Impact of Emerging Information Technology on Project Management

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This article was originally presented at the:

6th Construction Specialty Conference / 6e Conférence spécialisée sur le génie de la construction

Toronto, Ontario, Canada

June 2-4, 2005 / *2-4 juin 2005*

https://csce.ca/en/publications/past-conferences/

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IMPACT OF EMERGING INFORMATION TECHNOLOGY ON PROJECT MANAGEMENT

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ABSTRACT: New information technologies for the construction industry are emerging that emphasize the integration of project information and the ability to work with comprehensive, computer-based building models. These hold the potential to radically improve project work practices. However, the technologies and tools themselves provide only one portion of the required changes—they must be accompanied by corresponding changes to management practices that can adopt and fully exploit the technology potential. This paper discusses how project management practices must become more explicit in dealing with the interdependencies between different project views if they are to evolve along with the emerging integrated information technologies.

1. INTRODUCTION

Current trends in *information technology (IT)* are yielding a wide range of new computer-based tools to support the *architecture, engineering, construction and facilities management* industries (collectively referred to simply as "construction" in this paper). These tools—everything from project collaboration web sites to virtual building environments—promise great increases in the effectiveness and efficiency of designing and managing construction projects. However, these improvements cannot be realized without corresponding changes in the work tasks and skill sets of the project participants. In particular, this paper explores the assertion that new advances in IT must be accompanied by corresponding changes in project management. This paper focuses on changes to the overall process of project management in general (expanding on earlier work in Froese and Staub-French 2003). Elsewhere, we address changes in the form of an enhanced information management process and the role of a *Project Information Officer* (Froese 2005). This paper addresses the early phases of research on this topic: clarifying the observations and research questions, discussing the context (e.g., characteristics of project management), and suggesting solution frameworks. Future work will include further development of the proposed solutions, experimentation and validation.

This paper will not address specifics of emerging IT itself. The most notable overall characteristic of this emerging IT, however, is a shift in focus from individual tools (e.g., CAD or scheduling applications) and human-to-human communications (e.g., project collaboration web sites) to enabling all of the software tools used throughout the entire lifespan of a project to share project information. This emerging technology is perhaps best represented by the Industry Foundation Classes (IFCs), (IAI 2003) an industry-wide data standard for the exchange of building information models between software applications.

2. CHARACTERISTICS OF PROJECT MANAGEMENT AND THE INTEGRATION OF VIEWS

2.1. Complexity and Interdependencies in Construction Projects

Construction projects are often described as large and increasingly complex. A greater understanding of the nature of this complexity can point to the areas where the need for improved management is greatest.

Studies have identified the following characteristics as generally common to any type of complex system[1]:

1. Complex systems are comprised of a multiplicity of things; they have a large number of entities or parts. Generally, the more parts a system contains, the more complex it is.
2. Complex systems contain a dense web of causal connections among their components. The parts affect each other in many ways.
3. Complex systems exhibit interdependence of their components. The behavior of parts is dependant upon other parts. If the system is broken apart, the components no longer function (like the parts of the human body).
4. Complex systems are open to their outside environments. They are not self-contained, but are affected by outside events.
5. Complex systems normally show a high degree of synergy among their components: the whole is more than the sum of its parts.
6. Complex systems exhibit non-linear behavior. A change in the system can produce an effect that is not proportional to its size: small changes can produce large effects, and large changes can produce small effects.

To some extent, all of these features can be observed in construction projects. Construction projects are made up of components such as the physical elements in a building, the design or construction activities, the people and resources utilized, etc. In many cases, the individual components are not complex. Yet the number of components that make up the project is vast, and the causal connections between these components are numerous. For example, a change in the intended use of some space in a building could affect the heating and cooling requirements for that space, which could affect the design of parts of the mechanical system, which could alter the elements of the electrical system, which could change a purchase order for material supplies, which could delay a material delivery, which could influence the construction schedule, which could reduce the productivity of a work crew, which could increase a work package cost, which could affect a sub-contractor's financing, and so on.

Construction projects, then, are justifiably described as complex, largely because of the quantity and interdependence of the components that make up the project.

