Step Data Standards and the Construction Industry

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STEP DATA STANDARDS AND THE CONSTRUCTION INDUSTRY

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ABSTRACT

Product and process model data standards are required to provide the unifying language through which integrated computer systems for architecture, engineering, and construction can converse. STEP, the Standard for the Exchange of Product Model Data, is a large international effort to develop such standards throughout numerous industries. This paper introduces the STEP effort and provides an overview of the organizational makeup and the model development process. The paper then outlines STEP efforts within the building construction domain, highlighting the Building Construction Core Model project as a central unifying model for computing systems in construction.

Keywords: STEP, Construction, Product Models, Process Models, Project Models, Standards, Computer Applications, Computer-Integrated Construction, Integrated Systems.

THE GOAL OF INTEGRATION

The ability to share information between computer systems is an important capability for current computer-based tools for the construction industry, and it is seen as paramount for construction tools of the future. A primary mechanism for enabling information sharing is the use of standards for representing information. Data standards provide the common language through which users of integrated computer applications can converse. For complex data such as the information used to describe constructed facilities and construction processes, the standard data representations must be highly structured so that not only the syntax but also the semantics of the information can be maintained between systems. This allows, for example, one system to know how to interpret a set of letters and numbers received from another system as a representation of a concrete wall of specified dimensions, concrete strength, and cost. The level of integration that can be supported by data standards ranges from simple file exchange between application programs through translators that are largely transparent to users, to highly integrated company-wide, project-wide, or even industry-wide systems.

The largest effort currently underway to create data standards for industrial products is called *STEP*. While STEP has the potential of becoming a key information technology throughout many industries, it can be difficult for the uninitiated to understand. This paper introduces the STEP effort and provides overviews of the STEP organization , the STEP methodology, and other efforts that bear some relation to STEP. The paper particularly focuses on developments relating to product and process model data standards for the construction industry. A discussion of the potential levels of implementation for integrated systems is also provided.

STANDARD FOR THE EXCHANGE OF PRODUCT MODEL DATA

A large international effort is underway within the International Standards Organization (ISO)[1] to develop standards for representing information about products in many different industries. The standard is generally known as the *Standard for the Exchange of Product Model Data, or STEP* (officially known as ISO Standard 10303, Product Data Representation and Exchange). STEP is intended to provide an international standard for computer-based description and exchange of the physical and functional characteristics of products throughout their life cycle, independent of any particular system (ISO 1994b). STEP provides the overall framework and the implementation technologies for representing product design and production data in a form that can be exchanged between computer systems as files or direct on-line access—the type of data used by Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), and Computer-Aided Manufacturing (CAM) applications, for example. This overall framework is applied to specific industry applications through STEP product models.

STEP technology is being aggressively pursued in many industries as both a major enabling technology of future international commerce in the global economy and as a key to implementing informational technologies for productivity improvement throughout enterprises. Active participation has come from industries such as automotive (including companies like Ford, General Motors, BMW, Chrysler, and Mercedes-Benz); aerospace (e.g., Boeing, GE Aircraft Engines, Pratt & Whitney, and Rolls-Royce); and electronics (e.g., IBM, Digital Equipment Corporation, and Hewlett-

Packard). Efforts to apply STEP to the Architecture, Engineering, and Construction (AEC) industries are also underway.

An initial set of STEP parts were released as an international standard in December, 1994[2], and some production implementations have been announced as of December 1995 (McDonnell Douglas used STEP to exchange the equivalent of 525 drawings for part of its C-17 between two design sites).

STEP, THE ORGANIZATION

STEP is being developed by the ISO Technical Committee on Industrial Data and Processes (TC184)[3], Subcommittee on Industrial Data (SC4)[4] (see Figure 1). In addition to STEP, SC4 is responsible for two other related standards: ISO 13584, Standard for Part Libraries[5] and MANDATE, a standard for manufacturing management data.[6] Work within SC4 on STEP is carried out by a number of working groups. Among these is Working Group 3 (WG3) which is responsible for the development of the actual product models, and within WG3 is Team 12 which is responsible for Architecture, Engineering, and Construction (AEC) activities. This encompasses the areas of Off-shore (Group 1), Shipbuilding (Group 2), Process Plant (Group 3), and Building Construction (Group 4). Work on STEP also overlaps with many other organizations:

- The ISO *Initial Graphics Exchange Specification (IGES)*[7] is a neutral data format for exchanging information among CAD systems. IGES has acted in many ways as a precursor for STEP.
- *Product Data Exchange using STEP (PDES)* is the name of the STEP project within the US. PDES work is carried out through the IGES/PDES Organization (IPO)[8] under the parent organization of the US Product Data Association (US PRO)[9]. The STEP Standard has been adopted as an American National Standard (ANS US PRO/IPO-200) by the American National Standards Institute (ANSI)[10], which has named the IPO as the accredited standards body for product data exchange standards.

