# Standard Product Models and Project Databases for Context-Aware Information Access and Retrieval in Construction and Other Engineering Applications

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## Abstract

For the last several years, many research efforts have focused on enabling and advancing information technology to enhance work efficiency and collaboration among field workers by providing mechanisms to deliver pertinent information required for decision-making in a timely manner (Halfawy et al. 2001). Evolving technologies such as location-aware computing and interoperable product models and project databases offer significant potential of improving traditional, time-consuming, manual information retrieval processes, and supporting important decision-making tasks in the field. Field construction tasks such as progress monitoring, inspection and others require access to a wealth of textual and graphical project information. Rapid and convenient access to such project information, through continuous position tracking of mobile users (i.e. engineers, managers, and inspectors) can lead to significant cost and time savings due to the accuracy and immediacy with which relevant project information can be made available to field personnel. This paper describes the results of experiments conducted at the National Institute of Standards and Technology (NIST) to evaluate the capability of interoperable product models and project databases, such as the CIMsteel Integration Standards (CIS/2) product model, for automated context-aware information access and retrieval in construction and other engineering environments.

## 1. Introduction

Collaborative working in construction projects is very important as many activities are usually performed involving participants based in different geographical locations. Recent years have seen the emergence and development of a plethora of visual software modeling tools and modeling standards and methods. Standard product models and databases facilitate the exchanging, sharing and delivery of pertinent construction information, as well as enhance work efficiency and collaborative processes (Aziz et al. 2005). This has been allowing an improved and integrated flow of information among all project participants involved in the construction work.

In this paper, interoperable product models such as the CIMsteel Integration Standards (CIS/2), and project information systems such as MS Access databases have been investigated to study their potential in improving manual information retrieval processes in the field, by automatically and rapidly retrieving contextual information and presenting it to construction site personnel.

## 2. Current State of Knowledge

During the early 1980s, Information Technology (IT) was almost exclusively used to support activities which could be categorized as creation of new information. The use of Computer-Aided Design (CAD) started to proliferate, but still the emphasis was on support for the creation and the viewing of data (Bjork 1999). The support for information retrieval and making information available in the construction industry came in the form of very expensive plotters enabling the plotting of drawings which emulated manually produced drawings. Construction managers, inspectors and other site personnel were mainly occupied with information retrieval and communication with co-workers. In the early years, there was relatively little IT support for retrieval and communication tasks, especially in construction (Aziz et al. 2005).

There has therefore been a need for an effective communications infrastructure that facilitates seamless inter-working between the disparate professionals involved in construction projects (Eastman et al. 2005, Halfawy and Froese 2001). Such an infrastructure needs to be based on interoperable information and communications technologies, and should facilitate information interchange between members of the project team and across stages in the project lifecycle from construction to inspection to maintenance. It has been suggested that the central kernel of this communications infrastructure should be inhabited by a shared construction project model in the form of integrated product models and project databases (Kiviniemi 2005ab, Niemioja 2005).

## 3. Building Information Models

A building product model or building information model is a digital information structure of the objects that make up a building, captured in the form, behavior and relations of the parts and assemblies within this building. Product models can have several pieces of information including CAD drawings, project specifications and schedule, bill of materials, change orders, and other information pertaining to any construction entity of the building (Howard and Bjork 2007 )(Figure 1). The basic idea of a building product model is to facilitate and automate the data transfer between different applications used in different project life cycle stages, from construction to inspection to maintenance (Hakkinen 2007).
In the presented research, the authors evaluated these existing methodologies for their ability to support on-site information access and retrieval. Integrating all construction documents (plans, sections, elevations, schedules, structural details, etc.) within one product model assists in the automated contextual access and retrieval of digital

textual and graphical information. As a mobile user is moving on the jobsite, relevant information on visible and identified entities at a particular instant in time can be retrieved from the underlying product model.