The two concepts of *components* and *interdependency*, as two important characteristics of all construction projects, correspond to two concepts that are important characteristics of the way that people manage and carry out construction projects. These are, respectively, the notion of distinct project *views* (incomplete, partial perspectives of the whole project), and *integration*, the degree to which distinct views are explicitly perceived to inter-relate with one another.

2.2. Views and Integration in Project Management Approaches

One of the fundamental mechanisms that the construction industry has developed for dealing with complexity is the approach of decomposing project work into well-defined work tasks and assigning each work task to a specialist group. These tasks are then carried out, to a large extent, as if they are fairly independent from each other. To be sure, each participant has some notion that their work must follow certain work and must precede other work, and that certain actions or outcomes of their work will influence others. Also, a few individuals in the project have explicit responsibility for overall coordination (e.g., the project manager). By and large, however, participants adopt a view that focuses primarily on their individual tasks, with any concerns about these interdependencies addressed in a very ad hoc and

[1] Paraphrased from Homer-Dixon 2001, pp.110-114.

reactive way. Most participants try to optimize their own work while the few people responsible for managing the project as a whole have little opportunity to optimize the entire system.

Clearly, it is beneficial to organize work in such a way as to minimize interdependency among work tasks. However, we contend that a weakness of current project management practice is that it tends to treat typical construction work tasks as being far more independent than they actually are. Instead, project management approaches should strive to make the interdependencies between work tasks more explicit. This does not increase interdependence and complexity, but it does make the existing interdependency and complexity more visible, and therefore more manageable. In summary, construction projects are complex because of the quantity and interdependency of their components, and project management techniques should strive to make these interdependencies explicit by increasing the level of integration among the project views.

2.3. Views and Integration in Project Information

Construction design and management tasks work with information rather than physical resources. This information all describes or models the physical construction project, and thus it can be said that all designers and managers work with information models of the project. To a large extent, each task works with a type of information model that reflects the task's unique view or perspective, with little integration between these different information views. This wide range of disparate information views adds to the fragmentation of these tasks. There is very little of a common, shared vision of the project across all participants—at least until the physical structure begins to emerge, at which point the physical building itself provides a unifying common perspective for all participants.

Figure 1 links projects, participants, and information to concepts of view integration. It shows several levels of abstraction of a construction project:

- the actual *real world* project itself (no abstraction),
- the *mental models* that project participants build up in their own minds to understand the project (i.e., individual's understanding of the real world project),
- the *documents* (paper or electronic, including individual views presented by computer tools) that provide most of the information from which participants construct their mental models,
- the *computer applications* used to support the various work tasks, and
- the computer-based *data models* that underlie the computer applications.

For each level of abstraction, figure 1 describes the level of integration that exists between distinct views within that level. These are shown for three cases: the current situation, the effects of emerging IT, and the desired situation for fully exploiting integrated IT in the future. In all cases, the project components within the real world are highly inter-dependant, so we would describe this as fully integrated. In the case of the current situation, we have shown that participants construct their own mental views of the project construct with a low degree of integration between these views. There is generally a one-to-one relationship between documents, the computer applications used to create these documents, and the data sets that these applications use; and all of these are capable of little or no integration. With emerging integrated IT, the potential to integrate the data sets that underlie many of the computer applications is significantly increased. The ability of computer applications to work with integrated views of data is only slightly improved, however, with very minor changes in the basic documents and, correspondingly, the participants' mental models of the project. To fully exploit the potential of integrated IT in the future, the ability to integrate all project data must continue to improve to the degree that the collective project data set captures much of the inherent interdependencies of the real world. No computer application, document, or individual's understanding of the project can come close to capturing the totality of project information and all of its interdependencies, but all of these can and must improve their ability to integrate the distinct views significantly over the current situation.

