Information System for Infrastructure Management

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Abstract

Information system is one of the basic components needed in infrastructure management to take advantage of the available computer and networking capabilities. An ISO/STEP based standard is adopted in this paper. The information is stored in a spreadsheet format. This information is automatically converted to graphical representation by a simple public accessible graphical programming language. Examples of the spreadsheet database and the graphical representations are shown. STEP standard is based on the concept of parts and assemblies. Description of designs based on parts and assemblies forces the designer to think about the construction process. This approach is expected to reduce constructibility problems during construction.

Introduction

A typical sequence of event in the AEC industry is as follows: First, the architect(s) begin with a conceptual drawing. This drawing is refined to a design and a set of requirements. Next, the engineer(s) creates a model for this design and select member sizes and connection types. Some special connections are designed. A steel fabricator uses the engineering and architectural drawings to determine the detail for connections and assemblies of members to be built. These drawings are returned to the structural engineer for approval. The steel fabricator does not always interpret the engineering and architectural drawings accurately. Re-design is inevitable to some extent at this stage. When all parties have agreed to the design and how it has to be fabricated, construction begins and the steel erector attempts to put the fabricated parts together. Unlike the automotive industry where fit and construction sequence is well known at assembly time, steel buildings are nearly always a one-of-a-kind project. Fabricated pieces sometimes do not fit properly, and access can make certain assembly steps impossible to achieve. These unforeseen problems are sometimes solved by the engineer at the site and sometimes require redesign and fabrication of new parts. This process is streamlined when the architects, engineers, and fabricators are experienced, and produce designs that are constructible. The problem of parts that do not fit can be readily solved by the use of three-dimensional graphic simulation. The problem is that engineers and architects at the design level have not been asked to perform this check historically. The use of a database that can be automatically viewed in three-dimensional graphic helps mitigate this problem. The proposed database requires that each individual part be described in detail before fabrication. Putting parts together into assemblies graphically mimics the actual construction sequence.

An effective project delivery process depends on the availability of current and correct information for all the participants, wherever they are and whenever they need it. Achieving the seamless integration of project information has become a primary goal for many organizations associated with the building and construction industries, ranging from the Construction Industry Institute (CII) to the Construction and Building Committee of the President's Science and Technology Council. Ongoing benchmarking studies by organizations like the Business Roundtable and the CII confirm the business stake in this goal.

A number of technology developments will make more and richer information available to project participants. They include (1) more complete descriptions of the project design itself and of the products and services procured for the project, (2) large amounts of previously unavailable spatial-temporal information supporting the realization of the project design on the construction site, and (3) comprehensive commissioning procedures tied to the as-built condition of the resulting facility.

Integrating and managing this information presents significant technical challenges. Two very different approaches have emerged during this decade. The first is a data-driven approach based on the evolution of computer aided design systems. Open system standards such as the International Organization for Standardization's Standard for the Exchange of Product Model Data (ISO/STEP) and Parts Library (ISO/PLIB) and the International Alliance for Interoperability's Industry Foundation Classes (IAI/IFC) are being developed to capture the complex, deep-structured technical data using computerized tools. These

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standards allow the exchange and sharing of information in such a way that it remains as functional in the receiving system as it was in the originating system, with integration taking place at the level of individual information elements.

However, neither the standards nor the systems based on them yet cover all the functionality needed in a typical project, and especially not throughout the entire delivery process. This has led to a second, document-driven approach based on the evolution of the Internet and the World Wide Web. Frequently called project extranets, systems based on this approach collect and distribute project information, ranging from long-lived design drawings to transitory email requests, as configuration-controlled documents, with integration taking place at the level of hyperlinks among the documents. Compared to the first approach, the information exchanged in this approach is shallow-structured and superficially integrated. Because the basic unit of information is a document, however, these systems automatically cover all the functionality needed in a traditional document-centric project, and their use is beginning to make a difference in the U.S. construction industry.

