INTEGRATION OF BRIDGE MODEL DATA AND ENGINEERING DOCUMENT INFORMATION

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ABSTRACT

This study provides a method for the integration of a 3D bridge model and document fragments. Since the document contents can change as the corresponding engineering process changes, this study adopts a loosely coupling concept for supporting independence of each information set rather than proposing a specific data model in integration. As a core technique for the integration, this study used an enhanced document analysis technique. The technique provides a generic method extracting document hierarchy and generating XML-based semi-structured document information. In addition, an extended IFC-based bridge data model was adopted in order to manipulate the 3D model information of bridge. As a validation example, retrieval of document fragments on the specific component in the 3D bridge model was performed.

Keywords: bridge, semi-structured document information, Industry Foundation Classes (IFC), bridge information modeling, integrated information operation

1. INTRODUCTION

The Computer-Integrated Manufacturing (CIM) based on a common CAD database had affected to the establishment of the concept of Computer-Integrated Construction (CIC) (Sanvido and Medeiros, 1990; Wright, 1988). Concurrently, the academic research community developed several integrated models such as the Architecture, Engineering and Construction (AEC) Building System Model (Turner, 1988), Generic AEC Reference Model (GARM) (Gielingh, 1988). Although these information models have not been implemented in commercial software, the concept of the centralized common CAD model has been highlighted in this research field. For example, Tatum (1990) emphasized the role of 3D CAD systems in promoting efficiency of communication among all construction project participants. Teicholz and Fischer (1994)confirmed the 3D CAD models were more efficient than the 2D drawings. They asserted that the 3D-based and object-oriented information model could facilitate the update of all the data used downstream when the design is changed during the course of a structural project.

Later, the CIMsteel integration standard (CIS) specification (Crowley and Watson, 2000) and the Industry Foundation Classes (IFC) of buildingSMART (previously the International Alliance for Interoperability) have been practically deployed for the AEC industry as open standards. The Building Information Modeling (BIM), which is actively evolving in the AEC industry, can be seen as a specialized application field of 3D model based integration. A standardized information model in the BIM is critical for sustaining interoperability. The IFC developed by buildingSMART is becoming a *de facto* and *de jure* standard supported by commercial BIM software. However, most construction elements provided in the IFC are related to buildings rather than the other civil infrastructures including bridges, roads, and tunnels.

In the other side, Boddy *et al.* (2007) illustrated well-organized literature reviews on process-centric approach for the CIC. The process approach aims to adopt the advanced IT concepts for operation of distributed computing environment. Examples shown in the reference (Boddy *et al.*, 2007) are summarized herein. Liu *et al.* (2003) proposed a distributed computing environment for multiple collaboration services based on ontologies. Aziz *et al.* (2003) selected the use of web services to extend computing environment to the construction site workers. Grilo *et al.* (2005) proposed a process oriented services based on the Model Driven Architecture (MDA) of the Object Management Group (OMG) and suggested employing the Service Oriented Architecture (SOA) in the implementation of applications for a platform independent representation. Boddy *et al.* (2007) asserted that the process centric integration could offer great potential for improving the end user's experience of the CIC. However, the examples shown in mentioned above are also based on structured information sets for information processing. Unfortunately, most of the information generated and managed in engineering practice of the construction industry still remains in the form of unstructured document files, and no research efforts have shown how the process records in the engineering document and product model data can be linked together. This study, thus, employ a document analysis technique to build a semi-structured information set of the unstructured engineering document, and demonstrates how the different information sets can be linked. Especially, this study focused on the structural calculation document as a representative engineering document.

2. BASIC CONCEPT FOR INTEGRATION

The ISO 12006-2 describes that 'Construction Result' are results of 'Construction Process' carried out during the lifecycle of the construction entity. Lee *et al.* (2006) denoted that the product information can be categorized into "information that directly represent products and information that qualifies products". If we project these concepts on the bridge, then the information set of a bridge can be defined as follows:

$$BI = \bigcup \{L, U, RL\} \tag{1}$$

Where *BI* is an information set manipulated during the lifetime of bridge; *L* represents a set of information that directly indicate bridge and its components; *U* is a set of the qualifiers that describe ; and denotes a set of relations among information objects. More specifically, *U* can be categorized as follows:

$$U = \bigcup \{E, A, P\} \tag{2}$$

where *E* is a set of environmental information; is a set of the activity information; and represents a set of the physical body information of a bridge. The detail descriptions and exemplary information items of *E*, *A*, and *P* are listed in Table 1.

