CORE PROCESS MODELS AND APPLICATION AREAS IN CONSTRUCTION

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ABSTRACT

Integrated computer systems for the construction industry require high-level, general purpose *core models* of construction information to support information sharing. This paper introduces core models for building and construction, in particular an effort within the ISO STEP organization. The paper then reviews several typical areas of computer applications for construction—planning and scheduling, estimating and cost control, and contract and document management—and discusses the implications of each application area on core models of construction processes.

1. INTRODUCTION

Integrated computer systems offer the capability of improving the effectiveness and efficiency of construction management processes (Russell & Froese 1995). A central requirement for such systems is the ability to share information among multiple computer applications. The challenge of developing and standardizing high-level, generic *core information models* of construction processes has been of particular interest to us in our work within this area. Core models are used as unifying data frameworks for integration among more detailed data models for specific areas of application (Froese 1995a, b).

The development of standard data models is receiving much interest and research effort recently. However, most of this effort is currently aimed at developing *product models* that focus on the articles being manufactured or constructed. From a construction management perspective, it is equally important to focus on *process models* that examine the procedural contexts in which the products are constructed, including construction processes, resources, participants, etc. Models which combine both product and process views can be called *project models*.

We have recently collected and compared a number of models from a variety of projects that are either explicitly core project models, or else they fulfill a "core" role within larger models (Froese 1995a, b). We have compared and contrasted these models and shown that, while many differences exist in approaches to specific aspects of process modeling, there is enough overall similarity to suggest that widely-adopted basic elements and structures for core process models are emerging.

Of particular interest among the variety of existing core models is an effort underway within the International Standards Organization's (ISO) Standard 10303,

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Standard for The Exchange of Product Model Data, or *STEP* (ISO 1994b, NPDERC 1995) by the AEC committee, who are embarking on a project to produce a Building Construction Core Model (BCCM) (ISO 1994a) which would play the role of a core model for the various modeling efforts undertaken within the STEP AEC Building Construction area. This model is of interest because the initial drafts are representative of many other models in this area, and thus it serves as a useful focus for the whole area of core project models. More significantly, since this model is associated with the large international and inter-industry STEP effort, it (or something very much like it) offers the best potential for gaining wide-spread acceptance as a standard core model for construction project information.

Again, The STEP BCCM is not intended to be a complete, all-encompassing model for all construction-related applications, but rather a unifying reference for the many more-specific application models that will be developed to support information sharing within specific construction applications areas. Also, a more general core model development effort is being pursued at he overall AEC level (West 1995) (which, within the STEP organization, includes the areas of Building & Construction, Process Plant, Shipbuilding, and Offshore). Furthermore, many of the general issues relating to the roles and mechanisms of core models are being addressed elsewhere within STEP, such as under Working Group 10's activities on application protocol inter-operability.

2. THE STEP BCCM

2.1. Description of the STEP BCCM

This section briefly introduces the STEP BCCM (which, again, is representative of many other construction core models). Figure 1 illustrates portions of the model (this figure is based on some available information about version 3.0 of the model as well as information about previous versions). The model identifies four major types of building construction objects:

- *Product objects*, which are systems and components of the constructed facility itself,
- *Process objects*, representing processes or actual construction effort on the project,
- *Resource objects*, representing the resources used on projects such as materials and equipment,
- *Control objects*, which are items that control, influence, or constrain other project objects, such as contracts, budgets, design standards, etc.

From the construction management perspective, our interest centers around the process object, which is modeled as requiring product objects and using resource objects, as being controlled by control objects, and as resulting in internal product, resource, or control objects. Process objects are also shown to have required, proposed, and realized characteristics, to involve various actors, and to have related predecessor and successor processes.