Once the project information is available, accessing and viewing it presents additional technical challenges. Traditional presentation mechanisms are based on static views of tabular data extracted from databases, and stored two-dimensional drawings and documents. These mechanisms have carried directly into the graphical user interface based on Web browser technology, used in document-based project extranet systems. While the industry has a decade of experience in developing graphical user interfaces for 3-dimensional project models (an early example was the Bechtel Walk-thru system), these were typically based on proprietary CAD system data structures and presented static design models with only limited access to non-geometric information.

As technology advances in the information technology sector, the user will be challenged to deal with increasing volumes of increasingly complex information, and the need for facile and intuitive graphical user interfaces will increase dramatically. The objective of this paper is to show how these goals can be achieved by developing standards-based, open-system technologies for accessing and viewing construction project information and demonstrate them in prototype systems.

Approach

To enable the capture of technical project information, a portion of emerging product data standards from experimental databases will be created. The ISO/STEP and PLIB standards suites and the IAI/IFC are relevant starting points. A good starting point is the CIMSteel Integration Standard CIS(2), which is based on STEP technology and is the precursor of the STEP Application Protocol 230 on structural steelwork. STEP technology uses EXPRESS to represent the data structure and the relationship of the objects to each other. These EXPRESS representations can be difficult for the novice users to interpret. We will implement a small subset of the information in our database in the form of a spreadsheet. This format is familiar to nearly all computer users with different backgrounds. Familiarity with the format may foment the use and adoption of this useful database.

The scope of the database is limited to the structural steel skeleton of the building at this point in our development. It will encompass the following stages of the building's life cycle: (1) design, (2) analysis, (3) fabrication, (4) delivery, and (5) erection of structural steel work.

One of the main reasons of redesigns and poor constructibility in a design is that designers don't always envision how their designs are put together. The proposed database mitigates this problem by requiring every part of the structure to be modeled, and it requires specific information on how the parts are put together to form an assembly. Parts and assemblies are modeled in the same manner. An assembly may be composed of parts or other assemblies *ad infinitum*. The concept of assembly forces the designer to think of parts and how they need to be put together. The assembly instruction is accomplished through the STEP *axis2_placement_3d* entity. For this discussion, let the coordinate system of the assembly be denoted as the parent (global) coordinate system. Let the coordinate system of the parts be the child (local) coordinate system. The coordinate system of the construction site will be called the site (world) coordinate system. Placement of a part in the assembly is accomplished through a coordinate transformation from the child system to the parent system. And the placement of the assembly in the construction site is done by a coordinate transformation from the parent system to the site system. Table 1 shows an excerpt of the spreadsheet database with this information.

Once the parts are defined, Table 1 provides all the necessary information to place the parts on the assembly and show the assembly with the parts using VRML either in the assembly (global) coordinates or the site coordinates. More on the VRML representation in the next section.

Table 1. Axis2_placement3D entity in spreadsheet format

		Def of origin of part's coord			Def of local z axis (dir cosine)			Def of local x axis (dir cosine)		
From part to this assembly	Part	x	y	z	x	y	z	x	y	z
Assembly of	VT1-P1	12	0	0	-0.57735	0.57735	0.57735	0.57735	0.57735	0.57735
Assembly of	VT1-P1	52.25	0	0	0.57735	0.57735	0.57735	0.57735	0.57735	0.57735
Assembly of	VT1-tube 4x4x3/8-50.25	7	0	0	0.57735	0.57735	0.57735	0.57735	0.57735	0.57735
		assembly origin in site coord			global z axis (dir cosine)			global x axis (dir cosine)		
From this assembly to site coord	(all entries in site system)	x	y	z	x	y	z	x	y	z

Representation of members necessitates the cross sectional information, length, cut outs and attachments. Attachments can be viewed as an assembly of the attachment onto the member. This can be done via the concept of assembly of parts shown in the previous paragraph. Two formats are used to describe the cross section of the member. First, a list of points defining the outline of the cross section can be used. A more efficient method is to create a table that associates the name of a member to the cross sectional dimensions. Then only the name of the member needs to be entered. Since nearly all members used in steel construction are standard members, the second approach can be used most of the time. CIS(2) allows many forms of cutting on the member be specified such as: non-perpendicular end cuts, notches, and holes. These modifications are specified in the spreadsheet as a Boolean subtraction operation. An example of the portion of the spreadsheet with the member information is shown in Table 2.