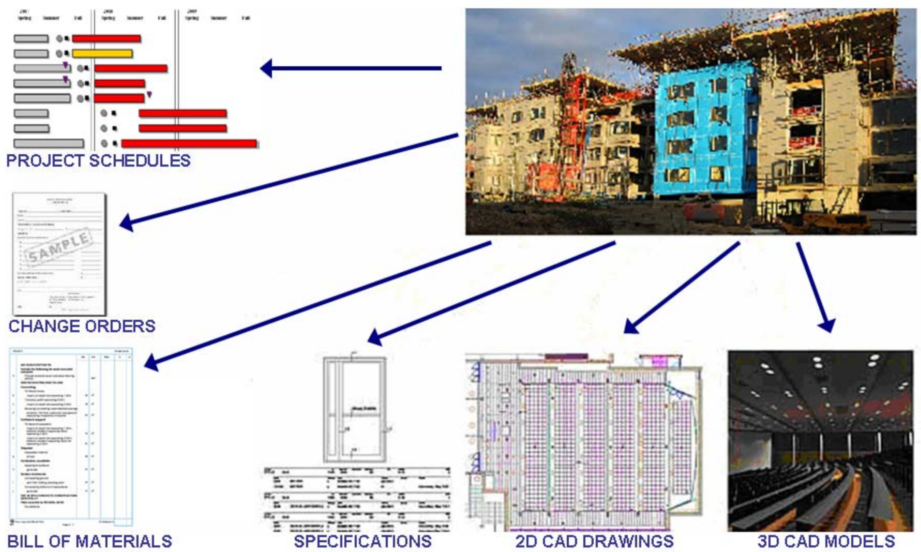


**Figure 1 – Information Contained in Typical Product Models**

### 3.1 CIS/2 Standard Product Models

The CIMsteel Integration Standards Release 2 (CIS/2) is a logical product data model for structural steel building information (Lipman and Reed 2003). It is the result of the pan- European Eureka EU130 CIMsteel Project and has been endorsed by the American Institute of Steel Construction (AISC) as the technical basis for their Electronic Data Interchange initiative (Kamat and Lipman 2006). The objective was to decrease steel construction timelines, eliminate duplication of effort, and enable software applications to exchange data electronically.

CIS/2, also represented by Standard for the Exchange of Product model data (STEP) (ISO 10303:1992, STEP Website 2008), has been implemented by many steel design, analysis, and engineering, fabrication and construction software packages to create a seamless and integrated flow and archival of information among all entities involved in the design and construction of steel framed structures (Reed 2002). The geometry of the structure is only one property of the product data model. Other attributes of the structure include how parts are combined into assemblies and structures, analysis loads and reactions, material types, connection details, associations between members and drawings, and modification history. Therefore, the CIS/2 standard provides data structures for multiple levels of detail ranging from frames and assemblies to nuts and bolts (Figure 2).

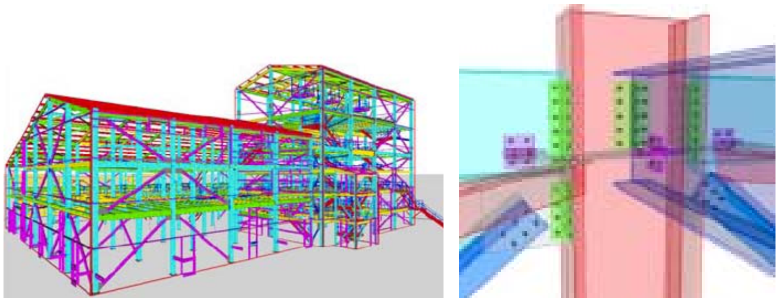

**Figure 2 – CIS/2 Product Model of a Building Structural Frame (Left) and Connection Details with Bolts (right)**
***[Images courtesy of Mr. Robert Lipman, NIST]***

