DEVELOPMENT OF DATA STANDARDS FOR CONSTRUCTION—AN IAI PERSPECTIVE

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ABSTRACT

The architecture, engineering, and construction industry will eventually adopt information technology-based work practices for the design and management of projects. One of the cornerstone technologies that can enable this is the establishment of industry-wide data standards for representing and communicating high-level information about building projects among project participants and their computer applications. A tangle of overlapping data standards efforts is emerging within the industry. This paper provides an overview of some of these emerging standards efforts and outlines the activities of one, the International Alliance for Interoperability (IAI), and of their North American Project Management Domain Group in particular. Projects to define data standards for construction estimating and scheduling are described, and the complementary roles of standards bodies, industry efforts, and research are contrasted.

Keywords: Data Standards, Project Management, Construction, IAI, IFC, Scheduling, Estimating.

INTRODUCTION

We subscribe to the vision that the architecture, engineering, and construction (AEC) industry will, sooner or later, evolve to one in which detailed, integrated, computer-based models of the AEC projects act as the predominate medium for carrying out design and management work and for communicating the resulting information among project participants.

Several industries have already undergone the initial shift towards information technology (IT) based work practices (e.g., automotive, aerospace, telecommunications, etc.). AEC faces many significant barriers—some of which do not apply to typical manufacturing industries—that create real difficulties and costs for wide-spread integrated computer tools (e.g., high organizational fragmentation, short duration of projects and participant groups, difficult work environments, etc.) (Russell and Froese 1997). Never the less, the cost-benefit ratio will continue its slow but inevitable tip in favour of widespread computer–based information technologies for AEC design and construction.

Among the several cornerstone technologies and trends that must exist before the industry can make this IT transition are the following:

1. Ubiquitous computing resources and skills.
2. A wealth of applications that add value at each step along the AEC project lifecycle.
3. The creation of an “information economy” within the industry, in which information (interpretable by both humans and computers) is recognized as having inherent monetary value, is widely exchanged as the basis of business transactions, forms the basis of competitive advantage among companies, and is supported by appropriate organizational and legal structures. One part of this is the availability of product catalogs and other information libraries in software-accessible form.

4. An “IT Infrastructure” that enables the information created through the AEC design and construction activities to be maintained, exchanged, re-used, etc.

The first two of these cornerstone technologies seem to be well established. The third may well be the most difficult to establish, and is not the subject of this paper. However, the fourth requirement is just as vital. Without this underlying infrastructure, IT tools in the AEC industry would be like transportation systems without roads and rails or market economies without currencies. A part of this IT infrastructure is industry-independent. The establishment of these capabilities, such as widespread connectivity (e.g., through the Internet), database technologies, distributed computing systems, etc., is very active and rapidly advancing. However, there are industry-specific components to this infrastructure as well. A particular need is a standardized language, or set of high-level data structures, with which all applications can exchange and interpret information that is common throughout a project or throughout the whole industry. Work on the development of industry data standards for AEC has been underway for quite some time. The level of effort has blossomed in recent years, however, with several significant efforts under active development by collaborations of industry participants, software developers, researchers, and government agencies. These data standard development efforts within the AEC industry are the focus of this paper.

First, the paper outlines a range of data standard development efforts now underway that have some bearing on the AEC industry. The list of identified efforts is incomplete and it emphasizes a North American perspective, but it does provide some indication of the range and magnitude of the work. Second, the paper discusses the work of one particular group—the North American Project Management Domain Committee of the International Alliance for Interoperability (IAI). This work includes the development of estimating and scheduling data standards for inclusion in the IAI’s Industry Foundation Classes (IFC) standards. Finally, comments are offered on the relative roles of standards organizations such as ISO, industry-based development such as the IAI, and university-based research.

THE TANGLE OF EMERGING STANDARDS

In the preceding introduction, we developed the motivation for data standards in the construction area. This need for standards has indeed been recognized and there are many such efforts ongoing. The proliferation of activity in this area has created problems of its own. Many professionals find it difficult to follow all these activities and identify applicability and relevance to their work. This section briefly addresses this tangle of emerging standards and presents an overview of a selection of relevant efforts in standard-making for construction data. Table 1 summarizes these efforts and presents some of the most important information.

Several types of standards are of interest for construction data: 1) CAD symbology and content standards; 2) object-oriented content standards; 3) Geographical Information System (GIS) standards; 4) construction specifications and aggregation formats; and 5) miscellaneous other standards. Only the first two types are included in table 1.