There are various information sets according to documentation of bridge information in practice. For example, structural calculation document (SCD) explicitly describes how engineers analyze the structural behavior of a bridge with design codes and conditions. The determined geometric information based on the structural analysis is also presented in the SCD but limited to critical sections of bridge members while the 3D model focuses on detail geometric shapes of all bridge elements. Let be the information sets *M* and *D* of 3D CAD model and SCD, then *M* and *D* can be expressed as follows based on the equation (3) and (4):

$$M = \bigcup \{L, E_m, A_m, P_m, RL_m\} \tag{3}$$

$$D = \bigcup \{L, E_d, A_d, P_d, RL_d\} \tag{4}$$

where *m* and *d* indicate the domain of the information set.

Table 1: Descriptions and examples of modifiers

Category	Description	Example
Environmental information	environmental conditions or constraints that are generally given by natural conditions and performance requirements	wind velocity, geological features, peak ground acceleration, water velocity, budget, etc.
Activity information	information that is manipulated in lifetime activities conducted for multiple purposes (environmental information and physical body information are excluded)	design codes like load factors and limit states of bridge members, structural analysis results (i.e. moments, shear and axial forces), condition states of bridge members, etc.
Physical body information	geometry and material information describing physical elements of the bridge	locations, lengths, strengths of materials, sectional dimensions and properties, etc.

Figure 1 shows a conceptual method for integrated operation of the two different information sets *M* and *D*. The intersection of *M* and *D* shown with an inner dotted box of Figure 1 represents a bridge and its components; that is *L* for bridge. Suppose that *e*1 in the two different sets E_m and E_d is design wind velocity at bridge location, then the *e*1 can be mapped on the whole bridge level. In another case, if *p*2 in the sets p_m and p_d represents material properties of specific bridge members, then the can be mapped at the bridge member level. In this manner, the information items can be mapped to the proper level of bridge components, and the bridge components can be a start point to access the other information items.

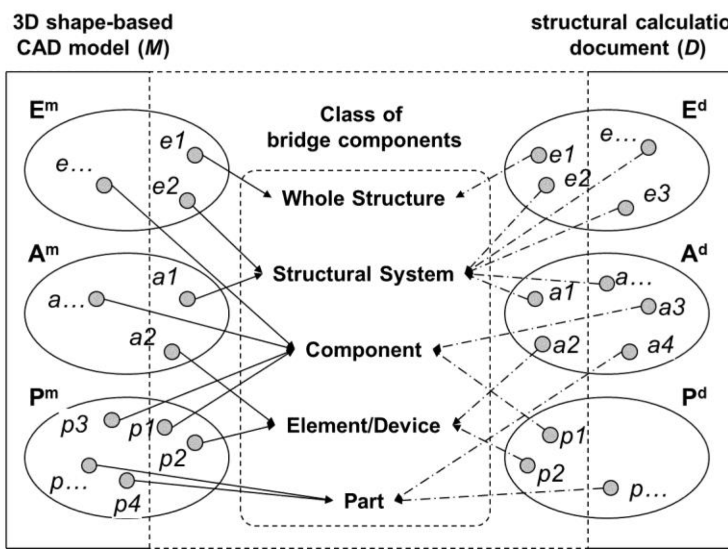


Figure 1: A concept for integration of a 3D bridge model and SCD

3. DOCUMENT ANALYSIS AND TRANSFORMATION TO SEMI-STRUCTURED FORMAT

This study uses a document saved as a text file as input file to eliminate error that occurs when recognizing letters from visualized documents. Figure 2 represents the entire process of creating semi-structured Extensible Markup Language (XML) document from a text document (Lee *et al.*, 2011). As shown in Figure 2, entered text file is transformed into XML document according to structure of subtitle by three main steps. The first step is to save each string of the text file, in sequence, by classifying strings for heading symbol group, heading symbol, subtitle, content and reference into a temporary table according to the content model of engineering document. The temporary table is rearranged after identifying the structure of sentence by using characteristics of information saved in the temporary table, and by using the information for heading symbol of the rearranged temporary table each subtitle is given hierarchical information located in the tree structure of the document. Lastly, XML file is created by using information saved in the temporary table and hierarchical information. Content analyzing and modeling method of document information are further explained in Kim *et al.* (2010).