- The US *National Institute of Standards & Technology (NIST)*[11] supports many aspects of STEP development such as the National PDES Testbed.
- *PDES Inc.*[12] is an international consortium of major companies whose goal is to accelerate the development and implementation of STEP.

In addition, there are many efforts that do not directly focus on product model standards but do overlap with the overall scope of information technologies and standards for the construction industry:

- *Classification Systems* have long been used in the construction industry to provide consistent categorization and coding schemes for project information—specification sections, for example. ISO committee TC59/SC13 has been working to develop international standards for classification systems in construction products and services and to improve upon the technology of existing classification systems (ISO 1994a). This group has established links with the STEP building and construction group in order to harmonize efforts on these two complimentary elements of information technologies for the construction industry.
- *Electronic Data Interchange (EDI)*[13,14,15] is the electronic transfer of business data between independent computer systems using standard data formats. EDI is well established within some common business operations such as purchasing and is now moving into technical areas such as CAD data, product catalogues, etc. Organizations have been established to create EDI standards, including the United Nations *EDIFACT* organization and *MD5*, the technical body within the Western European EDIFACT Board charged with developing EDI messages for the construction industry.

- The

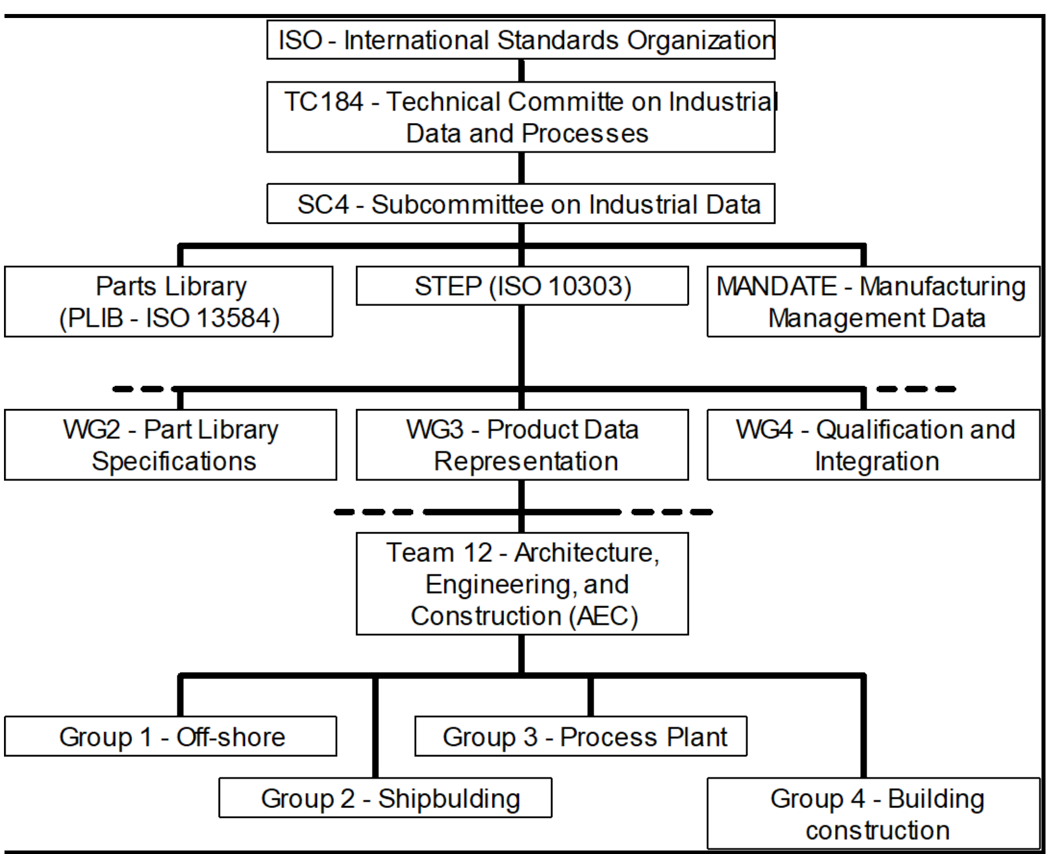

Figure 1. The Organization of STEP.