Examples of type 3 include those lead by the Federal Geographical Data Committee (FGDC), such as the US National Spatial Data Infrastructure (NSDI) effort. The NSDI is defined as the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and non-profit sectors, and the academic community. Another important effort under this umbrella is the Content Standards for Digital Geospatial Metadata. Metadata—or “data about data”—describes the content, quality, condition, and other characteristics of data. This standard specifies the information content of metadata for a set of digital geospatial data. The purpose of the standard is to provide a common set of terminology and definitions for documentation related to metadata. The “Uniformat” and other construction specifications and aggregation formats developed by the Construction Specifications Institute are examples of type 4. As an example of type 5, the US Army Corps

Table 1: Summary of Relevant Standards

Standard Abbreviated Name	NIBS CADD Council – National CADD Std.	USGS/SDTS	Tri-Service A/E/C CADD Standards	ISO STEP	IAI - IFC	OGIS
Standard Full Name	National Institute of Building Sciences	Spatial Data Transfer Standard	Tri-Service A/E/C CADD Standards	ISO 10303: Product Data Representation and Exchange	IAI Industry Foundation Classes	Open Geodata Interoperability Specification
Internet address	http://www.nibs.org/cadd1.htm	http://mcmcweb.er.usgs.gov/sdts/	http://tsc.wes.army.mil	www.nist.gov/sc4/www/stepdocs.htm	http://www.interoperability.com	http://www.opengis.org
Developed by	National Institute of Building Sciences & members from public & private organizations	US Geological Survey, began in 1980	Tri-Service CADD/GIS Technology Center – Department of Defense	International Standards Organization (ISO), many countries participate	IAI, a non-profit organization made up of many private companies	Open GIS Consortium, Inc., a tax-exempt membership corporation
Implemented by – private companies	Parts of the standard are already in use but not as a whole	Avenza, ERDAS, Intergraph, UNISYS	None	Implemented by several private companies	Many, including Autodesk and Bentley Systems	No software yet implements the OGIS standard
Ways of promoting standard	Membership in organization to have input in standard development	SDTS data available for free to create demand for applications	Part of National CADD standard (NIBS)	ISO standards are recognized through-out the world by many governments	Membership in organization to have input in standard development	Membership in organization to have input in stan-dard development
Intended user group	All CADD users	Intended for scientists, US Govt. Secondary users	All CADD users	No specific group, wide range of uses (focus on Industrial)	Commercial CADD software applications	Industry and gov-ernment, but more industry-sided
Intended applications	CADD applications	USGS maps, possibly other private uses	CADD applications	Many applications including Auto, Aero, Electrical, Ship/Offshore.	Building Construction, including Design, Estimation, and FM	Earth Imaging, spatial databases, virtual reality, GIS, multimedia
Current status	Parts of the standard are complete and undergoing revision	"in its final form" and changing; approved in 1992	Under continuous development	Some international standards, develo-pment continuing	IFC 1.5 Specification implemented in commercial software	Draft "Simple Features Spec." completed
Cooperation with other standards	Tri-Service CADD, IAI, ISO STEP	Tri-Service CADD, FGDC	NIBS, FGDC, USGS/SDTS	NIBS, IAI	NIBS, ISO-STEP	FGDC/SDTS

of Engineers developed a “Scheduling Data Exchange Format” (SDEF). SDEF allows various scheduling software packages to exchange data. SDEF is important to the IAI project management domain group as an example of an existing standard that describes a baseline required scheduling exchange capability.

The first three columns in Table 1 present the CAD standards; the second three show evolving object-oriented standards. The CAD standards are important for solving current data exchange needs and providing common grounds for interpreting design documents. They are also important for providing symbology in future design systems using object-oriented standards. CAD standards vary from drafting and layer standards to plotting and other standards. Most of these are included in the current draft “National CAD Standard” promulgated by the National Institute for Building Sciences (NIBS), such as the Uniform Drawing System (UDS), AIA (American Institute of Architects) CAD Layer Guidelines, and the Tri-Service CADD/GIS Technology Center CADD and Plotting Standards.

The US Geological Survey started the Spatial Data Transfer Standard (SDTS) in 1980 and it was elevated in prominence by the US Federal Information Processing Standard (FIPS) 173 published in 1992. Of most interest here is the Computer Aided Design and Drafting (CADD) Profile. The CADD profile contains specifications for an SDTS profile for use with vector-based geographic data as represented in CADD software. The purpose of this profile is to facilitate the translation of this data between CADD packages without loss of data, and support the translation of this data between CADD and mainstream GIS packages. The data supported by this profile is 2 dimensional vector data, or 3 dimensional vector data, where the 3rd dimension is the “height” of the object.