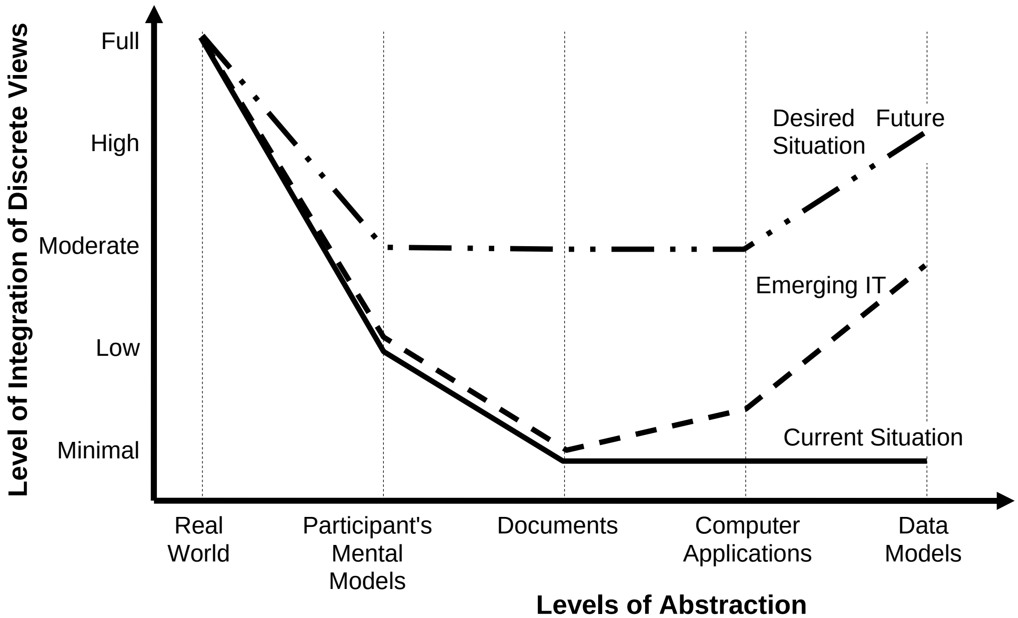

Figure 1: An illustration of the level of integration between views within various levels of abstraction of construction project information.

2.4. Increasing Integration in Construction and Other Industries

New IT is emerging that addresses issues of information integration. The conclusions of the discussion in the previous section show that this trend cannot focus on integrating the underlying project data alone, but must extend to the computer applications, the individual computer views and documents that participants work with, and the participants' own mental images of the project. This is the central issue in understanding problems with the fit between current project management practices and IT integration, and in identifying changes to project management practices that can fully exploit the integrated IT potential: *the current project management practices that de-emphasize interdependencies must evolve to processes that effectively work with and manage these interdependencies.*

Improving the management of interdependencies is an achievable goal. There are examples from other areas of management where this trend has occurred. For example, there is currently a great deal of attention being paid to the area of lean construction, which spans a wide range of management issues related to construction projects (Lean Construction Institute, 2005). Among these issues is the concept that a project is made up of many interdependent tasks, and a focus on optimizing each task independently leads to sub-optimization of the overall project. Therefore, project management practices should ensure that tasks are managed with careful consideration of their role within the overall project workflows; they should not be treated as isolated, independent activities. Many specific lean construction techniques address these issues, such as improving planning reliability along an entire production chain.

Another useful comparison is the software engineering industry. Although construction project management has been around much longer than software project management, some valuable techniques and lessons can be learned from the software industry, particularly related to integrated information structures for managing projects. Much of the software engineering community has consolidated around the Unified Modeling Language (UML) (Object Management Group, 2005), a standard language for representing the components involved in the design and implementation of software projects. UML provides a much more uniform and integrated (if less comprehensive) view of project requirements, processes, and elements, than comparable representations within construction (i.e., project plans and specifications, construction schedules, etc.).

Furthermore, UML-based software development methodologies have emerged (e.g., the Unified Process, Kendall, 2002) that tightly integrate the various project workflows with the various project artifacts (deliverables) throughout each phase of the project lifecycle. These methodologies also accentuate the cyclical and repetitive nature of the related work tasks that are carried out within workflows as they move through the phases of the project lifecycle. Unlike approaches that treat each activity as an independent, one-time task, this reinforces attempts to continually improve performance in this work. While these techniques are not directly applicable to the construction industry, some of the approaches and best practices are quite relevant.

3. MANAGEMENT SOLUTIONS: A UNIFIED APPROACH TO PROJECT MANAGEMENT

We have argued that existing project management practices underemphasize the interrelationships between individual work tasks and other project components. This leaves the interdependencies under-recognized and under-managed, and promotes a “one-time event” thinking that hinders the quest for ongoing performance improvements. We have begun to conceptualize a unified approach to project management that addresses some of the weaknesses and opportunities identified above. In this approach, a heavy emphasis is placed on the way that managers should organize and structure project information and activity.