Continuous Acquisition and Life Cycle Support (CALS) program[16,17,18] of the US Office of the Secretary of Defense is aimed at data standards for the exchange of information relating to the procurement and acquisition, configuration management, and maintenance and life-cycle support of parts and systems. This has lead to several US Military standards that overlap in scope with STEP, and collaboration efforts have been underway between the two groups.

- The *Industry Alliance for Interoperability (IAI)*[19] is a consortium of building product suppliers, architects, engineers and software companies dedicated to producing standardized *Industry Foundation Classes (IFC's)*, an object class library for representing data about the built environment (the initial development of IFC's came from an Autodesk project, but the program has now been moved to the independent IAI organization). Although much younger than STEP, the IAI delivery targets are more ambitious with initial releases planned for 1996. While there is much overlap in the scope of STEP building construction and IAI, the exact extent and nature of the overlap is not yet clear. There have now been several joint meetings between IAI and STEP and many individuals are active in both groups. The collaboration potential has been recognized and avenues of shared development effort, particularly of the data models themselves, are being explored.

THE STEP MODEL DEVELOPMENT METHODOLOGY

STEP does not attempt to produce a single standard model that applies across disciplines. Rather, the STEP approach is to produce standard product models for use within specific areas of application, called *Application Protocols (AP's)*, and to strive to harmonize and coordinate these models across application areas to the greatest extent possible. The process of developing an AP is illustrated in Figure 2 (Fowler 1996).

To begin, AP's grow out of specific perceived industry needs, and these needs must be well formulated and understood. Given industry need, the role of the AP is documented in an *Application Activity Model (AAM)*. The AAM identifies the business processes in which the AP is used, and shows the information flows among the processes. The AAM is presented typically using $IDEF_0$ notation, which lists business activities and the information flows between them (see Figure 3). The AAM is often the first interface with industry participants in the modeling process and is the primary tool for determining how the model is to be used.

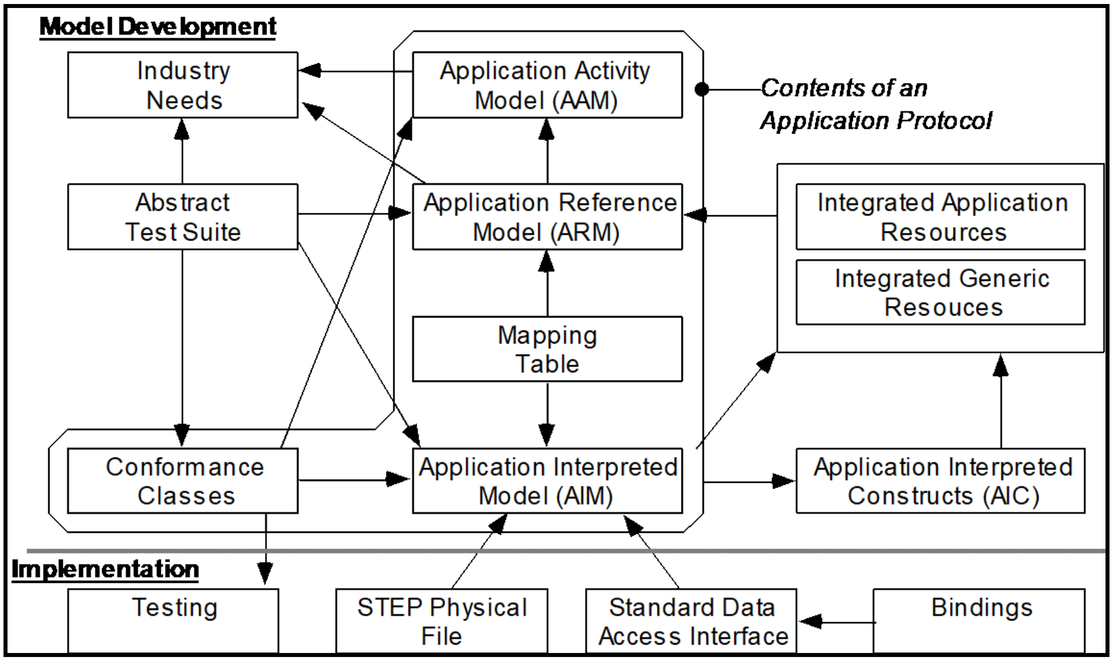

Figure 2. The Application Protocol Development Process and Implementation Components (arrows indicate reference to other sections).