Since much of this paper is devoted to the IAI, it will not be further addressed here. The ISO-STEP effort had been previously reported in several papers to this audience. Open Geodata Interoperability Specification (OGIS) is an object-oriented standard in the GIS domain under development by the Open GIS Consortium, a public, non-profit organization. The technical goals of OGIS are: to provide a single “universal” spatio-temporal data and process model that will cover all existing and potential spatio-temporal applications; to provide a specification for each of the major database languages to implement the OGIS data model; and to provide a specification for each of the major distributed computing environments to implement the OGIS process model. This standard is important to the IAI effort because the IFCs currently have no geospatial capability.

OVERVIEW OF THE IAI AND IFCS

With the conglomeration of emerging standards outlined above, it is difficult to keep track of developments within AEC data standards efforts and to understand their relative roles. This section of the paper provides an overview of one of these standards efforts, the IAI, and of the work of their North American Project Management (NA/PM) Domain Group in particular. The authors are all active IAI members: Grobler is the chair of the NA/PM group and the PM-1 project described below, Froese is a technical co-chair of the PM-1 project, and Yu is the chair of the North American Facilities Management Domain Group.

The IAI is a global, industry-based consortium for the architecture, engineering, construction and facilities management (AEC/FM) industry (IAI 1996, 1998). Their mission is to enable interoperability among industry processes of all different professional domains in AEC/FM projects by allowing the computer applications used by all project participants to share and exchange project information. The IAI’s scope is the entire lifecycle of a building project from strategic planning, design and engineering, construction, to building operation. Their goals are to define, publish and promote a specification—named the Industry Foundation Classes (IFCs)—for sharing data throughout the project lifecycle, globally, across disciplines and technical applications. The IFCs are used to assemble a project model in a neutral computer language that describes building project objects and represents information requirements common to all the industry processes.

IAI members come from AEC/FM industry firms, software vendors, research institutes and universities, professional organizations, and government agencies. The IAI is organized into different regional chapters overseen by an International Co-ordination Council. Current IAI chapters include North America, German-speaking countries, United Kingdom, France, Singapore, Nordic countries, Japan, and Austral-Asian, with more than 600 members around the world. Based on the interest and initiative of the IAI members, a series of domains committees are established within each chapter to represent specialized industry sectors and to provide information requirements for the IFCs from these sectors' perspective. Domain committees include architecture, structures, codes and standards, building services, HVAC, project management, and facilities management, etc.

The IFCs Architecture

The IFCs architecture (Wix and Liebich 1997) is based on layers containing schemas. The layers include a resource layer that describes distinct underlying concepts (e.g., geometry, units and measures, etc.); a core layer that defines a kernel meta-model and core extensions to define the basic AEC/FM objects (e.g., projects, products, processes, resources, etc.); an interoperability layer that defines data that is used across multiple domain areas (e.g., building elements, structural components, etc.); and a domain layer that defines detailed data used within specific application areas (e.g., space layout, power and lighting system design, property management, etc.).

Instances of the IFCs are initialized, linked, and assembled by AEC software to create an object model of the building project. In the simplest form of interoperability, the project model is communicated from one software package to another in a data file (e.g., using ISO 10303 Part 21 format, ISO 1991). Upon receipt of the data file, the software will re-create the project model for further processing and design additions. Currently, there are approximately 15 commercial software packages that have demonstrated interoperability using the IFC standards (Release 1.5), with more being added.

The IFCs can adopt other existing or evolving industry standard models that benefit its users. Adopting external standards may save a great deal of time and cost in IFCs development. A major source of these standards is ISO-STEP (ISO 1994). The decision to use EXPRESS and EXPRESS-G as the primary modeling languages is partly for this reason since they are used for developing the STEP models. By using the same languages, the STEP models can be easily referenced within the IFC schemas. Examples of STEP models used in the IFCs include ISO 10303 Part 41 for measuring units and ISO 10303 Part 42 for geometry resources.

IAI Development Methodology

The IFC standards are developed through IAI projects targeted at specific IFC releases (IFC Release 1.5 was finalized in late 1997 and major releases are expected approximately every year). IAI projects are carried out by IAI members who represent two basic roles: domain experts—who contribute their domain expertise and define the information requirements for the industry processes—and technical experts—who provide software engineering skills in information process analysis and modeling. Domain experts are organized into domain groups that meet approximately every six weeks. IAI projects development follows a process-oriented methodology, which involves the following major steps:

- *Processes Selection:* Proposals to develop new industry processes are prepared by interested IAI members who identify a need and take the initiative to organize resources to perform the work. These industry process are then selected for development in IAI projects based on a number of criteria, including their broad applicability and priority within the industry, their impact on the IFC models, the existence of necessary domain experts among the IAI members, and the existence of software companies interested in implementing the processes within application tools. This step also defines the scope of the selected processes.