Table 2. Member Property Definition

	Part or primitive	Attributes		
Boolean subtract				
Boolean subtract				
Boolean subtract				
Def. of cross section		local x	local y	local z
by points	**section def. Point 1**			
	section def. Point 2			
	section def. Point 3			
	section def. Point 4			
	section def. Point 5			
	section def. Point 6			
	section def. Point 7			
	section def. Point 8			
	section def. Point 9			
	section def. Point 10			
	section def. Point 11			
	section def. Point 12			
	section def. Point 13			
	section def. Point 14			
	section def. Point 15			
	section def. Point 16			
or by name	**name of section**	T4x4x3/8		
General characteristics				
	Length (in)	50.25		
	Height (in)			
	Width (in)			
	Weight			
	Material	steel		

Color
Finish
Fire rating
Price

Graphical User Interface (GUI)

A public accessible tool for three dimensional object construction and viewing called Virtual Reality Modeling Language (VRML) is used. VRML specifications developed by the Web3D Consortium and promulgated as ISO/IEC 14772 offers an advantage because any user can employ widely available Web browser technology to access and display the results. The construction object definitions that were developed using VRML programming capabilities are extended and enhanced to include more information. When an element or assembly is touched, the list of information appears on the screen.

Realistic infrastructures can contain a large number of assemblies and parts. Past implementations of 3D viewers have often been overwhelmed by the amount of objects that had to be displayed. The result is graphical displays that update very slowly. In some cases, updating time exceeded 10 minutes. One solution to this problem is to display only relevant information on the screen. When an individual object is called, all its attributes become relevant and are shown to the user. When the object is not specifically called, then many of its components may remain hidden. In this case, only the default external parts are displayed. These hidden parts are tagged as internal. For example, the internal parts of a truss do not need to be displayed when a truss is displayed as an assembly in a power plant. However, if the truss itself is selected, the parts of the truss such as the gusset plates and bolts become relevant. Using this scheme, the main members of the truss are labeled as external part, and the gusset plate and bolts are labeled as internal parts. External parts are always displayed, while internal parts are only displayed when the assembly (truss) is selected.

By this approach, all Boolean subtraction features may be considered to be internal features. For example, a hole is an internal feature of a gusset plate with holes drilled into it. Boolean addition is done by juxtaposition of two parts. In this case, a small added feature of a part could be designated as internal feature. The connection plate of the diagonal member of the truss as shown in Figure 1 is a good example of such added components that do not need to be displayed when the truss is viewed. In this manner, the displayed VRML objects are mostly made up of VRML primitive shapes such as parallelepiped prisms, cylinders and spheres.

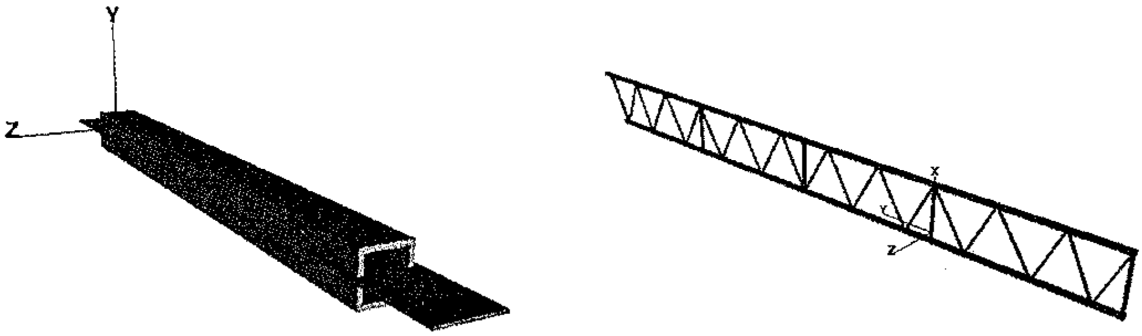

Figure 1. Component with internal parts and assembly showing component without internal parts.

