Product Modelling of Buildings for Data Exchange Standards: from IGES to PDES/STEP and Beyond

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ABSTRACT

Digital data exchange problems are severe in the building community because of its organizational and operational complexity and the vast scope of its information needs. Early CAD data exchange standards, such as the Initial Graphics Exchange Specification (IGES), dealt exhaustively with the syntax or arrangement of the data to be exchanged. Most of the semantics or meaning of the data must be imposed by the user of the standard. Current work to develop the first international standard, called both the Standard for the Exchange of Product Model Data (STEP---the ISO nomenclature) and the Product Data Exchange Specification (PDES---the USA nomenclature), is based on an explicit definition of semantics at the user level. The response of the building community to these two different approaches to standardization is reviewed in terms of product modelling of buildings. A number of challenges are discussed in the context of building data.

INTRODUCTION

The building community has been quick to embrace useful computing technologies as they emerge, ranging from the earliest graphics systems to the latest decision-support tools based on artificial intelligence techniques. The building community has successfully automated a variety of tasks previously performed manually.

Because of its organizational and operational complexity and the vast scope of its information needs, the building community has encountered severe problems in replacing traditional paper-based information exchange with digital data exchange. The computing environment in a typical building project is both distributed and heterogeneous. Graphic computer-aided design (CAD) systems are becoming the greatest common denominator in the building community. Consequently, CAD data exchange protocols have become a focus of attention in the quest to achieve comprehensive and reliable data exchange.

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GOALS OF DATA EXCHANGE

Developers of digital data exchange protocols strive for completeness in the exchange, i.e., all the desired data including underlying structures and relationships should be exchanged. A corollary of this completeness goal is that the useability of the data on the receiving system should be on a par with that on the sending system.

To meet these goals in a heterogeneous environment, the semantics or meaning of the data to be exchanged must be standardized as well as the syntax or arrangement of the exchanged data. Any system sending data must be able to map its internal semantics to the standard semantics and map its internal syntax to the standard syntax, while any system receiving data must be able to perform the reciprocal operations. The exchange should be accomplished in a neutral format so that all systems have equal access to it.

Secondary goals in the design of data exchange protocols are to achieve conciseness and minimal redundancy in the exchanged data sets. Standardization of semantics aids in the attainment of these goals as well.

PRODUCT DATA AND PRODUCT MODELLING

To a single user, the term product data denotes the data elements needed to support his own view of a product or project. However limited a single view may be, the union of the views of all building participants will define the totality of data elements needed for programming, designing, constructing, operating, maintaining, and renovating a building: that is, the building product data.

Attempting to achieve this union at the level of the data themselves is known to lead to chaos.

About ten years ago, the ANSI X3 Standards Planning and Research Committee (SPARC) [1] developed a three-level architecture for the logical design of data bases. This architecture separates the users at the external level from the physical data at the internal level by introducing a middle, conceptual level. In the SPARC approach, conceptual schema that capture the meaning of the data in each user's view are integrated into one global conceptual schema that can be tested for consistency and completeness. This use of conceptual schema is clearly desirable in the design of data exchange protocols.

With a defined global conceptual schema, new user views can be created without unnecessarily modifying the physical data structure, and alternative physical data structures can be employed without affecting the user views (of course, the mapping functions must be changed). These properties are as desirable in the design of data exchange protocols as they are in data base design.

Product modelling in the SPARC approach consists of the development of a conceptual schema that specifies the semantics of the data according to some data model through such relationships as association, aggregation, and generalization, and the development of a logical schema that extends the conceptual schema to include the domains of the lexical objects (the objects actually expressed as data) and the constraints on these domains. In this paper, the term product model denotes these schema taken together. The term product model is often used loosely to denote a set of data organized according to these schema.

IGES

The Initial Graphics Exchange Specification (IGES) [2] was developed initially by the National Bureau of Standards, Boeing Airplane Company, and General Electric Corporation, and published as an NBS report in January 1980. The IGES Committee, comprising developers, vendors, and users, was created in that same year to maintain and extend IGES according to ANSI procedures for consensus standards. In the succeeding years, IGES has undergone three revisions, has been adopted as an American National Standard, and has influenced the development of other protocols such as the French SET.

As its name implies, IGES is strongly oriented toward the graphic capabilities of CAD systems. IGES information is intended for human interpretation (What you see is what you got!). IGES defines a neutral representation of geometric and non-geometric product data in terms of fundamental units of information called entities. Geometry entities represent the definition of three-dimensional curves, surfaces, and solids. Non-geometry entities define properties, associativities, aggregations (called subfigures), macros, and a number of graphic-oriented characteristics such as drawing definition, font definition, annotation, and the like. IGES supports best a product model consisting of a geometry model and sufficient attributes to produce drawings and views of the geometry.