- *Usage Scenarios:* The domain experts for each project develop descriptions of situations that show the use of the IFCs to carry out the target processes. These usage scenarios are used to understand and assist in defining the processes and to develop test cases.
- *Process Definitions:* Next, each project describes the steps required to carry out the process, their logical sequence, and their information requirements in a formal process modeling language (IFC-PDEF or $IDEF_0$) (IAI 1997b). Both domain and technical experts are responsible for the process definitions—the former defines the semantic meaning and logic of the process steps and the latter ensures the appropriate use of model syntax.
- *Information Analysis:* The high level information input and output requirements of each process step are used to define modifications and additions to the IFCs in terms of detailed data elements. Examples are encouraged to precisely describe the nature of the information requirements. Since this analysis provides the basis for information modeling, it should be as detailed as possible (i.e., at a level where data can be represented in actual numbers, text strings, etc.). Both domain and technical experts perform this analysis.
- *Information Modeling and Validation:* The information modeling process transfers the results of the information analysis into the formal modeling languages EXPRESS and EXPRESS-G. The information elements and types are interpreted and represented in the IFC models as entities, attributes, or entity relationships. This step is carried out mainly by the technical experts. The domain groups validate the models by test case implementations, which also serve to provide feedback about the models for a final release. The software vendors that participate in the test programs gain early experience in implementing the IFC models.

THE PROJECT MANAGEMENT DOMAIN GROUP OF THE IAI

Although a central purpose of the IFCs is to represent the physical facility and its components (the product model), developers envisioned from the outset that they would also capture other information such as construction process information, organizational information, resource data, etc. The IFC Release 1.0 contained process, resource, control, and other “non-product” objects in its kernel model and provided some basic attributes, relationships, and sub-types of these objects. In developing these objects, however, project management applications were not analyzed in detail. Beginning with IFC Release 2.0, a variety of IAI projects were established to further develop the project management portions of the IFCs. This section presents some of these projects underway within the NA/PM domain group, specifically cost estimating (ES-1) and project scheduling (PM-1). The relationships between these projects and other international IAI projects are also discussed.

IAI Cost Estimating Project, ES-1

The ES-1 Cost Estimating project was initiated for IFC Release 2.0 to examine costs and estimating is much greater detail than had be done for Releases 1.0 and 1.5. The project leader of the Estimating Domain Group is Mike Cole from Timberline Software, Portland, Oregon. This group merged with the Scheduling Domain Group to become the NA/PM group.

The underlying premise of the ES-1 project is that information previously placed in an IFC-based project model can provide some of the information required to determine project costs during an estimating activity, and that this cost information could then be added back into the project model. This can occur early in the project, when only very preliminary information has been added into the project model, and the costs are determined by applying overall unit prices to broadly defined objects such as the entire facility itself, whole floors in the building, etc. Alternatively, this can occur late in the project when the project model is very detailed and complete, and the costs are determined by identifying and pricing-out the detailed task and resource requirements (i.e., the work plans; ES-1 emphasizes this detailed estimating view). ES-1 can also be used to capture and exchange cost data *independent* of other portions of a project model (e.g., for simply exchanging a traditional “stand-alone” estimate from one application to another), but this is not the focus of the work since it fails to take advantage of the potential of IFC-based integration.

Process Diagram

The overall processes identified for ES-1 (shown in Figure 1) are as follows:

- *Scope Analysis:* The scope of the estimating task is first examined to identify the type of estimate required, the estimating methods to be used, the level of detail and intended use for the estimate, the portions of the facility to be costed, etc.
- *Identify Objects:* The objects to be costed are identified. These may be at the level of the entire building, sections of the building, individual elements (such as a door), project tasks or resources, etc. These objects will normally be identified from within the existing project model and will be associated with appropriate object-type information from a costing database or equivalent source.
- *Identify Tasks Needed to Install the Object/Identify Resources Needed to Perform Task:* If the estimating method includes task and resource modeling, then the construction tasks needed to install the objects identified in the previous step, and the required resources, must be identified.

