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The impact of emerging information technology on project management for construction

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ABSTRACT

Changes brought about from advances in information and communication technology for the architecture, engineering, and construction industries (construction ICT) are not purely technical, but must be accompanied by changes to the management processes. Elsewhere, we have discussed a framework for project information management in construction. This paper addresses changes to the practice of project management as a whole. Broadly, it suggests a unified approach to project management that involves defining a set of widely-applicable common views of the project information, explicitly defining the inter-relationships between the information in these different views, and modifying project management tools and procedures to work with these integrated views.

1. Introduction

Current trends in *information and communication technology (ICT)* 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—particularly those associated with building information models (BIMs) for project modeling and integration—promise great increases in the effectiveness and efficiency of designing and managing construction projects. However, these improvements require more than just technical solutions; their full potential cannot be realized without corresponding changes in the work tasks and skill sets of the project participants. We are exploring the relationship between emerging ICT and project management and, in particular, how project management should evolve to fully exploit the emerging ICT potential. Elsewhere [1] we have discussed a specific sub-discipline of *project information management* and the role of a *Project Information Officer*. This paper considers adaptations to the overall practice of project management to more explicitly recognize, represent, and manage the interdependencies between different project views, presenting a conceptual framework for a *unified approach to project management.*

1.1. Emerging construction ICT

We have categorized trends in construction ICT into three eras [2]. The first era of construction ICT (now more than four decades old and continuing) focused on developing stand-alone tools to assist specific work tasks such as CAD, structural analysis tools, estimating, etc. These tools are well established within current practice. A more recent second era (from the mid-1990s) of construction ICT has focused on computer-supported communications such as E-mail, the web, document management systems, etc. This is a less mature field, with new tools and core features still emerging, and business processes still adapting. Much of the construction ICT research and development over the past decade has pursued a third era of construction IT focused not on individual applications or transactions, but on the potential for uniting all of these as a cohesive overall system through integration, building modeling, etc. This emerging ICT has seen some impressive innovative use in industry but has yet to reach mainstream application.

1.2. Types of impact on project management

We have defined three broad ways in which these ICT trends impact construction project management. First, the trends in construction ICT are leading to information systems that are increasingly complex, increasingly central to the management of the project, and require increasingly specialized knowledge and work practices. As a complex and critical project resource, the project information and information systems must be explicitly managed. We have addressed this issue of project information management as a specific sub-discipline of project management [1]. Second, we argue in this paper that current project management practice de-emphasizes the interdependencies between project tasks as a necessary mechanism for dealing with project complexity. While not a problem for the "stand-alone" first era ICT systems, the second and third era ICT systems assume and require a relatively high degree of integration and collaboration across project tasks. Because of this difference, emerging ICT often has difficulties fitting into current practice, and current practice is not able to take full

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advantage of the potential of such systems. This paper suggests that project management practice, enabled by emerging construction ICT, could more explicitly recognize, represent, and manage the interdependencies that are pervasive throughout construction projects, thereby fully exploiting the potential of the ICT to improve overall project performance. Third, a major thrust of third era ICT (typified by technologies such as BIM, IFCs, virtual design and construction [3], and nD [4]) suggests fundamental changes to construction projects in which the project team comes together to produce comprehensive, computer-based, virtual prototypes of all aspects of the construction project as the central activity for the design and management of the project. A full virtual design and construction approach (which would indeed involve significant changes to project management practices) is outside of the scope of this paper, but the issue of addressing project interdependencies through a unified approach to project management (as discussed here) is fully compatible with, and an essential element of, a virtual design and construction approach.

The ultimate objective of the work described in this paper is to produce practical guidelines for modified project management processes. However, this paper focuses on the early phases of research on this topic: developing a conceptual framework for understanding the issue of multiple views and interdependencies in project management, and suggesting a general approach for how project management practice and emerging ICT might exploit this framework. As such, the paper is largely conceptual in nature. Future work will include further development of the proposed solutions and industrial experimentation and validation.

2. Characteristics of views and interdependencies in project management

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 [5]:

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 dependent 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.