New entities can be created in terms of the existing ones using the macro definition and instance entities. Since there is no generalization capability in IGES, all entities including those defined by macros are essentially at the same level of abstraction.

No distinction is made between the conceptual schema and the physical schema in IGES (there are alternative physical file formats, but they represent the same physical schema).

The architecture, engineering, and construction (AEC) subcommittee was chartered in early 1984 to address the use of IGES in the building community. The challenge faced by the AEC subcommittee was the large gap between the semantic richness of typical building product data and the limited expressive power of the entities defined in IGES. The subcommittee tackled this challenge in a number of ways because it recognized that the capabilities of existing CAD systems were just as limiting as the capabilities of IGES:

(1) The subcommittee proposed a number of new pattern hatch codes and a new line font definition entity to provide for the exchange of patterns (e.g., concrete) and line fonts (e.g., condensate return) that are graphic standards in the building community. This example illustrates that even AEC drawings are semantically rich and require attention in the design of a data exchange protocol that deals with graphics.

(2) The piping and plant design group worked with other subcommittees to enhance the IGES capability for defining piping diagrams, electrical and electronic schematics, and physical designs. This work resulted in the modification of some entity definitions and the addition of new ones such as the connect point entity (all adopted through the consensus process) to provide for the logical (schematic) and physical representation of flow paths. Because this work had to be done at the physical schema level, interactions with other applications that also used the (modified) entities weren't always revealed until implementations were developed. This example illustrates how IGES has been able to gain some undesirable characteristics even as it becomes more capable.

(3) The AEC subcommittee wrote guides for the use of IGES in certain applications. Two examples are contained in appendices of IGES Version 4.0. One defines the use of a subset of IGES entities to exchange process flowsheet information. The other defines the use of another subset of IGES entities, including macros that define solid objects parametrically, to exchange three-dimensional piping models. This example illustrates how subcommittees could easily overwhelm the specification, as well as the user, with hundreds of specialized product models and associated application guides for the use of IGES.

(4) The AEC subcommittee identified basic information structures, such as a relational data structure and a generalized network (arc-node) structure, considered essential for building applications. These structures bore some similarity to existing IGES structures such as the property entity and proposed entities defining boundary representations of solids. Without a conceptual-level schema for IGES that allowed a rational comparison and integration of these various structures, the subcommittee was forced to define new IGES entities for adoption. The IGES Version 4.0 includes attribute table entities that implement a relational data structure. This example illustrates how IGES has acquired a number of entities with similar capabilities which can give rise to ambiguity in data exchanges. However, by allowing for explicit cross references between data in an IGES file and external classification and catalog systems, the new attribute table entities provide for significant new semantic expressiveness (for example, occurrences of a particular aggregation of entities can be identified as door assemblies of known characteristics in a table representing a door schedule).

Through these efforts, the AEC subcommittee succeeded in introducing some useful semantic content to IGES. However, the limited expressiveness of the

IGES entities and the inability to generalize prevent the creation of anything approaching a complete product model of a building in this piecemeal fashion. The absence of a planning model makes it difficult to manage even piecemeal work.

Recently, the process of introducing semantic content has been formalized in a methodology for developing application protocols [3]. An application protocol defines a specific work area such as drafting or piping modelling, defines in a conceptual schema the information content required for the work area, identifies the mapping of the information content into its representation by particular IGES constructs and describes the restrictions and conventions required in the use of the supporting IGES constructs. Application protocols define the context within which exchanged data are to be interpreted, thereby allowing meaningful exchange of information.

PDES/STEP

By 1983, it was generally recognized in the IGES Committee that, while IGES information was possibly adequate for present-day CAD systems, more complete product data exchanges will be required to support emerging computer-aided design, engineering, and manufacturing systems. The Product Data Exchange Specification (PDES) [4] project began in mid-1984 in what is now known as the IGES/PDES Organization.

Simultaneously, the Standard for the Exchange of Product Model Data (STEP) [4] activity was undertaken by the International Organization for Standardization in its Technical Committee 184 on Industrial Automation Systems. Subcommittee Four, External Representation of Product Definition Data, seeks to accomplish the development of STEP by closely coordinating existing and future national projects rather than by undertaking parallel development. Counterpart PDES and STEP technical committees meet jointly to ensure that a single international standard for data exchange emerges.

In PDES/STEP, the term product data denotes the totality of data elements that completely define a product for all applications over its expected life. The ANSI SPARC approach has been adopted to define this totality and the major effort in the PDES/STEP committees is devoted to arriving at an integrated conceptual schema for product data. Planning models for managing the development are being refined.