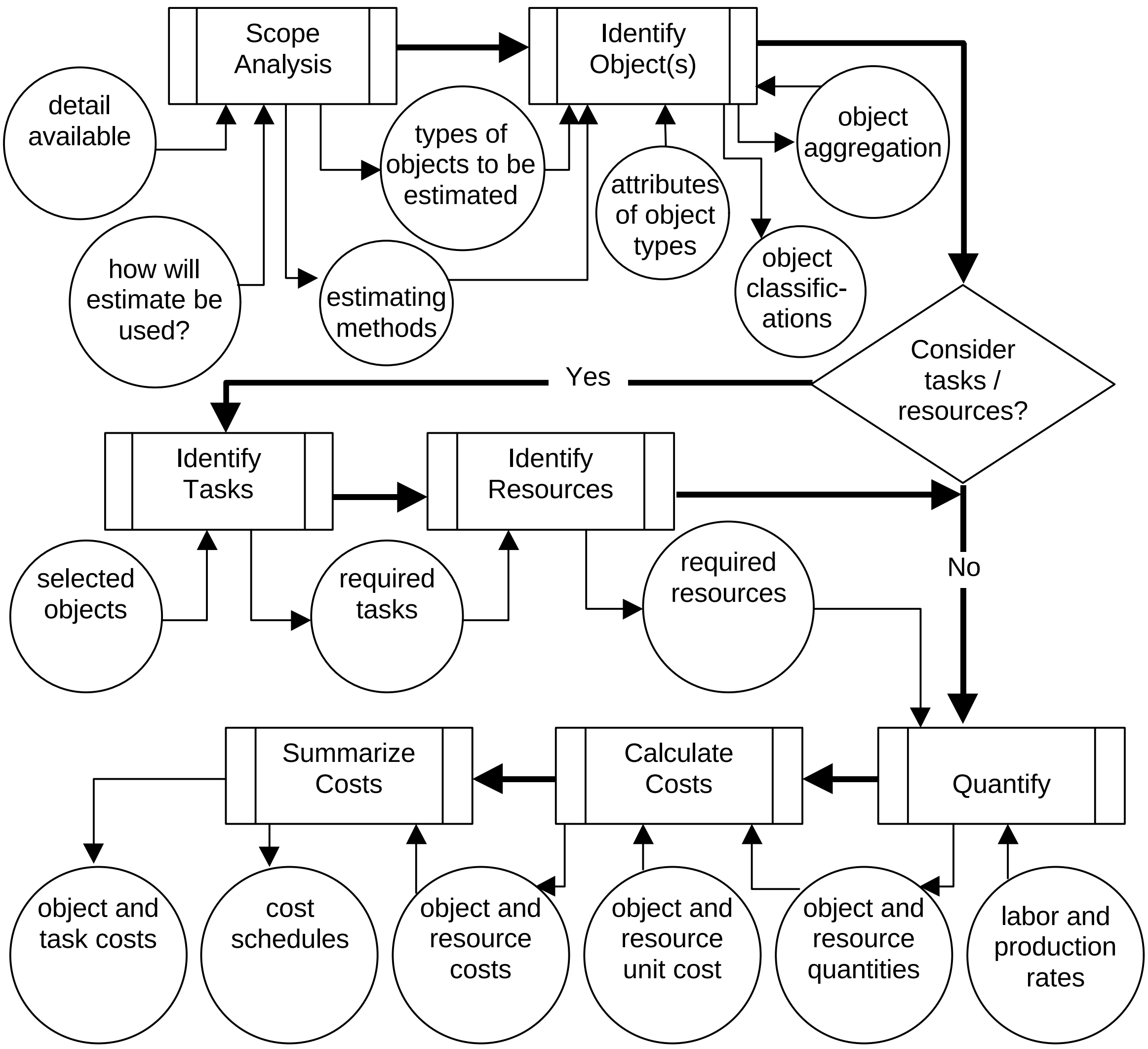

Figure 1: Process Diagram for IAI Estimating Project, ES-1

- *Quantify:* The appropriate units of measurement, dimensions, and total quantities of objects are identified.
- *Calculate Costs:* Appropriate unit costs are identified for all objects, drawing upon links to object type/cost database information in some cases, and the total costs are calculated. Markup costs such as taxes can also be determined.
- *Summarize Costs:* Costs are reported in a way that is suitable for the intended use of the estimate. This may involve rolling up the costs into summary costs, as well as transferring the cost data into the overall IFC-based project model.