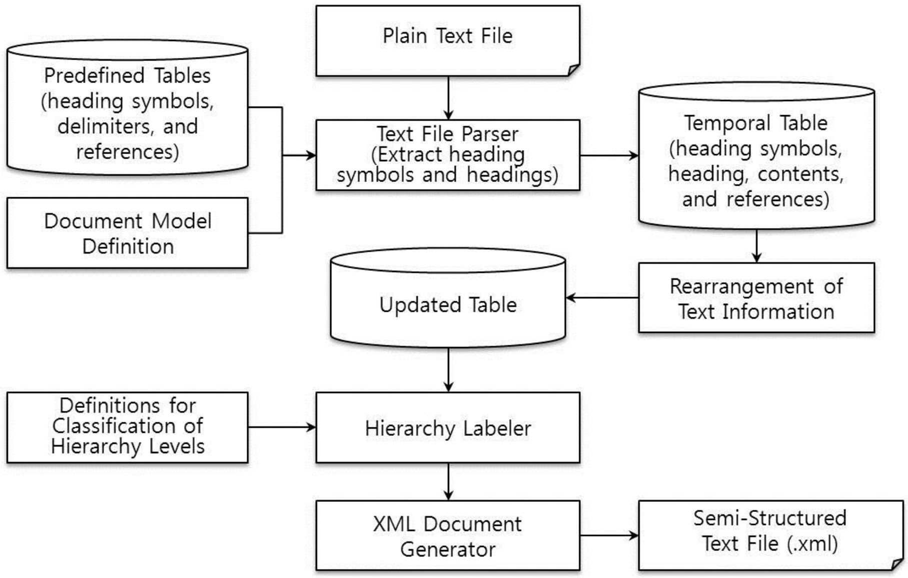


Figure 2: Document transformation process for the text information

4. ENHANCEMENT OF IFC-BASED BRIDGE DATA MODEL

Several efforts have been conducted for development of IFC-based bridge data model. Yabuki and Shitani (2003) have used IFC for representing 3D shape together with the other information objects for construction project. The French chapter of building SMART has driven development of the IFC-based bridge data model as an IFC extension project (Lebegue, 2005). However, the IFC-based bride data model has to clarify following issues:

1) How the bridge span and lanes can be identified as spatial elements while they are major spatial factors concerned in bridge lifecycle;
2) The specific definitions on substructure elements (e.g., pier, abutment, and pylon) because the data model defines them as spatial elements while ISO 6707-1 (ISO-TC59/SC2, 2004) classifies them into physical elements;
3) How can we identify common road elements (e.g., pavement, barrier, and curb), which are installed in typical roadway network including bridge;

In order to solve above issues, Lee and Kim (2011) proposed an enhanced bridge data model. They employed the IFC to develop a bridge data model because it provides well organized kernel and contains rich information objects used in the construction industry as aforementioned. This study used the results of Lee and Kim (2011) research for integrating document model information.

5. IFC-BASED BRIDGE MODELING AND DOCUMENT RETRIEVAL

A complex type of bridge system was selected as a sample bridge to validate the IFC bridge model and integration approach. The objective for the construction project of sample bridge was to widen lanes of the existing bridge.

2D drawings and structural calculation documents of the sample bridge were provided by an engineering company, Dasan consultants Co., Ltd.. According to the objective of the construction project, the drawings and SCDs mostly illustrate the new bridge section. The total number of SCD provided for the sample bridge was 24:4 for superstructures of each sub-bridge, 2 for abutments, and 18 for the new piers. Detail information on the shape of girder and other parts were available only for the new bridge section. Thus, this study also focused on the new bridge section in bridge modeling and validation.

