layers can be defined as follows:

- Graphic elements, consisting of the graphical primitives such as dots, lines, characters, etc, convey atomic bits of information.
- Graphs, which combine graphic elements into a presentation view that conveys the information from a single data set (e.g., a single table, line graph, 3D rendering, etc). The appropriate structure for a graph is a function of the data to be presented.
- Presentation views, which combine multiple graphs to convey all of the relevant information about an issue from one perspective. For example, multiple tabular and chart graphs to convey the complete cost view of a particular construction activity.
- Scenes, which can combine multiple presentation views to present all of the different perspectives on a particular issue, e.g., a scene which combines cost, time, actor, and resources views to

convey all pertinent information about a particular change order request.

Within the UCPMA, the Visualization Configuration Model was developed to provide a framework containing each of the above presentation layers, a combined presentation taxonomy that maps each of the layers to each other and to the underlying data sets, as well as a coordination techniques so that user interaction within any one graph or presentation view can trigger appropriate actions in the other views that make up the same scene.

6 PROTOTYPE

6.1 *Implementing the UCPMA prototype*

The work described above produced a comprehensive technical framework (i.e., conceptual design) for a project management information integrator system. This framework was implemented in the UCPMA prototype. At the data layer, much of the proposed integrated project management data schema was implemented in a relational database using Microsoft SQL Server. At the application logic layer, the proposed data winnow was implemented using the Microsoft SQL Server Analysis Services. At the presentation layer, the Visualization Configuration Model was implemented in Microsoft Visual Basic.

6.2 *Using the prototype*

Users would work with the prototype in two primary modes. In the configuration mode, users would run the UCPMA prototype and connect to a particular data source (a database in SQL server structured according to the UCPMA central data model schema). Although various scenes (with their associated data and presentation views) could already be preconfigured in the system, the user would be free to configure any additional scenes at any time. To accomplish this, the user can build up new scenes by selecting pre-defined views or creating new ones, and specify the data linkages between the views. In turn, the user creates new views by selecting appropriate graph elements and specifying the data queries underlying the graphs using the data elements defined in the data winnow. Figure 1 shows an example screen of the UCPMA prototype displaying a scene configured for a change order evaluation task. It contains areas showing the plan, supply, cost, and other related views. When the user selects a particular task associated with the proposed change order in one view, the visual coordination mechanism selects the information linked to that task in the other views.

Once the user has configured the system to their needs, they can use the system to explore the project

the ability to present the resulting information to users through appropriate interface elements). These