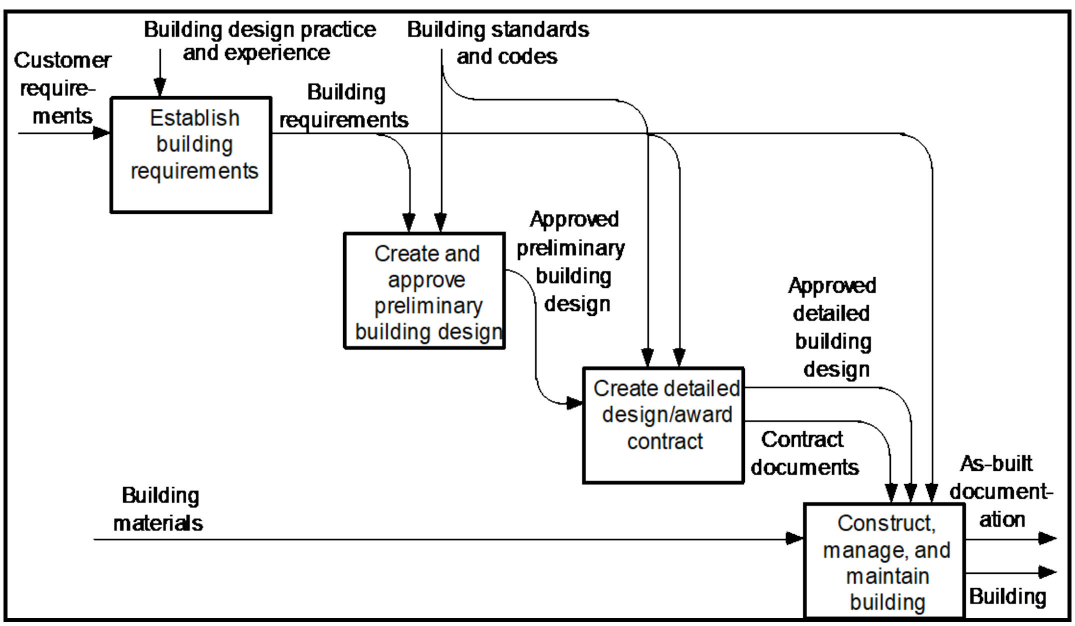

Figure 3. Example of an Application Activity Model (AAM) in $IDEF_0$ Notation (from AP225 (ISO 1995).

Given this understanding of the model's role, the *Application Reference Model (ARM)* is developed. The ARM is a model that depicts the information that needs to be included in the AP using the terminology and concepts of the application domain. The development of the ARM encompasses the bulk of the model development effort, but it is still within the scope of the industry experts (rather than being the responsibility of modeling specialists alone).

Once the AAM and the ARM are developed, the task shifts to developing a model that fully defines all the necessary data representation structures in a way that is compatible with other parts of the STEP standard. This is the *interpretation* process and it results in an *Application Interpreted Model (AIM)* which draws upon the ARM and other reference models, both STEP-wide or *Integrated Generic Resources (IGR's)* and *Integrated Application Resources (IAR's)*. A *Mapping Table* correlates the entities from the ARM and AIM models.

In addition, *Conformance Classes* are defined (i.e., different levels to which implementations of the model may adhere) and suites of test data are developed through which implementations can be tested. Finally, where the interpretation process leads to the same basic concepts being represented in two or more AIM's, these model segments are defined in an *Application Interpreted Construct (AIC)* for use in future AIM's.

The actual AP document includes the following sections:

- A statement of the scope of the AP.
- A list of normative references (e.g., other STEP parts that are explicitly referred to in the AP).
- A list of definitions and abbreviations used.
- The information requirements for the AP. This section describes the ARM in terms of a listing of objects organized into related sets called *Units of Functionality (UoF's)*; a complete listing of the *application objects* and their attributes; and a list of *application assertions* that specify the relationships between applications objects, the cardinality of the relationships, and the rules required for the integrity and validity of the application objects.
- The AIM described as a mapping table that maps ARM elements (objects, attributes, and assertions) to one or more AIM elements and as a complete listing in EXPRESS, a data modeling language that is itself part of the STEP standard.
- Appendices that include graphical representations of the AAM, ARM, and AIM.