Furthermore, the complexity is increasing—aside from the technical complexity of the facilities themselves, trends such as ISO 9001 quality management, public–private partnership financing, sustainability concerns, etc. have increased the number of important inter-related issues that must be simultaneously addressed. Construction projects, then, are justifiably described as complex, largely because of the quantity and interdependence of the components that make up the project. (Here, we have developed the notion of complexity to better understand the issue of interdependencies in construction—yet a deeper mining of complexity theory may well yield many other concepts and techniques beneficial to the construction industry. As Merali and McKelvey [6] describe, "The compelling argument for complexity science is that it provides a wide and powerful lens to define and move around the multi-dimensional 'problem' and 'solution' spaces in a dynamic way, at multiple levels of abstraction.")

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. Each group works with the subset of project information that is relevant to their work represented in a form suitable to their particular task, thereby creating a specific view of the project. 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 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

All 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 that 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. With a few exceptions (such as the basic architectural plans), 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.

Fig. 1 links projects, participants, and information to concepts of view integration. It shows several levels of abstraction of a construction project. To the far left is the actual *real-world* project itself (no abstraction). Opposite, on the far right, are 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). However, we have shown that designers and managers generally interact with the project through various information models, so their mental models are connected to the real-world project through various computer applications and documents. Following the convention that computer system architecture consists of the data layer, the application logic layer, and the presentation layer, these information systems can be decomposed into the levels of the computer-based *data models* that underlie the computer applications, the *computer applications* used to support the various work tasks, and 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.

For each of these levels of abstraction, Fig. 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 ICT, and the desired situation for fully exploiting integrated ICT in the future. In all cases, the project components within the real world are highly inter-dependent, so we would describe this as fully integrated. In the case of the current situation, 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. We have argued that participants construct their own mental views of the project (derived from these single-perspective documents) with a low degree of integration between the views. As an example, in the situation of the change to the intended use of some building space mentioned previously, the real world fully exhibits all of the interdependent changes mentioned; the data models, computer applications, and documents currently used would be unlikely to reflect any of these interdependencies until they were manually updated by the human users; while the participants may perceive many, but not all, of these interdependencies.

With the ICT of the emerging third era, 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 ICT 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.

2.4. Increasing integration in construction and other industries

We have shown previously that the emerging technologies within the third era of construction ICT are addressing 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 ICT integration, and in identifying changes to project management practices that can fully exploit the integrated ICT 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 [7]. 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

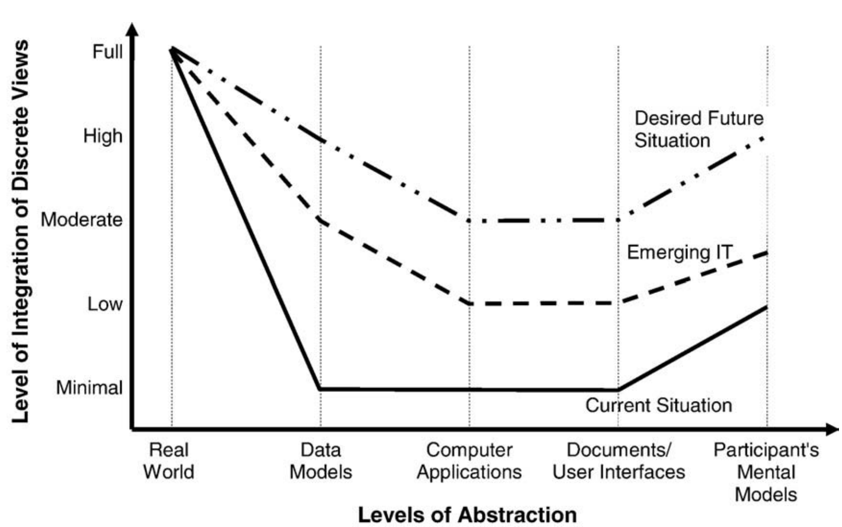

Fig. 1. An illustration of the level of integration between views within various levels of abstraction of construction project information.

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) [8], 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 [9]) 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 inter-relationships 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 organize and structure project information and its interdependencies.

3.1. The basic approach

In current practice, all project participants work with various sets of project information, which can be considered to be views of the overall project data set. However, the definition of these views is ad hoc and idiosyncratic, they are not treated explicitly and formally, and there is minimal representation of the interdependencies between views.