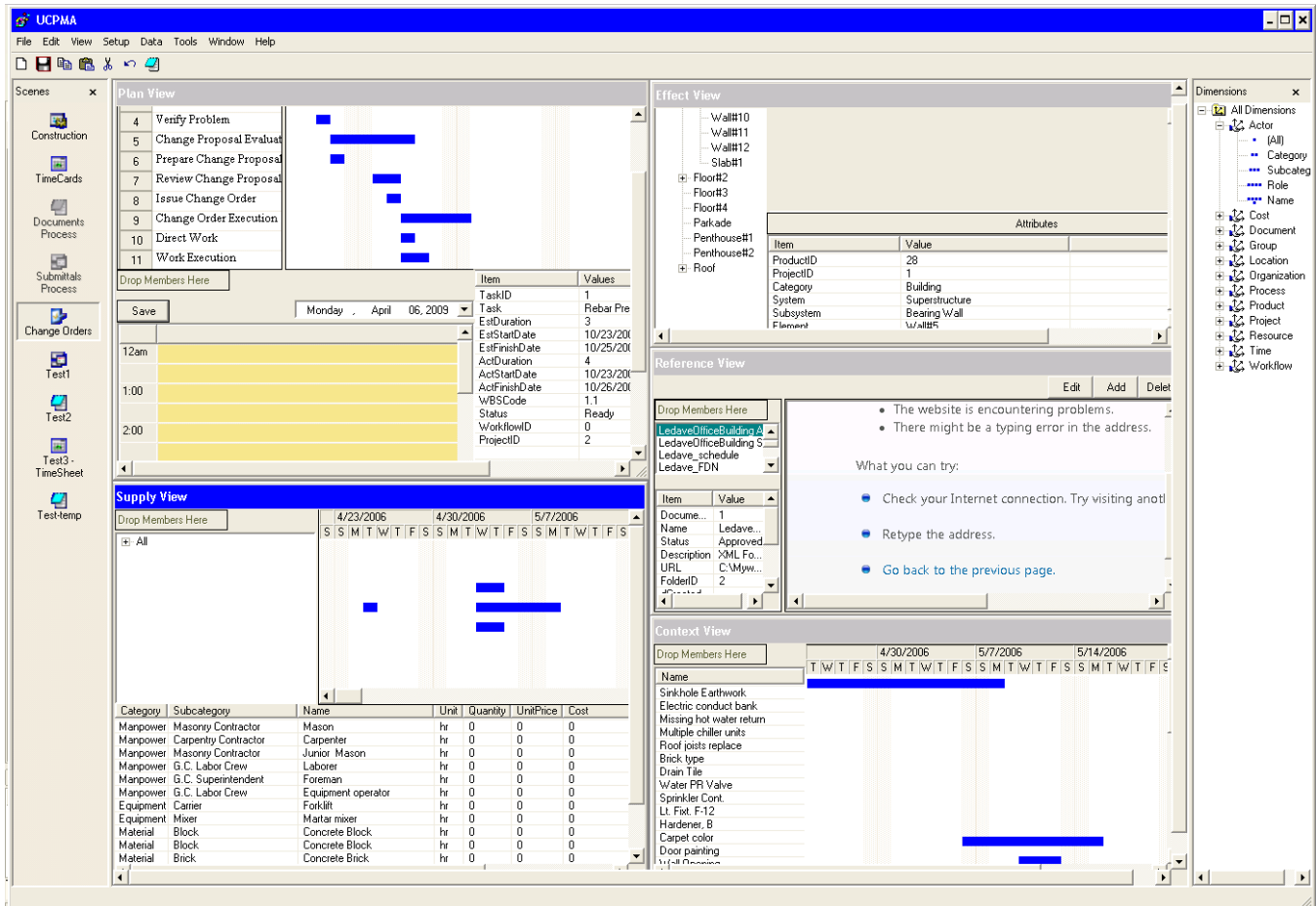


Figure 1. A data scene in the UCPMA system, showing several data views (each made up of various graphs and graphic elements) to support a change order management task.

management information contained in the database. Although the process of populating the project management database was outside of the scope of this research, the use of the IFCs as the database schema should enable a fairly straightforward process of exporting project data from any IFC compatible software and importing it into the UCPMA database. In the final system usage scenario, the UCPMA would not replace any of the traditional project management software applications, but the data generated by those applications would be collected in the UCPMA information integrator that would act as the integrated data browser/explorer/query support system for the combined project management data set.

6.3 Testing and validation.

The goal of this research was to develop a technical framework for a project management information integrator. A series of tests were devised to explore the ability of the proposed framework to achieve the technical requirements the information integrator concept using various datasets (e.g., the ability to represent and integrate a comprehensive range of project management data, to allow users to configure arbitrary data views from the integrated data set, and

tests, still underway, have so far demonstrated that the proposed framework fully achieves the required technical functionality. While the objective of this research was not to test the value and practicality of the information integrator concept itself, the prototype provides a platform to carry out such tests in future work.

7 CONCLUSIONS

In summary, a technical framework for an information integrator system has been developed. It builds upon IFC technology at the data layer, OLAP technology at the application logic layer, and data visualization technology at the presentation layer. At each layer, the research contributions stem from the application of these underlying technologies to the specific requirements of the project management domain, with the major contribution lying in the combination of these components to create an overall technical solution for the design of an information integrator system.

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