A fully developed AP—specifically the AIM model presented in EXPRESS language—is intended to be implemented to support information exchange. There are two primary implementation approaches directly supported by STEP. The first is file transfer, in which the data corresponding to some specific project is exported from one computer application, structured according to the AP, and formatted as defined by the *STEP Physical File Format* (STEP part 21). This file can then be imported by another computer application and interpreted. The second implementation method is direct access to the data as stored in a database or similar system. In this case, STEP Part 22 defines the *Standard Data Access Interface (SDAI)* which provides a programming interface to the on-line data (bindings of the SDAI interface to languages such as C, C++, and IDL are also being defined).

The actual STEP standard is made up of many individually-released parts, many of which are listed in Table 1 (also see "STEP-on-a-page"[20] for a listing of the current parts and their development status).

Table 1. Some of the Parts of the STEP Standard. Underlined parts are currently released as an international standard, other parts are under development. Many other proposed parts or work items exist that have not been listed here.

Description and Methods Part 1 - Overview and Fundamental Principles Part 11 - EXPRESS Language Ref. Manual Part 13 - STEP Development Methodology **Implementation Methods** Part 21 - Physical File, Exchange Structured Working Format, Active Transfer Part 22 - Standard Data Access Interface Part 23 - Early Binding for C++ Part 24 - Late Binding for C Part 26 - Binding for IDL **Conformance Testing Methodology Framework** Part 31 - General Concepts Part 32 - Requirements on Testing Labs & Clients Part 33 - Abstract Test Suites **Integrated Generic Resources** Part 41 - Fundamentals of Product Description and Support Part 42 - Geometry and Topological Representation Part 43 - Representation Specialization Part 44 - Product Structure Configuration Part 45 - Materials Part 46 - Visual Presentation Part 47 - Tolerances	**Integrated Application Resources** Part 101 - Draghting Part 102 - Ship Structures Part 104 - Finite Element Analysis Part 105 - Kinimatics Part 106 - Building Construction Core Model **Application Protocols** Part 201 - Explicit Draughting Part 202 - Associative Draughting Part 203 - Configuration Controlled Design Part 208 - Life Cycle Product Change Process Part 209 - Comp. & Metal Struct, Anal, & Related Design Part 215 - Ship Arrangements Part 221 Process Plant Functional Data & Its Schem. Rep. Part 225 - Building Elements using Explicit Shape Representation Part 227 - Plant Spatial Configuration Part 228 - Building Services: HVAC Part 230 - Building Structural Frame: Steelwork Part 231 - Process Engineering Data **Abstract Test Suites** (AP number + 100) **Application Interpreted Construction (AIC)** Part 501 - Edge-Based Wireframe Part 502 Shell-Based Wireframe Part 505 Dwg. Structure & Admin.

BUILDING CONSTRUCTION EFFORTS WITHIN STEP

Although there has been sporadic interest and involvement in STEP from within the construction sector reaching back to the mid 1980's, the current level of involvement began to take shape with an *Application Protocol Planning Project for Building and Construction (APPP-BC)* that was formally initiated in October 1993 (Storer 1996). The APPP identified nested families of models required to represent information from building construction industries. The AP's currently under development within the building construction group are as follows:

- *AP225 - Building Elements Using Explicit Shape Representation* (ISO 1995). AP225 is aimed at representing buildings as assemblies of elements—e.g., beams, columns, windows, etc.—along with the explicit (i.e., non-parametric) 3D geometry of each element and some additional information such as material properties, building element classification or element versions. The AP has been developed as a German nationally funded project headed by W. Haas, and it is the furthest along in the standards process of the building construction AP's, having reached

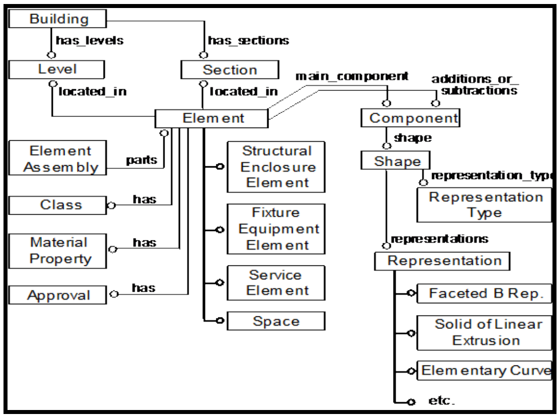

Figure 4. Some basic objects of AP225, Building Elements Using Explicit Shape Representation.