2.2. Comments on Core Models and the STEP BCCM

This section provides some comments on core process models in general and on the current version of the STEP BCCM. It is useful to consider what the specific role

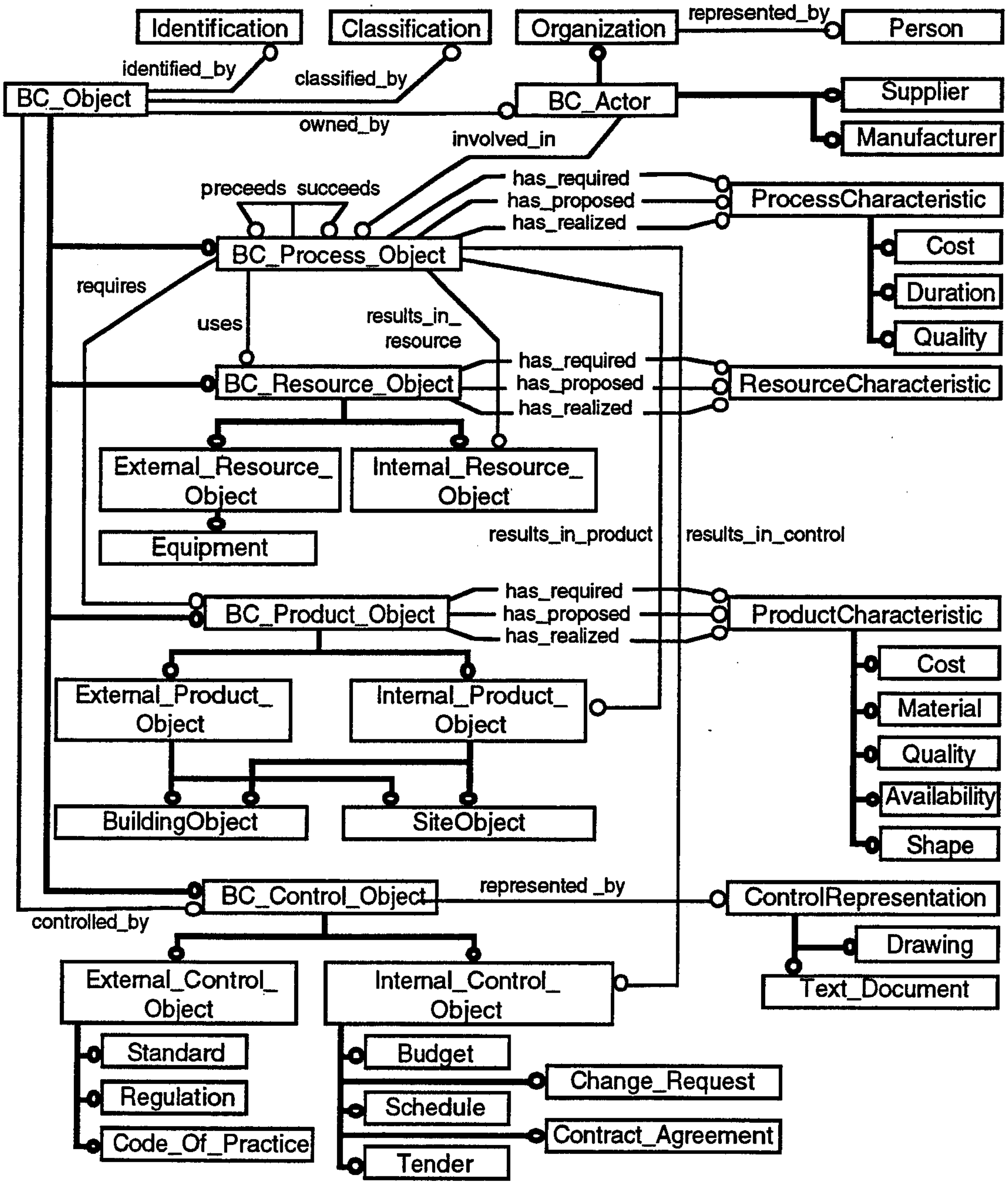

Figure 1. A Portion of the STEP Building Construction Core Model

of a core model is and how these roles influence the required contents of the model. We see core process models as fulfilling the following three roles:

1. Perhaps the most obvious and important role of a core process model is to identify and provide the basic relationships among the central entities within the construction domain. The model should identify and define, for example, construction products, processes, participants, etc., and should show the basic

relationships among these entities. However, this role involves general, high-level entities rather than extremely detailed ones. The complete set of attributes associated with these entities, for example, may be best left for the application models to define.