Information Requirements and Issues

Much of the information required to carry out the estimating processes is information that has already been defined in the project model for design purposes. For example, the objects to be costed are the building elements as designed. Information required for each object includes data such as the object's class, its classification according to various classification systems, material characteristics, specification requirements (such as fire ratings), dimension attributes, etc. The objects to be costed may be selected from the project model by searching for objects that meet certain search criteria based on these attributes (e.g., all objects of a specific type on one floor), and these selection criteria must be represented and stored for later re-use. The unit and total costs that are calculated and associated with objects, tasks, and resources must be represented within the project model. The estimate itself, including various views and summaries, etc., must also be represented. Furthermore, information must be captured for tasks and resources when they are modeled within the estimate.

Several modeling issues seem particularly critical to the estimating process. Generally, some basic mechanisms for addressing these issues have been included in the IFC Releases 1.0 and 1.5, but these need to be evaluated carefully with respect to the specific requirements of estimating to see where further developments are required. These include the following issues:

- *Aggregation Hierarchies:* During estimating, objects are often defined at one level, and then later they are broken down into greater detail for more precise costing. A mechanism must allow for aggregation (i.e., "part-of" hierarchies) of all estimate objects in such a way that an object might initially be defined as an "individual" thing, and then later be re-defined as a "collection of sub-parts". Both the individual thing and the collection must share all of the same attribute definitions. This general aggregation capability is required for many types of objects throughout the IFCs.
- *Resources:* A simple way of modeling construction tasks is to treat resources as inputs that are converted into the components (i.e., products) of the facility. The resources can be categorized as either materials—which are consumable and become part of the final facility—or crew/equipment resources—which are non-consumable and do not become part of the facility. Unfortunately, difficulties arise when basing a data model on this view of construction. First, some objects are not cleanly categorized according to consumption and inclusion in the final product (e.g., partially-consumed objects such as form lumber that can be re-used a few times only, or temporary structures such as falsework). Second, many resources are themselves products, and it is difficult (and context-dependant) to model them as either resources *or* products. For example, if a customized piece of equipment is designed for a facility, ordered from and assembled by a manufacturer, delivered to a site, and installed, the simple model above might treat the equipment as a material resource prior to installation and as a physical component of the project after the installation. This seems to be an awkward approach.
- *Costs of Resources and Tasks:* Clearly, costs can be associated with the physical components of a facility. However, if tasks and resources are being modelled, then they can reasonably have associated costs as well. Issues remain in ensuring that all types of "costable" objects can have costs associated with them, and that this doesn't lead to a double-counting of project costs (e.g., by including the costs of resources in an estimate

total when these costs have already been accounted for in the unit costs of the physical components).

- *Type and Occurrence Information and Libraries:* The estimating process deals with information about the costs of specific, individual items in a specific project (e.g., the cost of an individual concrete slab in a proposed building). However, estimating also deals with information about the typical costs, productivities, and other attributes of various *types of* items, (e.g., the typical unit price for some style of concrete slab). Thus, estimating models must deal with information about both types of objects as well as about individual occurrences or instances of objects. This topic relates to another significant issue of maintaining libraries of standard information such as parts libraries, standard design details, estimating standards, work method libraries, etc.
- *Views:* Although a single project estimate may lay at the center of an estimating task, several different versions or views of that estimate may be developed. Different views could serve different purposes by focussing on different levels of detail, different types of costs, different presentation formats, etc. The ability to define and work with multiple views of an estimate is essential.

IAI Scheduling Project, PM-1

All AEC practitioners use scheduling information for a wide variety of purposes throughout the project lifecycle, including planning, co-ordination, and communication. The IAI Scheduling project PM-1, initiated by the NA/PM domain group for Release 3.0 of the IFCs, addresses three main scheduling sub-processes. First, *generic scheduling* attempts to define the underlying concepts used throughout all of AEC/FM to logically and temporally order tasks and other events. This is intended to include many types of schedules, such as those for design services, procurement, documents, inspection, moving, energy control, phasing diagrams, occupancy, etc. Second, *construction project scheduling* refines the generic scheduling constructs to deal specifically with detailed construction scheduling as carried out by contractors and others for project planning and control. Third, the *use of estimating information in defining project schedules* is considered in an attempt to partially address the overlap between estimating and scheduling processes. This section will provide an overview of the construction project scheduling sub-process.

Project scheduling is considered within the context of a broad range of management processes that include schedule preparation, creating and managing versions of schedules, using schedules for project control, and archiving schedule data for future planning activities. Like estimating, schedulers are expected to draw some of the required information from the project model and to create new information that is added into the project model, though the scheduling model can also be used for exchanging scheduling information independent of other project model data. Also like estimating, schedules can be developed and linked to the project model at an early conceptual stage, or at a late detailed stage. Whereas estimating optionally includes task and resource planning, scheduling requires that project tasks be defined since tasks (or anything which occurs at some point in time and may have some duration) are the fundamental unit of schedule planning (resources can optionally be defined).