The basic approach is to adopt a framework that: 1) explicitly defines and works with the various views that are critical for managing projects, and 2) explicitly defines and works with the interconnections between these views. Examples of project views include the physical view (“what”), the process view (“how, who, when”), the cost view (“how much”), etc. (Russell and Froese, 1997). If the total collection of project information is thought of as a multi-dimensional information space, then the views define the dimensions. For each view, the overall project can be broken down into smaller elements. The simplest representation of a view would be a list or hierarchical breakdown structure of the elements that make up the view (e.g., a work breakdown structure, WBS). More complex representations would capture additional relationships between the elements, such as a CPM network or an IFC model.

3.1. Primary Views

There are many views that can be useful for managing projects. To act as a unifying management tool, however, these views should be shared with all participants, and this places a practical limit on the maximum number of views, since it would become too complex to require all participants to work with numerous, interconnected views. We propose that the following three views to be used as the primary project coordination mechanism for all participants:

- *The project lifecycle dimension*: The first primary view is time based, organizing the project into well-defined project phases, which are further refined into iterations. These phases are arranged in sequential chronological order, constituting a logical time-view. This dimension can also provide an absolute time-view by defining the calendar dates for activities that take place within the phases. Unlike current project management practices where project phases are treated “loosely”, the phases and iterations have formal management roles. All work requirements, assignments, outputs, etc. are defined relative to a specific project phase, and phases have formal progress review procedures. This approach to phases can be seen, for example, in the Process Protocol approach (Process Protocol, 2003) and in the previously-mentioned Unified Process (Kendall, 2002).
- *The workflow dimension:* The second primary view is process-based. It organizes the work into the various work disciplines required to complete the project. This is somewhat like the normal division of work into work packages, but rather than describing the tasks as discrete work packages, the work is organized as ongoing workflows, which can be further broken down into sequences or networks of sub tasks. Thus tasks are more explicitly placed in the context of the overall workflows than is common practice today.
- *The product/deliverable dimension*: The third primary view organizes the outputs or deliverables of work. This view combines two important main elements, the information that describes the construction product (facility) being created, and the physical product itself. During the early phases of

the project, the deliverables of design and management tasks are information about the physical facility. The collective sum of all of this information can be thought of as the building information model or virtual building (whether or not an integrated IT environment is used). During later phases, this information drives the physical deliverables of the construction work: the creation of the physical components themselves. This view emphasizes a continuum that flows from the virtual facility to the physical one.

Table 1 shows a highly simplified example of primary views for a construction project.

Table 1: A simple breakdown of primary views for a construction project

• Project Lifecycle Dimension: • Inception Phase • Design Phase • Construction Phase • Operation Phase	• Workflow Dimension: • Architectural workflow • Structural workflow • Building Services workflow • Cost workflow	• Product/Deliverable Dimension: • IFC Product Model • Project Documents • Building Superstructure • Building Systems & Finishes

3.2. Integrating and Representing the Primary Views

Given these three primary dimensions, the work can be further organized by expressing the interrelationships between the dimensions:

- *Workflows vs. project lifecycle:* Placing workflows and their constituent tasks within project lifecycle phases creates a schedule view of the project, showing what should happen when. This can include both the logical schedule (sequencing) and absolute schedule (calendar dates). It can also show that most workflows span multiple phases/iterations, and can indicate the amount of effort expended on each workflow over time, which emphasizes the "ongoing processes" nature of the work.
- *Product/deliverables vs. project lifecycle:* Similarly, the various project deliverables can be mapped to the project phases/iterations. The deliverables are generally cumulative, thus this shows how the total project output (the collective body of project information and the physical structure) develops over time.
- *Product/deliverables vs. workflows:* The assignment of project deliverables to workflows and tasks shows how work processes collaborate to produce the required deliverables.