2. At a higher level, core models could serve the role of an interface or link between lower-level application models and more generic, higher-level models. In this case, an AEC core model would exist at a level above the BCCM. However, the boundary between concepts that should be defined at the AEC level and those defined at the building and construction level is far from being determined, and it is probably best to continue to develop both core models in parallel, leaving the reconciliation of the two until later.

   At an even higher level, there are a number of generic "modeling mechanisms" which are required for modeling concepts from any domain and which can be defined in a "meta-model" (some of these are or will be fundamental parts of the STEP modeling methodology while others will need to be explicitly defined in resource models). Examples of these modeling mechanisms include: object identification, classification, composition, connectivity, versionning, fulfillment and similar life cycle concepts, representations, characterization, states, and model extensibility (Froese 1995a, b; Reschke & Teijgler 1994; West 1993). While the definition of these mechanisms does not depend on details of the building and construction domain, the approaches used to model many basic building and construction concepts may well depend upon the specific modeling mechanisms adopted. Thus, a possible role for the core model is to show which modeling mechanisms should be adopted and where they apply within the construction process domain.

3. At a lower level than the basic entity definitions, conversely, is the role of developing classification breakdowns of the basic entities. It is unclear how much of this should be within the scope of a core model. A core construction model, for example, could develop the basic idea of construction products to differentiate all of the various systems involved in facilities (architectural and spaces, structural, mechanical, etc.) as well as many of the sub-systems and individual components or elements of these systems. Another example would be to model details of many of the specific types of construction processes that exist on projects.

   Some degree of this type of classification breakdown is required in order to lay out the basic elements that are common to many application areas (as in the first example above, many construction-related application areas probably deal with the various systems in buildings, and a uniform approach to defining and interconnecting these systems would likely be useful). This requirement does not call for a large amount of classification breakdown, however. Another role that calls for some classification breakdown is to provide examples of how more comprehensive breakdowns are expected to fit within the core modeling schemes. Again, this requires only small, representative breakdowns. Beyond these requirements, it is likely that extensive classification breakdowns should be left to the application models that will reference the core models.

The following issues relate to specific aspects of the process portions of the current BCCM. These are areas of the model that we believe could use further clarification, addition, or revision:

- expanded treatment of precedence relationships,

• expanded treatment of costs,
• inclusion of construction methods,
• approach to life-cycle stages and entity characteristics,
• treatment of process inputs (resources and products) and process outputs,
• approaches for aggregation, classification, categorization, and breakdown structures,
• provision for a general state-transition model.

3. CORE MODELS FROM THE PERSPECTIVE OF APPLICATION AREAS

On the whole, we believe that the STEP BCCM does represent a consensus view of core construction process information. In this section, we proceed to a new step in evaluating the core model by returning to specific application areas that the core model must support, and checking how the features and characteristics of these areas impact on the proposed BCCM. We will look briefly at the application areas of scheduling, estimating and cost control, and contract and document management. We do not propose specific modifications to the core model here, rather we discuss generally the modeling needs of the application areas. Either the core model will need to incorporate these requirements in some way, or the requirements will need to be addresses in specific application models with which the core model must be compatible.

3.1. Planning and Scheduling

One of the primary areas in which computer tools are currently used to support construction management is project planning and scheduling. Programs within this area, typified by software such as Primavera Project Planner (Primavera 1991) or Microsoft Project (Microsoft 1994), are fairly uniform in their basic functionality, differing mainly in terms of user interface capability and in the suite of specific "advanced features" supported. Figure 2 illustrates the basic data model adopted by these systems (in this case, Primavera Project Planner). The model is centered around the *activity* or *task* (essentially a process entity), other main entities are the *project* itself, *resources*, *resource utilization* (the allocation of specific resources to specific activities), *precedence logic* (the inter-activity sequencing constraints), and *work calendars* (descriptions of the length and timing of the work week available for different types of processes).