Process Diagram

The overall processes identified for construction project scheduling in PM-1 are shown in Figure 2). This is a top-level view of the scheduling process only. Many sub-processes have been defined but are not shown here.

- *Scope Analysis:* The scope of the scheduling task is analyzed to identify the type of schedule required, the level of detail and intended use for the schedule, the portions of the facility to be scheduled, assumptions, constraints, etc.
- *Work Planning:* The activities to be scheduled are identified. PM-1 breaks work planning down into the sub-processes “define coding scheme”, “work method planning”,

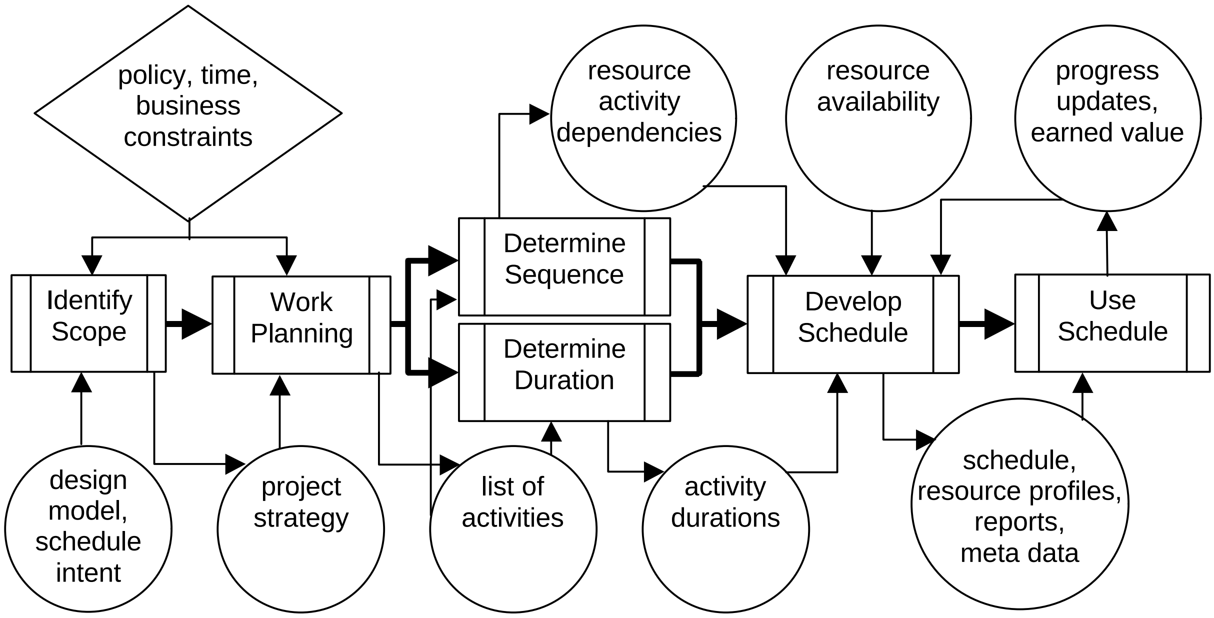

Figure 2: Process Diagram for IAI Scheduling Project, PM-1

"resource planning", and "identify activities". To the extent that work plans have been defined previously (e.g., during estimating), these existing plans can be incorporated into the scheduling process at this point.

- *Activity Sequence/Logic:* The schedule for work activities is determined from the logical order or sequence that the work must follow. This step defines the sequencing logic.
- *Activity Duration:* Activity durations are defined as either a single estimate of the time required for an activity, or an analysis based on productivity rates, number of resources applied, and quantity of work to complete.
- *Schedule Development:* Given the list of activities, sequence logic, and durations—the overall schedule calculations can be performed to produce schedules of the needed format, level of aggregation, etc. (using computer-based critical path method tools, for example).
- *Use Schedule:* Once a schedule is developed, it can be used in a variety of ways requiring a variety of views and operations on the schedule. PM-1 identifies three main types of uses: *strategic*, for designing and negotiating delivery mechanisms, cost and time constraints, etc., with project team members; *tactical*, for monitoring ongoing activities as the project is carried out, keeping historical records, and modifying future plans as different project scenarios arise; and *historical*, for recording actual performance on completed work for the purpose of preparing payment schedules, negotiating disputes and claims, and scheduling future projects. All of these uses require that multiple versions or views be developed from the base schedule, such as summary report views, views that use selection criteria to focus on portions of the schedule, baseline schedules against which progress is measured, etc.