In order to tract components and assemblies, their positions at different time need to be updated. This can be achieved by adding a time stamp to the Axis2_placement3D information. Using the spreadsheet representation for the Axis2_placement3D entity implies that a new page of spreadsheet is added for each time frame. Figure 2 shows the position of a tower and its parts at different time during construction. If the positions of the assemblies are tracked, then a comparison of the current position to the as-built position can aid in the monitoring and visualization of the structure during hazardous conditions or on a continuous basis.

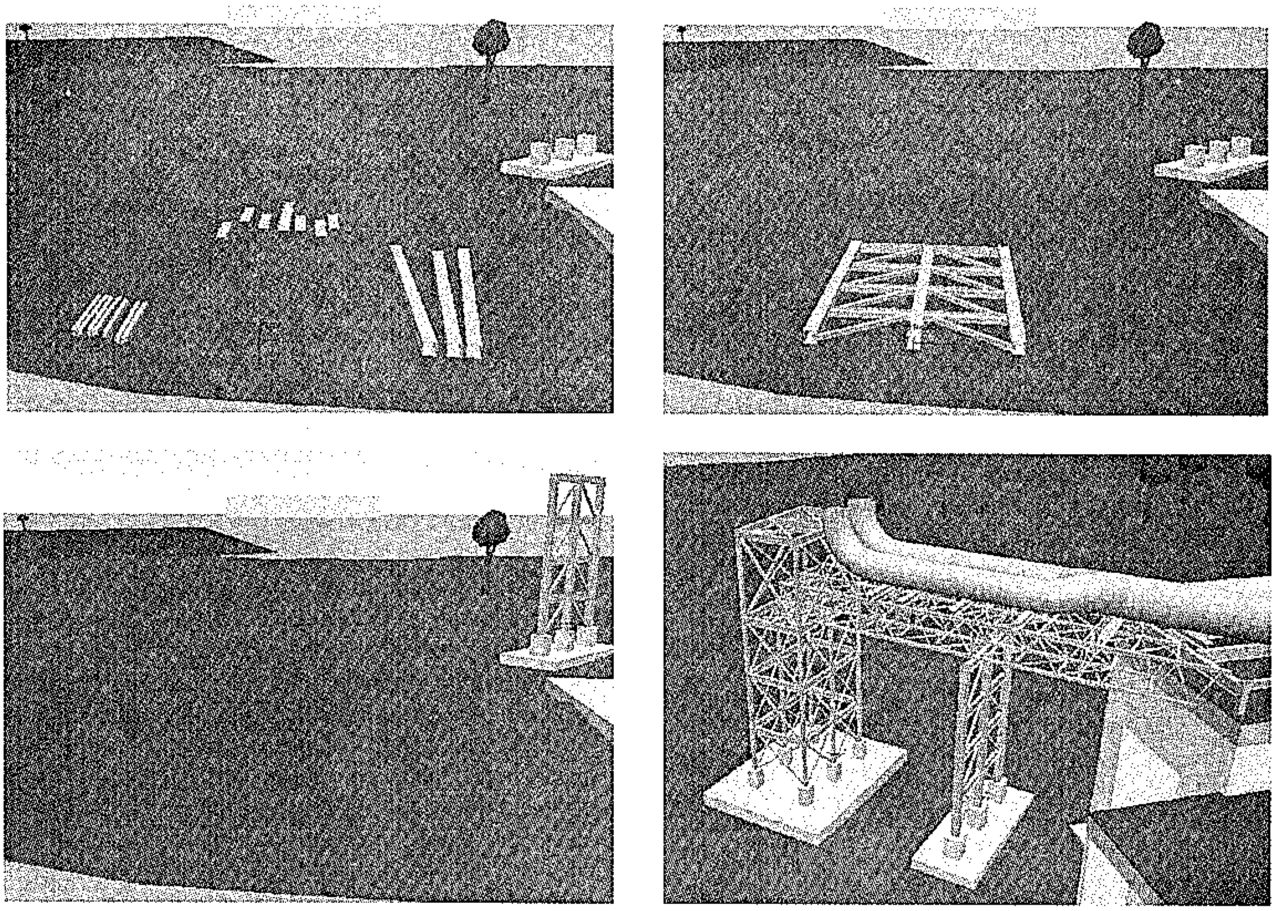

Figure 2. Spatial-temporal representation of components at construction site.

Further increase of efficiency can be achieved by reducing the levels of detail for smaller objects located at a longer distance. A member at a distance can be represented as a line. When the length of the element is also small compared to the distance, the element need not be shown, thereby reducing graphical processing time. This can be done by comparing the largest cross sectional dimension to the distance to the object. If the dimension is less than a predetermined fraction of the distance, then the three-dimensional object can be represented by a line without considerable loss of fidelity. An example of a reduced level of detail for objects far away is shown in Figure 3 below.