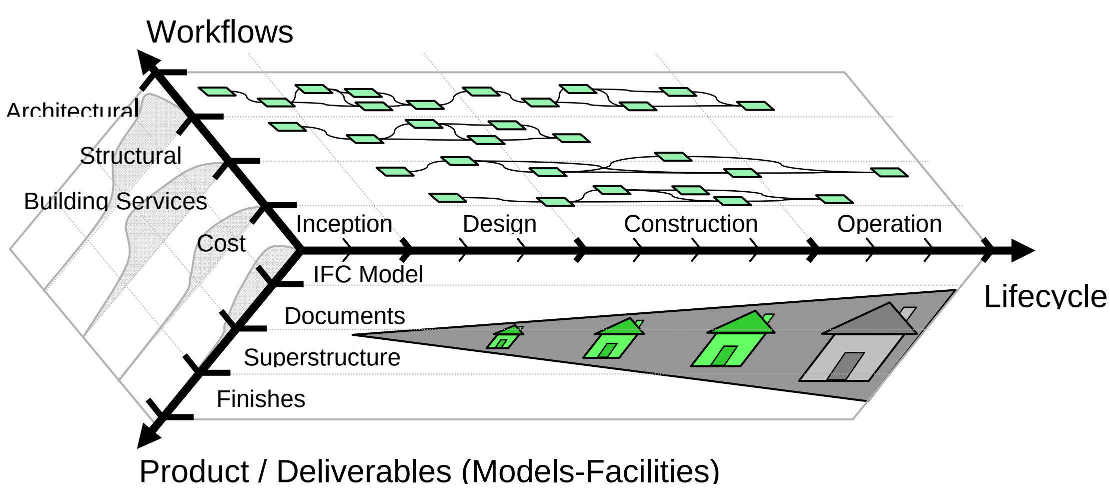

Figure 2: Schematic of the dimensions in a unified approach to project management

The definition of the three primary views and the interrelationships between them defines a three-dimensional space, as illustrated in Figure 2. Key to the applicability of this approach is the ability to represent the primary views and their interrelationships in a simple, intuitive manner that all project participants can work with. It would be ideal if this could be achieved in a single, three-dimensions format, but it seems unlikely that such a representation is possible (even the simplified representation in figure 2 shows the relationships of each pair of dimensions rather than the relationships between all three dimensions simultaneously). Therefore, it may be necessary to represent the primary dimensions as a set of two-dimensional matrices. Each of these matrices may be quite simple and intuitive. For example, the matrix of workflows vs. project lifecycle forms a bar chart schedule (Figure 3 shows examples of possible multi-dimensional project views). What is essential (and what would differentiate this approach from current practice) is that the collection of two-dimensional matrices is interrelated and kept synchronized, which would require an effective underlying project management tool.

3.3. Additional Views

We have suggested that the three primary views seem to be appropriate for the overall project organization and the coordination of all participants. However, those responsible for managing the project can add several more interrelated views. This would provide a very powerful representation of the project from all of the perspectives that are important for achieving project objectives, along with explicit representations of the interrelationships that exist between these views. Examples of the additional views include the following:

- *Organization View:* An organizational view identifies the project participants; can link participants to workflows/tasks, deliverables, etc.
- *Cost View*: This view identifies the various cost schedules (estimates, cost-control accounts, etc.) that are important to the project. Costs can be related to workflows/tasks, deliverables, organizational units, etc.
- *Risk View:* As part of a risk management approach, significant risks can be identified and associated with specific workflows/tasks, deliverables, organizational units, cost items, etc.