CIS/2 structures can be represented as analysis, design, or manufacturing models. The product data model is defined by a schema that details how all the information in the CIS/2 standard is represented and how each entity relates to each other. It also defines rules for using various entities and the information those entities contain. In addition, any software application can seamlessly have CIS/2 import and/or export capabilities. As a matter of fact, the CIS/2 standard has been demonstrated to be a very effective communication tool and was successfully deployed on a mobile computing at the National Institute of Standards and Technology (NIST) (Saidi et al. 2005). For these reasons, in this research, the utility of the interoperable CIS/2 product model was investigated and is presented as a suitable data structure to represent cross-referenced building data. Figure 3 shows a sample of a CIS/2 file for a part with a location. The file is represented in the standard STEP format (Kamat and Lipman 2006).

```
#43= LOCATED_PART(92,'92','brace',#42,#33,#20);
  #42= (COORD_SYSTEM('','Part CS',$,3)
      COORD_SYSTEM_CARTESIAN_3D(#40)COORD_SYSTEM_CHILD(#18));
    #40= AXIS2_PLACEMENT_3D('Part axes',#34,#38,#36);
      #34= CARTESIAN_POINT('Part origin',(0.,0.,0.));
      #38= DIRECTION('Part z-axis',(0.,0.,1.));
      #36= DIRECTION('Part x-axis',(1.,0.,0.));
    #18= COORD_SYSTEM_CARTESIAN_3D('','Assembly CS',$,3,#17);
      #17= AXIS2_PLACEMENT_3D('Assembly axes ',#11,#15,#13);
        #11= CARTESIAN_POINT('Assembly origin ',(720.,540.,120.));
        #15= DIRECTION('Assembly z-axis ',(-0.37139068,0.,0.92847669));
        #13= DIRECTION('Assembly x-axis ',(0.92847669,0.,0.37139068));
  #33= (PART(.UNDEFINED.,$)PART_PRISMATIC()PART_PRISMATIC_SIMPLE(#21,#26,$,$)
      STRUCTURAL_FRAME_ITEM(92,'92','brace')STRUCTURAL_FRAME_PRODUCT($)
      STRUCTURAL_FRAME_PRODUCT_WITH_MATERIAL(#27,$,$));
    #21= SECTION_PROFILE(1,'W14X158',$,$,5,.T.);
    #26= POSITIVE_LENGTH_MEASURE_WITH_UNIT
        (POSITIVE_LENGTH_MEASURE(258.48791),#3);
      #3= (CONTEXT_DEPENDENT_UNIT('INCH')LENGTH_UNIT()NAMED_UNIT(#1));
        #1= DIMENSIONAL_EXPONENTS(1.,0.,0.,0.,0.,0.,0.);
    #27= MATERIAL(1,'GRADE50',$);
  #20= LOCATED_ASSEMBLY(92,'92','brace',#18,$,#19,#10);
    #18= COORD_SYSTEM_CARTESIAN_3D('','Assembly Coordinate System',$,3,#17);
      #17= AXIS2_PLACEMENT_3D('Assembly axes ',#11,#15,#13);
        #11= CARTESIAN_POINT('Assembly origin ',(720.,540.,120.));
        #15= DIRECTION('Assembly z-axis ',(-0.37139068,0.,0.92847669));
        #13= DIRECTION('Assembly x-axis ',(0.92847669,0.,0.37139068));
    #19= ASSEMBLY_MANUFACTURING(92,'92','brace',$,$,$,$,$,$,$);
    #10= STRUCTURE(1,'cis_2','Unknown');
```

**Figure 3 – Located Part in a CIS/2 File**

### 3.2 Outdoor Experiments at the Steel Structure at NIST

Experiments were conducted at the National Institute of Standards and Technology (NIST), specifically at the steel structure on the main campus (Figure 4). The goal of the experiments was to simulate a mobile user such as a construction engineer or inspector surveying the structure, and evaluate whether different objects (e.g. steel columns) can be automatically identified based on the user's spatial context (Khoury and Kamat 2008), and whether the identified contextual parameters can be used to retrieve relevant information from CIS/2 product models.