Committee Draft stage in January 1996. Experimental implementations have been completed that exchange complex building CAD models between heterogeneous CAD systems.

The major Units of Functionality (i.e., object groupings) defined in AP225 are listed as follows and provide an overview of the model (see Figure 4):

— *building elements* are the discrete, large-scale pieces of or things in the building

— *building components* correspond to individual shapes that make up an overall building element. For example, a column element may consist of a main cylinder component along with other additive components to form base and capital sections and subtractive components to form blockouts.

— the *composition* UoF identifies buildings which decompose into building sections and levels. the building elements, which can be arranged into element assemblies, are positioned within these sections and levels.

— the *design administration* UoF identifies information such as approvals, modifications, or acceptance of building elements

— the *properties and classification* UoF represents non-geometric element information such as material properties and classifications.

— In addition, there are several geometry UoF's to describe specific shape representations.

- *AP230 - Structural Frame: Steelwork.*[21] AP230 arose from a large European EUREKA project called CIMsteel. One of CIMsteel's goals was to advance information integration within the structural steel industry, a challenge met with the development of product models and integration prototypes. In 1994, the CIMsteel product model was promoted as a STEP AP project covering construction steelwork frame design, analysis and detailing, and fabrication. The development is lead by A. Watson and M. Ward of Leeds University.
- *AP228 - Building Services: HVAC.*[22] AP228 focuses on heating, ventilation, and air conditioning building services. The project has drawn heavily from two European projects, JOULE COMBINE[23] and ESPRIT ATLAS.[24] The project is lead by P. Poyet and J. Monceyron of CSTB, France.

<u>Part 106 - The Building Construction Core Model (BCCM)</u>

A final current work item of the STEP building construction group is *Part 106, the Building Construction Core Model (BCCM)* project[25,26], lead by J. Wix (Jeffrey Wix Consulting, UK), F. Tolman, and R. Los (TNO, Netherlands). The BCCM is not an AP project, but rather an Integrate Application Resource—a model intended to serve as a unifying reference for building construction AP's. More specifically, three possible roles have been identified for the BCCM (Wix 1996):

1. *Kernel:* The core model should provide a basic model of the central building construction concepts that are common to all areas of the industry. Individual AP's within the industry, then, can adopt this kernel model and develop various areas in greater detail to suit the needs of the particular application area. This ensures a commonality of approaches among construction AP's.

2. *Common references:* Beyond a central kernel, there are many more detailed areas that are common to two or more applications within building construction and it is desirable to treat these areas in a consistent way. One role of the core model, then, is to act as a library of common reference models, or model constructs that apply to multiple construction areas. In STEP terminology, this role corresponds to AIC's, but at a reference (ARM) level rather than an interpreted (AIM) level (these could be called *Application Reference Constructs, ARC's*).

3. *Common data:* AP's are developed to allow information exchange among programs *within* an application area (e.g., within the structural design area). However, information also needs to be exchanged *between* application areas (e.g., to use design information for estimating). Information exchanged between application areas generally needs to be much less detailed than information exchanged within an application area. Another possible role of a core model, then, is to support the exchange of information between application areas, a capability not presently facilitated within the STEP framework.

Figure 5 illustrates portions of the model (based on Version Str 5.1). The model identifies a basic *Project Object* as an abstract super-type of most project information. For any project object, the following data can be described: a unique data item identifier, a status, a version number, an owning actor, references to library objects, object classifications, and controlling objects. There are four basic types of project objects:

- *Process objects* represent processes or actual design and construction effort on the project. Processes are performed by actors, they apply resources and process input products, they have preceding and succeeding processes, and they result in other project objects. Their characteristics include quality, cost, and time frame data. Sub-types of processes include design, logistic, and construction processes.