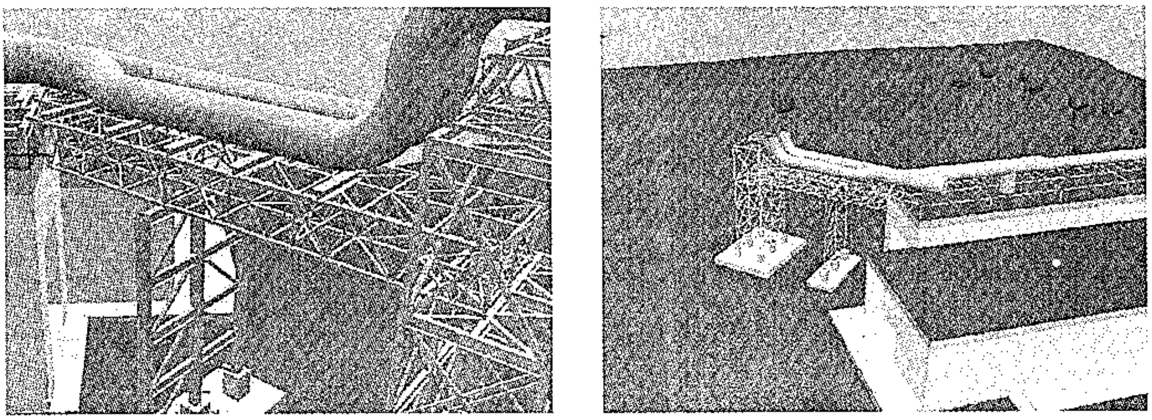

Figure 3. Low level of detail for small objects at a distance.

Summary and Conclusions

A subset of information in the ISO/STEP format for steel structures (CIS2) is written in a spreadsheet format. This information can be used readily to create three-dimensional objects. This format requires the designer to construct the structure virtually. The virtual construction process helps mitigate constructibility problems that usually arise during construction. A spatial-temporal positioning of assemblies and part is used to show stages of construction as the members are assembled. This information database will eventually be used in object tracking during construction and health monitoring after the construction is completed.

By showing only relevant information on the screen, graphics-processing time is reduced to a fraction of a second. Objects with reduced levels of detail can be further simplified when the size is sufficiently small. These two measures reduce the graphics-processing time to such a degree that projects of realistic sizes can be displayed easily by using typical personal computers.

The combination of graphical and spreadsheet information allows users to examine the details of a part, the design loads and level of stress in a member, construction sequence, and part location at any time if the parts are tracked.