In a unified approach to project management, all project participants would continue to work with their required project information, but these information sets would be more explicitly and formally treated as views of the overall project information set (even if the overall project information set does not exist as an individual physical thing). Although each user could define and work with any type of view, a few primary views would be common to all participants and would be widely used for communication and collaboration throughout the project, providing a unifying influence. Further, where practical, the interdependencies between the views would be captured. Emerging ICT tools would support the work with the views and interdependencies, and would be able to leverage them to provide significant new functionality. While the change in actual management effort would be minimal, the impact could be a substantial increase in the understanding of how each task interacts with others and with the overall project as a whole, in much the way that UML has brought similar improvements to the software industry. The following sections provide a more detailed discussion of some of the elements of this approach.

3.2. Views

We take a view to be some collection of information pertaining to the construction project for the purpose of carrying out a particular task. Since views describe some portion of the overall project information, a view is considered to be a subset of the total project information set. A view may be described in very informal and loosely defined terms, or as a formal, precisely defined data set. Examples of project views include the physical view ("what", as in project plans), the process view ("how, who, when", as in project schedule documents), the cost view ("how much", as in estimates), etc. [10]. 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. At times it may also be useful to differentiate between the notion of data views, which are used in the same sense as in database technologies to refer to a formally-defined subset of a larger data set, and the notion of presentation views, which refer to a specific organization of a specific data set for the purpose of document output or human–computer interfaces. For example, several different graphical and tabular presentation views may be constructed from one data view.

3.3. Primary views

In order for all project participants to be able to carry out their own tasks in the most efficient manner, they must be free to work with the information that they need presented in the way that suits them best. For example, a structural designer may need to represent the geometry of the structural elements as dimensionally accurate line drawings or data files, while an architectural renderer may require texture and color information but not high dimensional accuracy, and an HVAC designer may require only schematic representations. Any approach to a formal treatment of project views must allow this flexibility, thus a wide variety of types of project views will be defined across the lifespan of the project. However, this works against one of the major goals of formalizing the treatment of views, which is to provide everyone with a unifying common perspective of the project information. Our solution to overcoming this problem is to use a small set of widely-applicable views as *primary views* for communication and collaboration throughout the project, thus providing the common perspective for all participants, in addition to allowing all participants to define and work with other *secondary views* in order to maximize their own effectiveness. Various views are candidates for primary views. For example, the UML-based Unified Process mentioned earlier is organized around views describing a functional breakdown (workflows), the sequential phases, and the design artifacts (models and documents). In construction, however, a few views stand out as being widely used throughout the project. For example, one version of a set of primary perspectives has been articulated by Fischer and Kunz [3] in their POP model: Products, Organization, and Processes. (POP and the model proposed here are different models developed separately for different purposes—for example, POP is more directly tied to the Virtual Design and Construction process discussed below—yet they have similar roles of presenting high-level frameworks that give structure to a wide range of management and technology issues, and the similarity of their resulting forms reinforces the utility of the approach). We suggest that the following four views be used as the primary project coordination mechanism for all participants:

- *The Product View*: The first primary view organizes the outputs or deliverables of work. This includes the most basic of all views, the facility itself. Significantly, however, it also includes an explicit representation of another type of deliverable—the information deliverables that describe the constructed facility. 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 ICT 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.
- *The Process View:* The second primary view is process-based. It can be broken down by the functional tasks required during the project and/or by the sequential ordering of tasks.
- *The Resource View:* The third primary view defines the resources required to carry out the construction project. In particular, this includes all organizational resources (companies, individuals, roles), but it also includes other resources such as materials, equipment, financing, etc.
- *The Time View:* The fourth view defines the time dimension for the project. It can be expressed in terms of absolute time (calendar dates) or in terms of logical phases and iterations through the project progresses (useful in formalizing various decision gates, etc.). This dimension is not particularly significant when taken by itself, but it provides a fundamental dimension for mapping against the other three primary views.

As a highly simplified example, an AEC project might be organized into the following primary views (Table 1).

3.4. View interdependency

A salient feature of the primary views is that they can all be mapped to each other. The following lists some of the pair-wise interdependencies:

- *Process vs. Time:* Relating process workflows and their constituent tasks to the project timeline 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 vs. Time:* Similarly, the various project deliverables can be mapped to the project timeline. 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.

Table 1
Simplified breakdown of project into four common primary views.

Product view	Process view	Resource view	Time view
IFC product model	Architectural workflow	Organizational resources	Inception phase
Project documents	Structural workflow	Materials	Design phase
Building superstructure	Building services workflow	Equipment	Construction phase
Building systems and finishes	Cost workflow	Financial resources	Operation phase

- *Product vs. Process:* The assignment of project deliverables to workflows and tasks shows how work processes collaborate to produce the required deliverables.