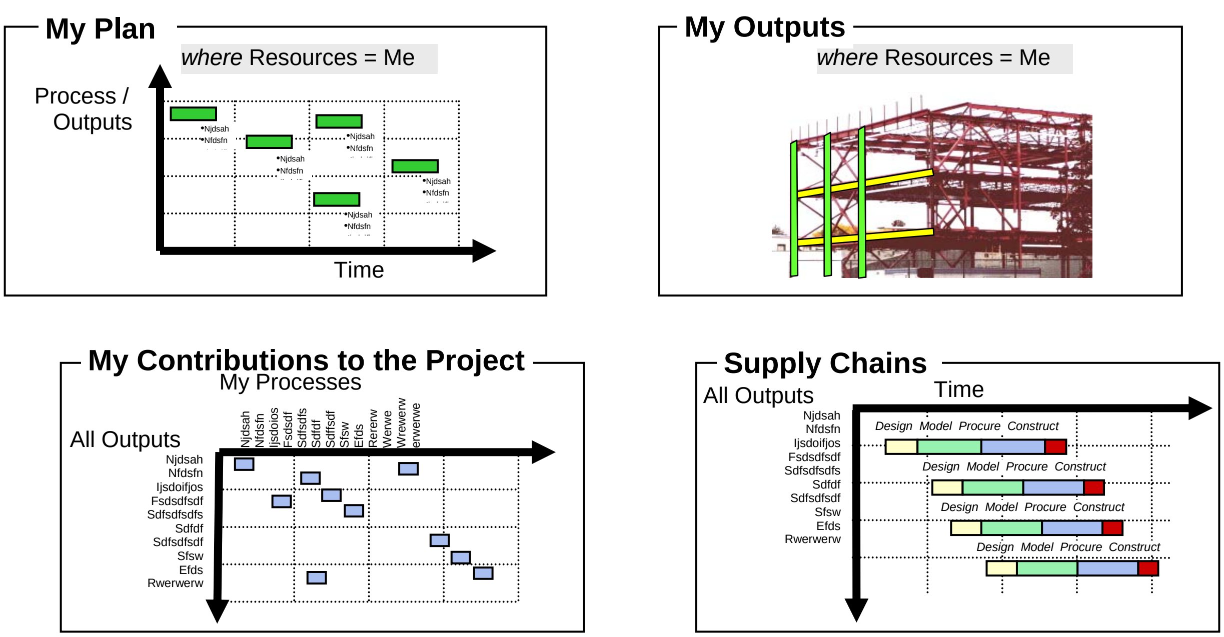

Figure 3: Examples of widely-applicable, multi-dimensional views of a project: Processes with associated outputs vs. time (filtered to show only the viewer's processes); The outputs of the viewer highlighted on an overall view of the project outputs; the contributions of viewer's processes to the overall project outputs, and a supply chain view of all processes associated with each output vs. time.

- *Quality View:* Quality management programs may identify quality metrics, inspection tasks and results, etc., associated with the workflow/tasks and deliverables.
- *Requirements View:* Software engineering methods formally capture system requirements using constructs such as use cases. On AEC/FM projects, requirements would typically be less structured, but it may be possible to define a view that explicitly represents the project requirements in a way that helps
- *As-Built View*: As construction work proceeds, the actual results of the work, in terms of final construction results, actual cost and productivity data, etc., can be captured in an as-built view.
- O*ther Views:* A view can be created for any other area of interest on a project where a set of items can meaningfully be identified that relate to other defined views, such as a contractual view, safety view, environmental impact/sustainability view, punch list/defect view, maintenance view, etc.

The possibility of defining a large number of views does not imply that a significant amount of additional management work is required. Rather, it suggests that when issues are already being addressed with some form of explicit management effort, then a representation structure can be used that captures the relationships between these issues and other key management issues.

In many cases, the relationships between any two views may form a narrowly banded matrix: each item in one view would be associated with a small number of items in the other view. This may lead to interesting possibilities, such as the ability to partially automate the creation of one view from another (e.g., automatic generation of approximate lists of construction activities and estimate items from a building product model), or the ability to recognize “exceptions”, cases where relationships deserve extra management attention because they lie outside of the typical band of inter-relationships.

3.4. Changing the Project Mindset

The unified approach to project management involves not only a change to the representational structures as outlined above, but this also a change in the way participants think of the underlying project mechanism and their role in it. Currently, projects are regarded as custom, unique endeavors and project tasks as a collection of one-off activities. The thought process is to find a satisfactory solution to the project requirements rather than to find “the best” solution. In part, this is because there is no room for trial-and-error exploration. Full-scale models are impossible and small-scale physical models are of limited use.

In the unified approach to project management, the integrated project representations acts as project prototypes or models that can play the same central role in construction as prototypes do in manufacturing. They provide integrated, computer-based collections of all known project information. They may contain geometric information to allow tools like 3D visualization, but they also contain non-geometric design and management information, such as material properties, supplier information, cost and schedule data, organizational information, etc. Thus, the perspective is changed to be more like that of manufacturing: a prototyping process followed by an ongoing production process. Design and planning tasks first work towards the creation of prototypes or models. In these models, alternatives are developed and explored, new issues are identified and resolved, and interactions and interfaces are hammered out. Once all concerns are satisfied, the prototype is used to organize the production process. Every participant views their role as carrying out their tasks by drawing information from the project model, placing their results back into the project model, and using the model to explore the interaction of their work with others and to support communications. In this way, the overall concerns of the project are more prominent to all and are easier to identify and explore—we believe this will produce better solutions.