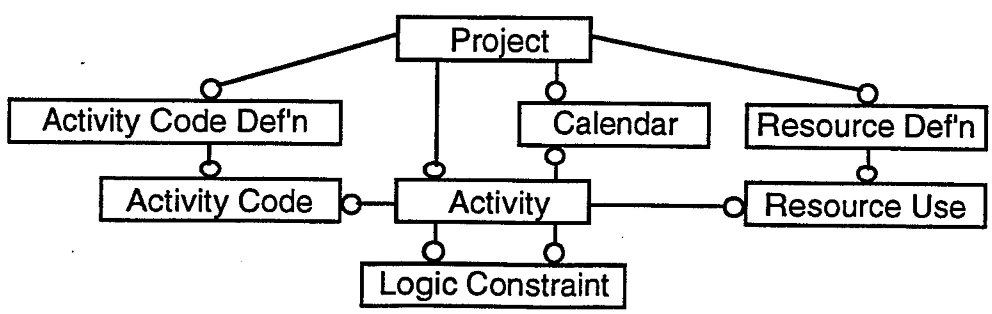

Figure 2. A Scheduling Application Model Based on Primavera Project Planner

A large number of attributes are associated with these basic entities. For example, Microsoft Project version 4.0, for example, has the following data structures:

- tasks have 114 data fields associated with them, including data relating to the following information:
  - durations, start and finish dates (early and late), float or slack time, and task delays,
  - work hours, task progress, and earned value analysis,
  - predecessor, successor, and scheduling constraints,
  - task costs,
  - hierarchical breakdowns (outlines), summary and rollup schedules, subprojects, and work breakdown structures,
  - resources,
  - task ID's, names, user-defined text and flag fields, notes, contact names, creation dates, and OLE linked objects,
  - milestone, criticality, priority, confirmation, and update indicators,
  - multiple versions of many of the above data items are stored, including *normal*, *actual*, *baseline*, *remaining*, and numerous user-defined versions.
- resources have 36 data fields associated with them, including data relating to:
  - costs, work hours, work calendars, variances, accrual basis, overtime, rates,
  - resource ID's, names, groups, units, notes and OLE linked objects,
  - progress, peak use, and over-allocation indicators,
  - multiple versions of many of the above data items are stored, including *normal*, *actual*, *baseline*, *remaining*, and *overtime*.
- data fields associated with projects (29 fields), resource assignments (13 fields), recurring or repetitive tasks (17 fields), and work calendars.

The implication of these planning and scheduling capabilities are that a core process model for construction should either include the following types of information, or it should be defined in such a way that these items could be added in derived application models:

- extensive and flexible attribute sets for schedule durations, dates and floats as well as precedent logic and other schedule constraints,
- resource assignment and utilization data (though the scheduling software does not differentiate among different types of resources),
- task and resource cost data,
- production data (percent completion, earned value analysis, remaining work, etc.),
- work calendars,
- support for process breakdown structures (summary processes, pub-processes, work breakdown structures, etc.),
- project level attributes (though a project could be treated as simply the top level process in a process aggregation hierarchy),
- flexible versionning capability (e.g., normal, baseline, actual, remaining, and user-defined versions of data).

3.2. Estimating and Cost Control

Estimating and managing costs are, of course, of primary concern on construction projects, and a cost view needs to be carefully addressed within a core project model. To date, development of a cost view has lagged behind other views, and a complete treatment of cost issues is beyond the scope of this paper. However, we will take a preliminary look at cost systems and their implication for construction project information. Figure 3 shows a model derived from a popular project estimating system (Timberline Precision Plus estimating software, Timberline 1990). The model is centered around two major elements, items in an estimate and item definitions in a database. The estimate side corresponds to a specific project while the database side corresponds to pre-defined average or typical item definitions that may be applicable across projects. The database item definitions can be used to provide typical unit prices and other information for the estimate items. On both the estimate and the database side, the representation of items is elaborated with entities that allow grouping of items and item definitions into work packages, assemblies, phases, etc. as well as