All of the other inter-relationships between the four primary views can also be meaningfully defined, e.g., showing resources against products, process, or time. The primary views and the inter-relationships between them define a multi-dimensional space (Fig. 2 shows a conceptual view that combines some of the pair-wise relationships into a three-dimensional representation). The key to the applicability of this approach is the ability to represent the primary views and their inter-relationships in a simple, intuitive manner that all project participants can work with. It would be ideal if this could be achieved using a single, all-encompassing image (presentation view), but it seems unlikely that such a representation is possible (e.g., the image in Fig. 2 is neither complete nor intuitive). 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 Gantt chart (bar chart schedule). Fig. 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 inter-related and kept synchronized, which would require effective underlying project management tools.

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 and the two dimensions could be organized such that the interdependent connections are predominately close to the diagonal in a matrix representation. 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. It may be that, because of this banding, a single combined view showing the product–process–resource tuples vs. time could provide a useful presentation of the combined primary views. We hope to explore the opportunities created by this banding in future work.

3.5. Secondary views

We have suggested that the four 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 many more inter-related 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 inter-relationships that exist between these views. Examples of the additional views include the following:

- *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.
- *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.

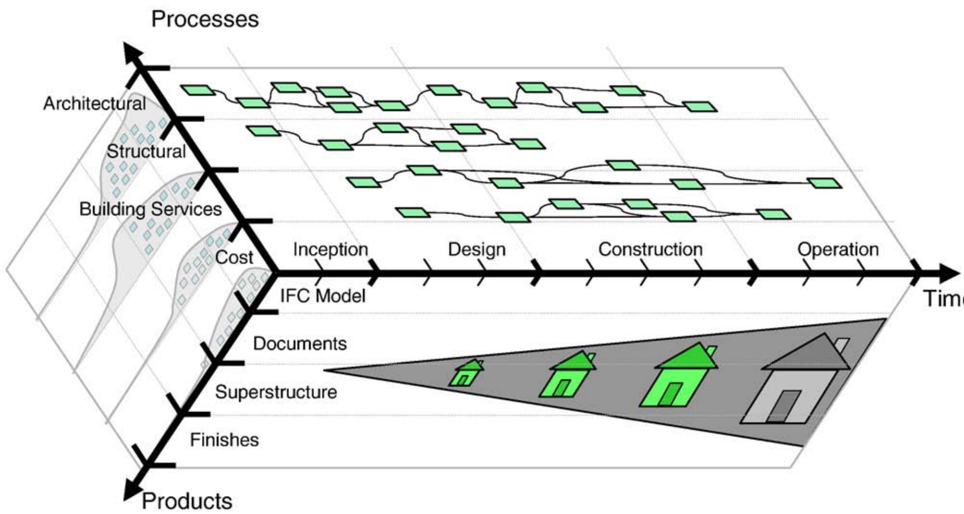

Fig. 2. Schematic of the dimensions in a unified approach to project management.

- *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.
- *Other 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 view, 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, a representation structure can be used that can capture the relationships between these issues and other key management issues.

3.6. 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 discusses the application of this approach by comparing it with best practices in project scheduling. 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, communications, and coordination, particularly with respect to the interdependencies 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. These are generally minor reformulations of the views used now.
- 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.