Information Requirements and Issues

At the time of writing (early 1998), the NA/PM group is completing work on the processes definitions for PM-1 and is beginning the requirements analysis stage to examine the impact on the IFC data models. However, some preliminary comments about the information requirements and issues can be made. As with estimating, most of the information about the project components to be scheduled should already exist within the project model as a result of design processes. One type of information that is useful for scheduling, but may not be well developed for other uses, is information about the physical relationships between components that impact activity sequencing decisions (e.g., supported-by, enclosed-in, and other relationships). Process representation (i.e., activities or work tasks) is critical, as is the relationship between processes and the physical products that are created. Finally, several issues that were discussed for the ES-1 project are also important for scheduling. These include the ability to arrange work tasks into aggregation hierarchies, a thorough and consistent treatment of resources and their relationship to physical components and work tasks (greater detail regarding the assignment of resources to individual tasks may be required here, such as the resource-use profile during the duration of the task), and the ability to represent information about various types of work in addition to the information about individual work tasks.

Other Related IAI Efforts

Several other IAI projects are underway that directly relate to the ES-1 and PM-1 projects:

- The ES-2 (formerly CM-1) project on cost planning, lead by the UK chapter, is closely related to ES-1, but focuses on preliminary cost planning based on non-elemental or "soft" project knowledge. The project includes processes for order-of-magnitude costs, preliminary appraisals of cost, approximate estimates, and cost plans.
- The CM-2 project on temporary facility planning, lead by the Japanese chapter, covers a range of planning activities (cost, schedule, construction zones, etc.) as they relate to two specific applications for temporary facilities: scaffold planning and lifting device planning.
- The PM-2 project from the NA/PM group focuses on estimating and scheduling integration. Initially, this was a Release 3.0 project covering the use of estimating information for creating schedules. However, this process was moved into the PM-1 project, and the PM-2 work was refocused as a Release 4.0 project aimed at the more broadly defined integration of product, cost, schedule, resource, and work planning. This level of integration has been demonstrated in various research projects (Froese 1996) and holds great potential for a wide range of management functions such as automated planning, but it does not represent management tools as they are typically used today.
- The XM-1 project (Referencing External Libraries) is a UK-lead project. The goal is to define issues related to establishing, managing and accessing object libraries. The initial focus is product data, design details, etc. The importance of cost databases, work crew compositions and numerous other "library" type aggregations important to estimating and scheduling has been recognized and may be included in future work.

Conclusions: Data Standards Research and Development

This paper has offered a glimpse of an emerging tangle of data modeling and standards developments for AEC, and has provided some insight into one of these efforts. One of several root causes of the overlapping but distinct activities is the difference between the mandates of standards bodies, industry groups, and institutional research efforts. An example can be found in the overlapping construction data modeling and standards efforts being pursued by ISO STEP, the IAI, and various research institutes. The mandate of STEP, as an effort under the International Organization for Standards and its member national standards organizations, includes requirements for widespread consensus, formalized procedures, and rigorous technical solutions. The IAI, as an industry-based consortium, places a greater emphasis on delivering a solution in the near term (with regular updates), using the best technical approaches it can achieve given the available time and resources. Research projects—such as the Total Project Systems (TOPS) project at the University of British Columbia (Froese et al. 1997), which is aimed at contributing to the vision of widespread integrated project management tools outlined at the beginning of this paper—can focus on more specific technical challenges with less priority on delivering complete, near-term, applied solutions.

While the differing priorities create multiple overlapping efforts, they complement each other very well. For example, the IAI has drawn extensively from STEP for modeling methodology and content. It would suit both organizations if the IAI standards were successful in making headway into common industry practice while simultaneously contributing to the STEP process, such that the IAI standards were eventually replaced with the ISO STEP standards. ISO and IAI have recently drafted a memorandum of understanding (early 1998) to formalize their relationship. Similarly, both the IAI and STEP have drawn extensively from work conducted by research institutes, they face technical challenges which may best be explored within research institutes, and they can benefit in their ongoing work from the lessons learned through a long history of data modeling research. Conversely, IAI and STEP provide research institutes with research issues and industry input, and the emerging standards themselves add to the capability of research-based systems. Finally, there is an extensive overlap of personnel from AEC industries, related software companies, research institutes, and government agencies in all of these efforts, and the intermingling of perspectives, ideas, methodologies, and issues is beneficial to all.

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