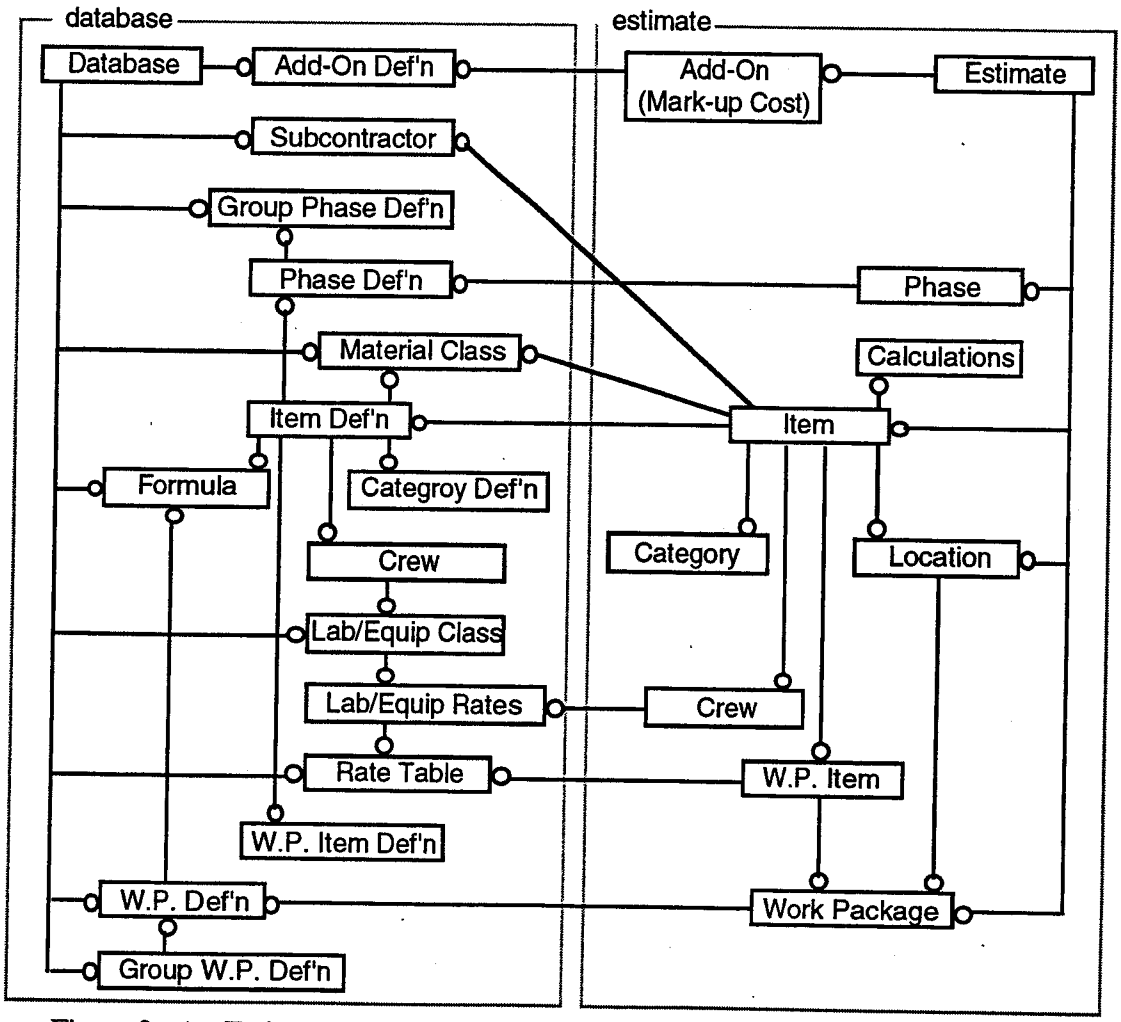

Figure 3. An Estimating Application Model Based on Timberline Precision Plus

the assignment of categories, crews, locations, subcontractors, etc. to item descriptions. To elaborate further, items have data fields relating to the following information:

- item sequence number, memo, and entry date,
- total unit price, total cost, and waste factor,
- item quantity and the calculations used to determine it,
- the location of the item,
- the crew details and subcontractor associated with the item,
- the work package to which the item belongs,
- related job cost and material classification codes,
- for each cost component (these are called *categories* and exist for labor, equipment, materials, subcontract, or other costs), the quantity to be ordered, a conversion factor (takeoff quantity units to ordering quantity units), the unit price and total amount, and taxability and waste allowance indicators,
- the item definition to which the item belongs, which defines the *cost breakdown structure* codes and descriptions as well as default values for many of the above data items.

Some of the implications of these estimating characteristics for a core process model for construction are as follows:

- A major issue is how a "cost item" corresponds to the entities in the core model. A cost item could correspond to any of the following:
  - a product object (implying that the *pieces* of the facility incur the costs),
  - a process object (implying that the *construction activities* incur costs),
  - an entirely distinct entity (implying that projects have *costs* which may result from products, processes, resources, etc.),
  - some combination of all of the above.