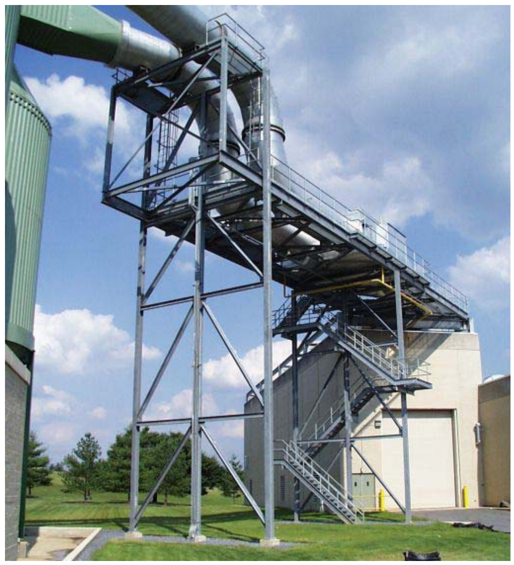

**Figure 4 – Steel Structure on NIST Main Campus**

In this case, four Ultra Wide Band (UWB) receivers were deployed around the area of the steel structure as shown in Figure 5, and one UWB tag and the orientation tracker were mounted on the mobile user who was navigating around the steel structure. As described in (Khoury and Kamat 2008), the user's position and orientation were continuously obtained from the UWB system and magnetic tracker.

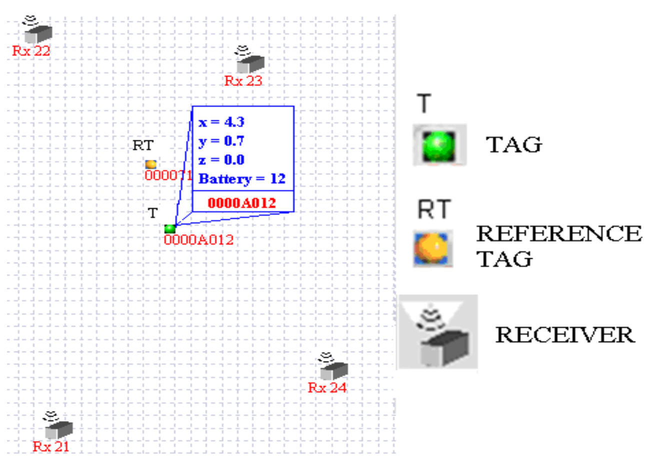


**Figure 5 – Deployment of UWB Receivers around the Steel Structure (NIST)**

One major step in these experiments consisted of using the NIST CIS/2 to Virtual Reality Modeling Language (VRML) translator (Lipman 2002) to convert CIS/2 files to their corresponding VRML (Virtual Reality Modeling Language) representation. The intermediate conversion of CIS/2 files to VRML was adopted for the following reasons (Kamat and Lipman 2006). First, the VRML translator provides a visual interface to the underlying CIS/2 data thereby providing a means to visualize the represented steel structure in a 3D virtual world. Second, implementing a VRML file parser that can traverse the described scene graph to extract member information is relatively straightforward compared to the implementation of a full-fledged CIS/2 file parser. Thus, the parsing and interpretation of CIS/2 information contained in a converted VRML file, yield information for each steel member contained in the represented structural steel frame, including but not limited to the name and the geometry of each member. Figure 7 shows how contextual information on identified specific steel members was automatically retrieved from the converted CIS/2 model (Figure 6).