Various PDES/STEP committees are developing models for product structure and configuration management, shape and size, tolerances, finite element models, electrical, features, material properties, printed wiring boards, drafting, and presentation. The shape and size model includes topology and geometry. Geometry, in turn, includes curves, surfaces, wire frame, boundary representation, constructive solid geometry, and polygonal representation.

Currently, the PDES/STEP AEC committees are working on six product models. These are the General AEC Reference Model [5], the AEC Building Systems Model, the Reference Model for Ship Structural Systems [6], the Ship

Outfitting Model, the Plant Design Model, and the Mapping Model. These models are not discussed here because they are the subjects of other papers in this seminar.

The General AEC Reference Model abstracts to a high level the kinds of data encountered in the building community (in fact, no entity in the model names a recognizable building object). This model is intended to provide a comprehensive framework in which other, application-specific models can be integrated.

The subjects of the other models are evident from their titles. For the most part, these models cover portions of the design and construction or fabrication stages of their subject areas. Within their stated scopes, the models are to characterize all the building data required. It should be apparent that the product modelling work of the PDES/STEP AEC committees falls far short of the total scope of life-cycle building data. The current models are sufficient, however, to (1) establish the semantic richness of building data for the education of the PDES/STEP Organization, (2) validate the approach to integration of models, and (3) provide early versions of PDES/STEP with capability of real use to the building community.

CHALLENGES

It has been essential for the AEC committees to focus on the development of a comprehensive model for building data in order to ensure AEC needs will be met in the ensuing PDES/STEP standard. This focus has precluded a thorough examination of issues that may determine the ultimate usefulness of PDES/STEP. The following examples illustrate this concern.

Like IGES, PDES/STEP accommodates multiple representations of geometry, including a wireframe representation, a surface representation, a boundary representation, and a constructive solid geometry representation. Implied in the work to date is the notion that the receiving system must do the best it can with whatever representation is received. This approach has not been successful in IGES. It would seem that the transformations between the different representations should be defined explicitly in PDES/STEP. The representations may need to be restricted so that such transformations do not lose information or else modified to include meta-information from which the lost information can be generated appropriately. More generally, is it possible to create a canonical representation from which the others can be derived? This is an important issue to the building community which undoubtedly will use all possible representations.

Many data in AEC applications are derivative in some instances and atomic in others. A simple example is the floor area of a room which may be the only datum needed in a building official's system but which can be derived from the dimensions of the walls in an architect's system. When the architect passes a completed design back to the building official, should both the wall dimensions and the floor area be passed? If both are passed, then who is responsible for ensuring their consistency? If only the wall dimensions are passed, then should the sending system's method for computing the floor area be identified as well? The AEC committees have endorsed the concept of minimally redundant data sets, but have not defined the principles by which this will be accomplished.

A related and ultimately more important issue is the absence in current PDES/STEP thinking of a mechanism for explicitly defining and exchanging methods and constraints, which represent important classes of building information.

The AEC committees have not determined how the AEC product model will lead to implementations of PDES/STEP translators. In the ANSI SPARC architecture, the external level is defined by the actual data requirements in application programs. The AEC committee's application models are in fact conceptual level representations. No vendor has yet shown whether the product models being developed can be mapped into realistic systems. The General AEC Reference Model is an extreme case because of its high level of abstraction, but the application-specific models also imply keys and attributes that simply do not exist in many present day systems. The semantics captured in the models represent the ideal sought by the committees. Vendors are left with the challenge of providing CAD systems that understand these semantics. It seems possible to control (but not eliminate) this problem by adopting application protocols ala' IGES.

The AEC committees have not determined how to complete the task of developing a global building product model. In fact, there is growing recognition throughout the PDES/STEP Organization that the global product model is unattainable in any realistic time frame. In IGES, this problem was partially addressed by the macro capability and by allowing for user-defined extensions that satisfied the syntax requirements. PDES/STEP, however, strives for explicit definition of the semantics in an exchange. A schema definition capability for PDES/STEP has been proposed [7] that would allow explicit representation in the exchange file of the semantics of user-defined extensions. An implication of this capability is discussed below.

FUTURE

The previous section highlights a characteristic that PDES/STEP inherits from IGES. Both protocols define a broadcast mode of data exchange with no possibility for negotiation between the sending and receiving systems. An alternative is to allow the receiving system to define its requirements to the sending system in advance of the exchange. This demand mode of operation would seem particularly appropriate in an environment of distributed knowledge-based systems. The schema definition capability mentioned above could be designed to support this mode. A recent study [8] developed an approach called modular semantic application layer protocols (MS-ALPs) that generalize this idea to true peer-to-peer communication in which one system can ask another for its conceptual schema and then request that certain data be exchanged in the context of some subschema. This appears to be an example of the next generation system.

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