  The current BCCM represents costs as characteristics of products, processes, resources, and controls, but it is not entirely clear if these correspond to what we would think of as an estimate item, and if this is the best way of modelling costs. Our view (without having investigated the issue to any great depth), is that cost items should be represented explicitly as separate entities, which may commonly be directly associated with either products or processes but are not necessarily required to be so. Regardless of which approach is used, the set of cost items used to represent the project will not be identical to the set of process objects used to represent the schedule, for example. Several parallel sets of such objects are required to represent the project with *mapping linkages* among them.
- Cost items must have various subcomponents (e.g., labour, materials, equipment, sub-contract, project markup, etc.),
- The cost model illustrated here provides a good example of the need to represent both specific project entities (the estimate items) and the classes or categories to which these items belong (the database item definitions) and from which the project entities can selectively inherit characteristics. This capability would likely be provided by a classification mechanisms in the core model or in higher-level meta-models.
- The cost model contains several requirements that are quite similar to some of the requirements of the planning and scheduling model, such as the following:

- project level attributes,
- productivity information, resource utilization rates, etc.
- support for cost breakdown structures, including good support for composition such as assemblies, resource composition groupings (such as crews, which are collections of specific labour and equipment resources), roll-up summaries, etc.,

3.3. Contract and Document Management

Yet another application area within construction management is contract and document management support systems. Such system help to track contracts, bids, subcontractors, work package progress, change orders, plans and specification revisions and distributions, and so on. In a contract and document management system currently being developed at UBC by Syed, Froese, and Russell (Syed 1995), the major entities of the data model are as follows:

- participants (clients, subcontractors, and supplier organizations, as well as contact people at each),
- work packages and work package items (which at various times may correspond to contracts, budget items, activities, or product objects),
- project documents (contracts, plans, specifications, submittals, work orders, change orders, correspondence, etc.).

Generally, the basic definitions of participants, work packages, and documents correspond well with the BCCM's actors, processes, and controls respectively. In particular, *participants* are the same as the BCCM's *actors* (though many different types of participants may exist). Work packages are somewhat less straight forward. They are similar to cost items in that they are closely related to process objects, but at times may be more akin to product objects or even control objects; thus they could be modeled as a subtype of a process object or as a distinct entity. The characteristics that must be associated with these work packages include the following:

- sub-items (possibly a breakdown hierarchy as seen with schedules and estimates),
- several associated participants (client, contractor, responsible individuals, insurance agents, client's representatives, suppliers, etc.),
- costs (budgeted, bid, final, etc.),
- progress information (percent complete, estimates to completion),
- schedule information,
- associated documents (supporting plans and specifications, addenda, correspondence, etc.).

Documents, too, are conceptually simple, but there are many forms of documents and many attributes required (e.g., participants, contents, various dates, cross-references to products, work packages, etc., document status, distribution information, revisions, approvals, etc.). Also, the designation of all of these as types of *controls* seems somewhat restrictive in the perspective it assumes. These items are all generally documents and they sometimes represent other things as well (the plans and specifications are representations of the product itself, contracts are representations of "as-specified" product characteristics, correspondence is a form of communication among participants, etc. Modeling these as controls identifies their *role* in a particular context more than their *fundamental nature* (West 1993).

4. FUTURE APPLICATION DIRECTIONS

This paper has discussed a small number of typical construction management applications and their implications for core process models for construction. Many other application areas could also be examined. For example, we are currently investigating systems for construction plan generation and analysis, construction methods and techniques recording and advising, and field reporting and progress analysis. More generally, we are pursuing suites of integrated systems that make existing application areas more efficient through information sharing, that extend the breadth of construction management areas that are supported by computer applications, and that focus in particular on the capture and subsequent application of the knowledge and expertise of construction practitioners and the lessons learned from projects. All of these goals rely on information sharing as a cornerstone technology and on comprehensive, "rich" data models of the construction domain (and rich data, in turn, only seems practical in the face of extensive data entry requirements if it is used in a shared environment). For these, standardized core models of construction processes must be realized.

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