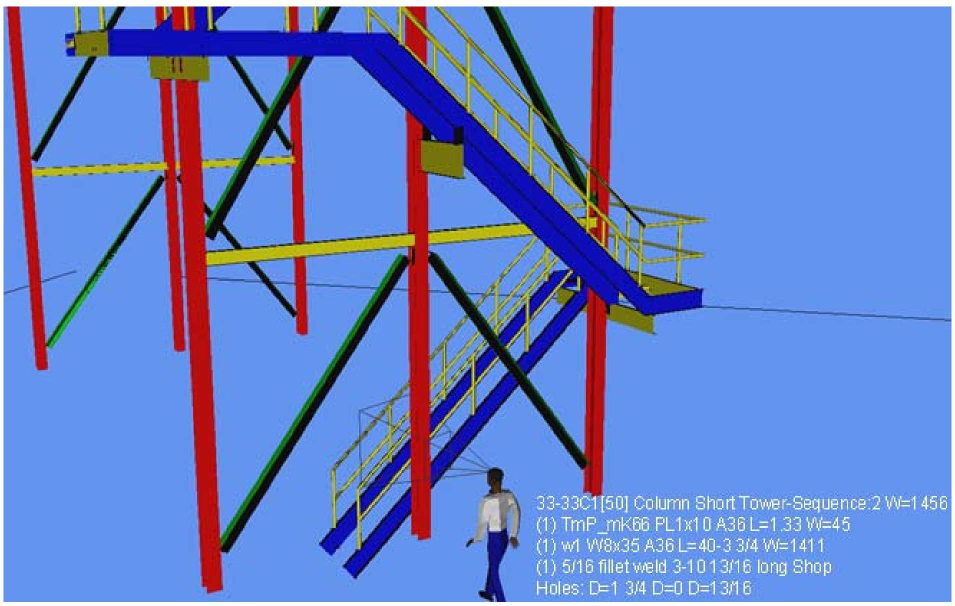


**Figure 6 – Snapshot of Contextual Information Retrieval and Visualization of Identified Steel Elements**

## 4. DBMS based Project Databases

A database is a well organized collection of information. A DBMS (database management system) such as Microsoft Access gives the software tools needed to manage data in a flexible manner. It includes various features which help to add, modify or delete information or data from the database. One of the most important features of a DBMS is asking questions or queries about the information stored in the database and generating reports or forms analyzing selected content. Microsoft Access, in particular, provides users with simple and highly flexible DBMS solutions in the online database market today, mainly in terms of compatibility and sharing (New York Times Company 2008). Additionally, MS Access, installed as part of the

Microsoft Office suite, is considered cheaper than other databases such as the Structured Query Language (SQL) server which is quite expensive (Harkins et al. 1999). In addition, MS Access uses standards that enable applications to work in large and harsh environments (DatabaseDev Website 2008). Therefore it constitutes a good means for storing large volumes of information which needs to be held for a long time and retrieved flexibly using varying criteria and sometimes in formal reports. It allows the user to store, retrieve, sort, analyze and print information stored in the database. It also allows defining input screens, and adding cross-referencing to make sure that data is internally consistent. Additionally, MS Access is feasible if multiple users, and especially non-technical users, will use the system, and will need to update the contents of the data store at one time.

For all the above reasons, Microsoft Access was considered as an option for demonstrating information retrieval capabilities developed in this research for use in Architecture, Engineering and Construction (AEC) applications. A validation experiment was conducted at NIST, specifically in the maze at the former NIKE missile base barracks building adjacent to the main campus (Figure 7). Four Indoor GPS transmitters were deployed inside and around the area of the maze (Figure 8) and one receiver and the orientation tracker were mounted on the mobile user who was navigating inside the maze.

**Figure 7 – Maze at Nike Site (NIST)**

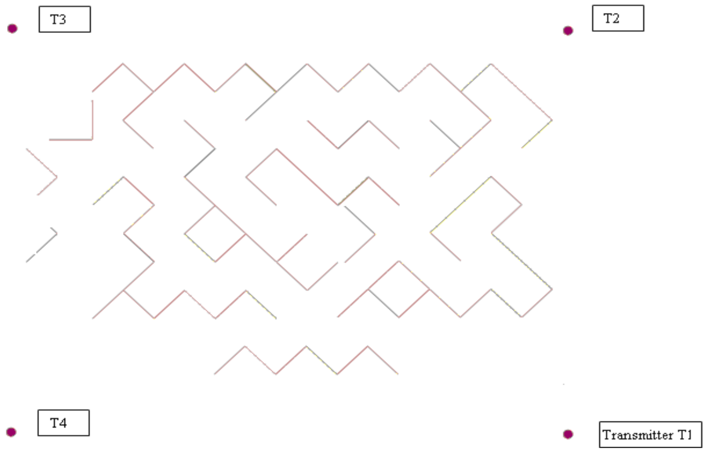


**Figure 8 – Deployment of Laser Transmitters around the Maze**

Having identified specific building components in the user's field of view, contextual information was then automatically retrieved from project databases. For instance, project database programs have the ability to search for any record a user needs and manipulate the data in many different ways. These are accomplished by creating a query**.** Most users rely on queries because they only need a certain group of records at any one time. Once tables have been established inside of a database, a user can develop a query to select a group of fields from those tables, select only records that adhere to a specific set of criteria, and retrieve those records. In this case study, the MS Access database used included all the details (textual and graphical) pertaining to the structural elements located inside the maze. Figure 9 is the textual table created in the database. It contains information about columns located inside (C1 and C2) and around the maze.