3.5. Working with the Unified Approach to Project Management

As shown, the unified approach to project management is based on defining formalized views of project information along with the interrelationships between the views. This section will discuss how this approach might be carried out by comparing it with best practices in how project scheduling is carried out. If good scheduling and schedule control practices are used on an AEC/FM project, the project will benefit from good work coordination; there will be more certainty about the timing of events; it will be easier to measure progress; and productivity, cost, and project duration will be improved. Similarly, good practices using the unified approach will improve the project outcomes through more effective planning, particularly with respect to the inter-dependencies between project views. The process would be approximately as follows:

- The project management team would define the project views to be used on the project.
- Project planning would be carried out much as on a typical project, except that the results would be represented using the defined project views. This would result in lists or breakdown structures for the project phases, workflows/tasks, deliverables, etc. This would be analogous to a typical project scheduling process, where the results are represented in a CPM network.
- The key inter-relationships between the views would be defined. This would be analogous to the way that precedence relationships are captured in a schedule, or the way that a schedule can be mapped to cost accounts, resource plans, or to a building information model (as in the case of 4D CAD). Other than the precedence relationships, this type of mapping is not typically done in current project management practices, so it represents some additional work for project planners. However, it need not be done at a very detailed level, and the use of hierarchical relationships and effective planning tools may minimize the effort required for this task.
- The execution of the resulting plan (e.g., initiating work tasks), project control and feedback (collecting progress information and monitoring results), and re-planning activities all take place using the representational framework. Work tasks themselves remain essentially unchanged, but because the planning and management system explicitly captures the interrelationships, the causal links between actions will be better recognized and understood, and the potential negative impacts of any action will be identified earlier and mitigated or avoided more easily. For example, in the case of the change in the intended use of some space in a building mentioned previously, the threads of the causal impacts of this change may be more easily traced through the design, construction, procurement, time, and financial aspects of the project—appropriate adjustments can be made in advance, rather than allowing the impact to propagate as a series of unanticipated, reactionary actions.
- As with scheduling, detail is important, but not all detail is required in advance. Planning for each view might be carried out at a summary level initially, with greater detail added over time, culminating in something like detailed, rolling two-week look-ahead unified plans.
- In scheduling, basic schedule representations such as bar charts are widely used as coordination mechanisms for all participants, while more advanced analysis like resource leveling is carried out by project management specialists only. Similarly, the many potential applications of the unified approach fall into three general categories: 1) the use of the primary views as a broadly-applicable coordination mechanism shared by all participants, 2) the use of multiple views to capture all of the detailed information relevant to one participant carrying out one particular task, and 3) the use of detailed information in multiple views to carry out some specialized project analysis.

We have discussed the unified approach to project management in terms of a representational framework and general methodology for project planning and management. However, the organizational context for the approach should also be addressed. This would include issues such as how the project team is organized (ideally, all key team members would be involved early in the process); who carries out which portions of the unified plans, when, and in how much detail; how incentives are structured to encourage effective use of the unified approach, etc. The approach would be closely tied into a project information management approach that we have discussed elsewhere (Froese 2005). The approach is also quite dependant on a set of appropriate IT tools to support the process, which we are also developing but which are beyond the scope of this paper.

4. CONCLUSIONS AND FUTURE WORK

This paper has argued that emerging IT will significantly alter the work practices of construction projects, and that corresponding changes to the construction project management practices are required. The paper has focused on enhancements to project management as a whole. This evolution promotes the use of integrated IT to allow project participants to share a more common vision of the project as it progresses through planning, design, construction, and operation, and to deal more explicitly with the interrelationships between views. We call this a *Unified Approach to Project Management.* These proposed changes to information and project management represent a conceptual solution to the defined problem. In future work, we hope to further develop these solutions and to apply them as pilot studies on full scale projects for testing and validation.

ACKNOWLEDGMENTS: We gratefully acknowledge support for this work from the Natural Sciences and Engineering Research Council of Canada, Collaborative Research Opportunities Program.

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