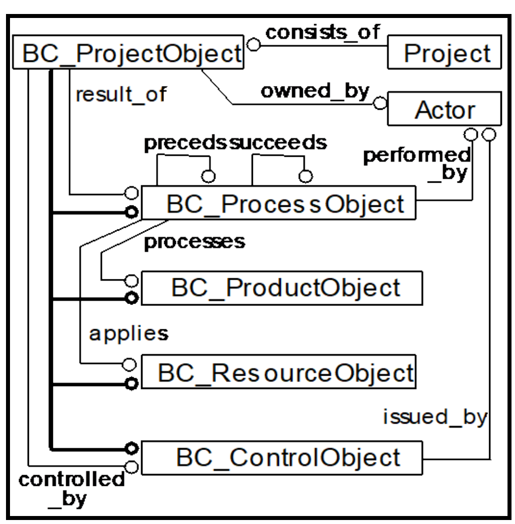

Figure 5. Some basic objects of the STEP Building Construction Core Model.

- *Product objects* are systems and components of the constructed facility itself. Their characteristics include quality, availability, cost, shape, material, and performance data. Sub-types of products include building, system, site, and civil engineering objects.
- *Resource objects* represent the resources used in carrying out processes. Sub-types of resources include human resources and construction aids.
- *Control objects* are items that control, influence, or constrain other project objects, such as contracts, budgets, design standards, etc. Control objects can have one or more representations of various version, media, status, etc.

Much work has already gone into the BCCM, and several draft revisions of the model have been developed and widely discussed within the building construction group. There is much work to go, however, including finalizing of the very role and nature of a core model within the STEP framework, developing the contents of the core model itself, and harmonizing the model with the other ongoing AP development efforts.

Other areas of interest

In addition to the formal projects currently ongoing within the STEP building construction group, several areas have been identified as being of interest for possible future AP development projects. Some of these areas have undergone much development already under other projects, but the STEP AP timetable (a maximum of three years from the acceptance of a new work item to the release of the international standard) requires that projects be fairly well formulated before being presented as new work items. These areas include roads, building spaces, reinforced concrete, project management, and AEC libraries

THE POTENTIAL FOR INTEGRATED SYSTEMS USING STEP

Once product model standards are established for an application area, a wide range of possibilities still exists for how they are applied within users' systems. The following list illustrates a range of the possible levels at which standard models can be used to support information exchange and sharing:

1. *Simple file exchange through translators.* Users could exchange a file from one system to another, retaining most of the file content and semantics. Each system would provide translators to express their internal data in the form of STEP AP's and the physical file format, though all of this could be largely transparent to the user.
2. *On-line file exchange.* Users could gain immediate, on-line access to information from databases or from other systems through STEP SDAI access based on the AP models. Some degree of system-level design for this approach may need to be dependent upon the AP models (e.g., decisions about what information will be exchanged when, by whom, etc., will depend upon the specific information types defined in the AP).
3. *AP-based tool configuration and use.* A tool such as a CAD system allows 3D models of buildings to be developed, but they impose no uniform technique for

decomposing an overall building into a series of logical elements and mapping these to the geometric shapes. In some cases such as this, product information cannot be exchanged unless the way that the information is modeled within the application tools themselves becomes more consistent. Thus, AP's may be used not only to move information between computer tools but also to help structure the way that the tools are configured and used in general.

4. *AP-based tool design.* To extend the preceding example, some new application software tools will be designed with the AP models at the heart of their internal data representation structures. The AP's could serve this role well because they embody much modeling effort relating the relevant application area and because they ensure an approach that will lend itself well to integration with other systems within the application area.
5. *Highly integrated, distributed systems.* Integrated systems are the goal of much current research. Such systems would incorporate the idea of standard product models in general and the content of certain models in specific within the very center of their data structuring and exchange approaches. Moreover, such systems would be expected to deal with multiple AP's and to allow for changing AP's over time.

CONCLUSIONS

This paper has presented an outline of the STEP product modeling effort, focusing on developments in the area of building construction. Although overall efforts to achieve international standards for product model data have been underway for a decade now, the past year or two have seen significant progress and technical maturing in the areas of modeling and standardization. Much work remains to be done of course, but these efforts now seem to be solidly *"on track"*. The greater uncertainty now, perhaps, may be shifting to how well both industry users and software developers are able to adopt and exploit the potential of these upcoming models and standards to increase productivity and effectiveness in the construction industry.

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The following are the Universal Resource Locators (URL's) for on-line World-Wide-Web references for this paper (this list can be found on-line through http://www.civil.ubc.ca/~tfroese/pubs/)

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