| Object | Material | Type | Scheduled | Completed |
|---|---|---|---|---|
| C1 | Concrete | Column | 09/16/2008 | 09/10/2008 |
| C2 | Steel | Column | 09/16/2008 | 09/10/2008 |
| C3 | Concrete | Column | 09/10/2008 | 09/02/2008 |
| C4 | Concrete | Column | 09/10/2008 | 09/02/2008 |

**Figure 9 – Maze MS Access Database Table**

A prior step to querying the database included defining the connection string, displaying the data source name, and connecting to the database, as shown below:

```
connection = new OleDbConnection();
connection->set_ConnectionString("Provider=Microsoft.Jet.OLEDB.4.0;"
"Data Source=.\\data\\db4.mdb;" "Persist Security Info=False");
connection->Open();
```

A query was then developed to retrieve information about specific columns identified to be in the user's field of view. The query was built and executed by attributing the *object ID* in the SQL *SELECT* statement to the identified column string variable *struct_elem*. A record set was then created as an instance of the *OleDbDataReader* class, data retrieved and displayed, and all handles closed:

```
OleDbCommand* command;
command = new OleDbCommand();
command->Connection = connection;
command->CommandText =
"SELECT Material, Type, Scheduled,Completed,Location FROM dbo_asset
where Object=struct_elem";
```

Figure 10 and Figure 11 represent snapshots of both textual and graphical contextual information retrieval. Figure 10 shows the textual information retrieved (i.e. material, type, scheduled and completion dates) after a specific column has been detected as visible to the mobile user navigating inside the maze. Then the user was prompted whether or not to accept retrieving graphical information about the same identified column (Figure 10) and upon acceptance, graphical information was retrieved (Figure 11).


**Figure 10 – Snapshots of Textual Information Retrieval**

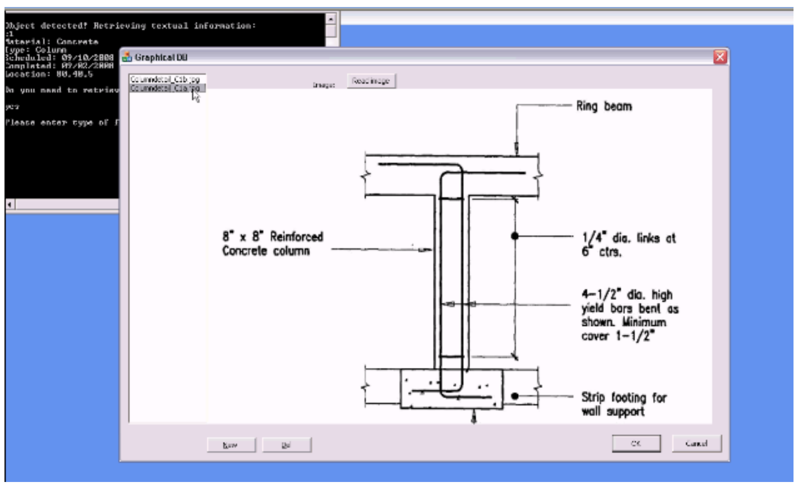


**Figure 11 – Snapshot of Graphical Information Retrieval**

## 5. Conclusions

The objective of this paper was to explore the means for directly comparing relevant design and construction data in product models and project databases with the construction entities identified to be in a user's field of view at a given time instant, and retrieving contextual information. The authors have successfully evaluated two types of project databases, namely CIS/2 product models and MS Access databases to retrieve contextual information about identified objects in users' field of view. In order to demonstrate the feasibility of the adopted project databases, and their applicability in a context-aware information delivery framework, experiments were conducted at NIST indoors, in the maze at the NIKE site, and outdoors at the steel structure on the main campus. The results of the experiments demonstrated how contextual information from project databases can be readily retrieved in real-time, thereby saving time and improving work productivity in harsh dynamic environments such as those found on construction sites.

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