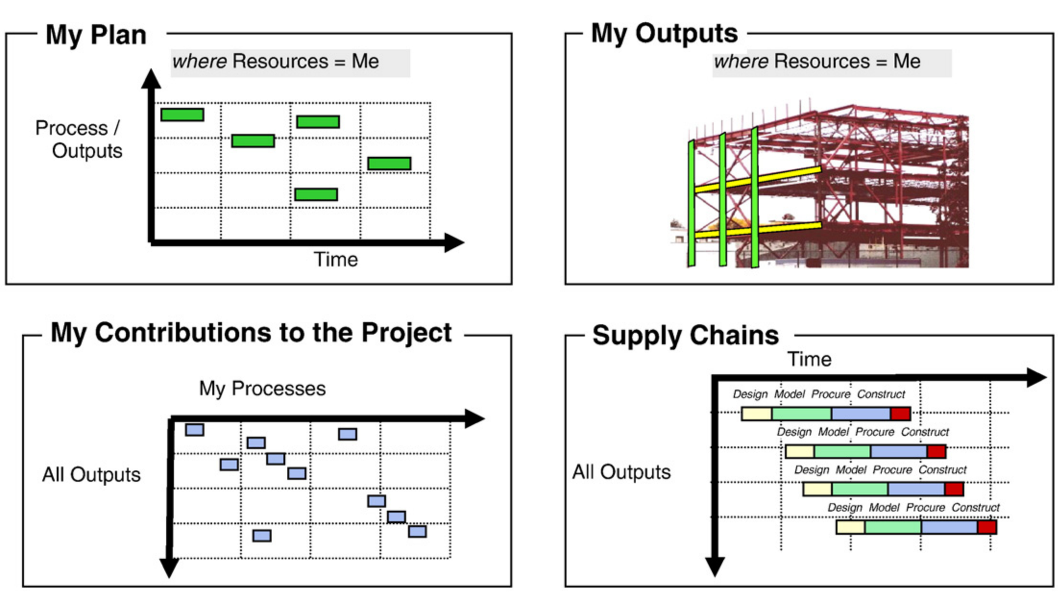

Fig. 3. Examples of widely-applicable, multi-dimensional views of a project: processes with associated outputs vs. time (filtered to show only the viewer's processes); the outputs of the viewer highlighted on an overall view of the project outputs; the contributions of viewer's processes to the overall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

- 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 capture the inter-relationships, 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 each portion 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 certainly be closely tied into the information management issues discussed elsewhere by the author [1]. The approach is also quite dependant on a set of appropriate ICT tools to support the process, as discussed in the later section on technical solutions.

3.7. Towards virtual design and construction

The unified approach to project management involves not only a change to the representational structures as outlined above, but 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—and particularly if the ICT trends are followed to the extent of full virtual design and construction approaches—the integrated project representations act 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.

4. Technical solutions: ICT tools to support the unified approach to project management

A practical minimum requirement for applying the unified approach to project management is some type of ICT platform that allows the views to be represented, inter-related, accessed, and utilized in an efficient manner by all project participants. We are currently developing the following framework for such systems:

- Generally, a project environment would utilize the traditional software tools to work with information within each specific project view (as described earlier, these first era systems are fairly mature and we are unlikely to develop radically improved tools for work within their traditional scope)—yet none of these existing systems captures all of the multi-dimensional and integrated nature of the proposed approach.
- Most traditional tools would become more efficient, and some would increase in functionality, because of the ability to share project information through third era ICT (such as IFC-based data exchange).
- A new class of software would act as “information aggregators”, collecting together the information from all of the individual tools into an overall project information set.
- Within the information aggregator tools, technology based on IFCs allows most project information to be represented and inter-linked.
- Technology based on Online Analytical Processing (OLAP) provides a structure for defining specific project information dimensions, combining these dimensions together into integrated data sets (data cubes), and applying various visualization and manipulation actions on these integrated data views.
- The information aggregator tools can be used to define a wide variety of multi-faceted information views. This capability is intended to be used to define a small number of views that are very widely used by most participants throughout the project (to provide the common perspective on the project), and then allow participants to define any additional views to better support their own work tasks.
- The basic functionality of the information aggregators would allow users to define and work with the inter-relationships between the views, find relevant information by following the relationships from one tool to another, and analyze inter-related information through various visualization techniques.

- Later functionality would operationalize the integrated models to provide simulation and analysis, e.g., as is done for certain views by scheduling software, 4D CAD systems [11] or organizational simulation [12]. The representation of work activities in the system could also tie into workflow management systems to partially automate the management of the project activity.

With such systems, the problem of fit between project management practices and emerging ICT technologies would be addressed in two ways. First, it creates explicit linkages between the project management framework and integrated ICT systems. Second, and perhaps more importantly, it strongly emphasizes the integration and collaboration of all project activities, which is a basic requirement of highly integrated and interoperable ICT approaches. We will be providing greater detail of these possible ICT solutions in later work.

5. Conclusions

We have argued that project management practices should evolve to fully exploit the opportunities offered by emerging construction ICT. This paper has addressed changes to the practice of project management as a whole. Broadly, we suggest that a unified approach to project management involves defining a set of widely-applicable common views of the project information, explicitly defining the inter-relationships between the information in these different views, and modifying project management tools and procedures to work with these integrated views. Work is ongoing to develop both the information technology and the corresponding management practices.

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