5.1 A 3D model of the sample bridge

5.1.1 Architecture of the modeling tool

This study adopted the AutoCAD platform for developing a prototype of an information modeling tool because AutoCAD is one of the major CAD tools widely used in the construction industry. The methodology for developing the modeling tool can be found in the references (Lee *et al.*, 2005), and the basic architecture of the modeling tool is briefly introduced, herein.

Figure 3 shows the architecture of the modeling tool. The application modules based on the AutoCAD program shown in Figure 3 are composed of a Built-in System Database, a Built-in System Function, an Expanded System Database, and an Expanded System Functions. The Built-in System Database is a part of saving and managing AutoCAD objects such as point, line, surface and solid, layer, color etc. This study makes the application module that visually provides the geometric shape of steel bridges by generating a solid model using the Built-in System Functions provided in Object ARX API and registering a solid model in the Built-in System Database. The Built-in System Functions are all commands provided in AutoCAD such as creation of point, line, surface, and text. This study used a line object to model the shape of bridge structures before automatically generating a three-dimensional solid model to apply cross sectional properties.

The Expanded System Database corresponds to the local database of the application module as a part supporting programming interfaces for manipulating information according to the IFC based information model of the bridge in AutoCAD. In order to build the Expanded System Database, ST-Developer, which is provided by STEP Tools Inc., was used. Since the C++ classes define attributes of an EXPRESS entity as data fields of object-oriented techniques and include methods or functions for getting or setting attribute values, bridge information generated into C++ classes can be manipulated and operated in AutoCAD.

Finally, the Expanded System Function is a part of the user interface developed to execute newly defined functions such as creation of project information, assignment of cross section property and connection design, in AutoCAD. This user interface has been developed using various programming classes supported by .NET framework. This study used Object ARX development environment to communicate with AutoCAD and to integrate those four parts. Object ARX development environment consists of an object-oriented programming interface including a programming library with classes corresponding to AutoCAD system components. The programming interface enables developers of application modules to expand AutoCAD functions to satisfy the end-user requirements. The application modules developed in the Object ARX programming environment are executed in the same manner as in existing AutoCAD commands. End-users can use the application modules for manipulating information in the same manner as they would use existing AutoCAD commands.

5.1.2 Bridge modeling

A 3D model of the sample bridge was built by using the prototype of bridge modeling tool described in section 5.1.1 The names for the 3D objects in the model were referred to design drawings and structural calculation documents. Figure 4 and Figure 5 illustrate examples of spatial components of the sample bridge. Figure 4 depicts a sub-bridge system of the sample bridge. The IFC bridge V2 R7 (Arthaud and Lebegue, 2007) can also represent the relationship among partial type, unit type and complex type. However, as shown in Figure 5, the proposed IFC bridge model can further divide the bridge by span. As shown in the hierarchy of physical elements, the segments contain several parts such as flanges, ribs, and webs that are defined by *Ifc Bridge Element Part* proposed in research of Lee and Kim (2011).

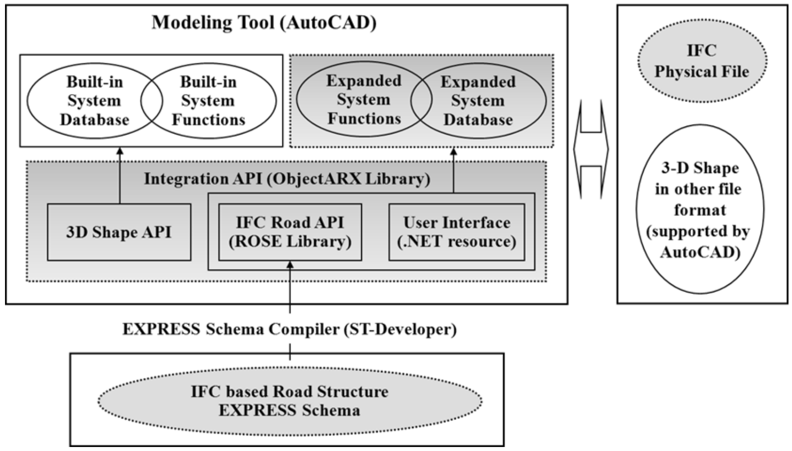


Figure 3: Components of 3D bridge modeling tool

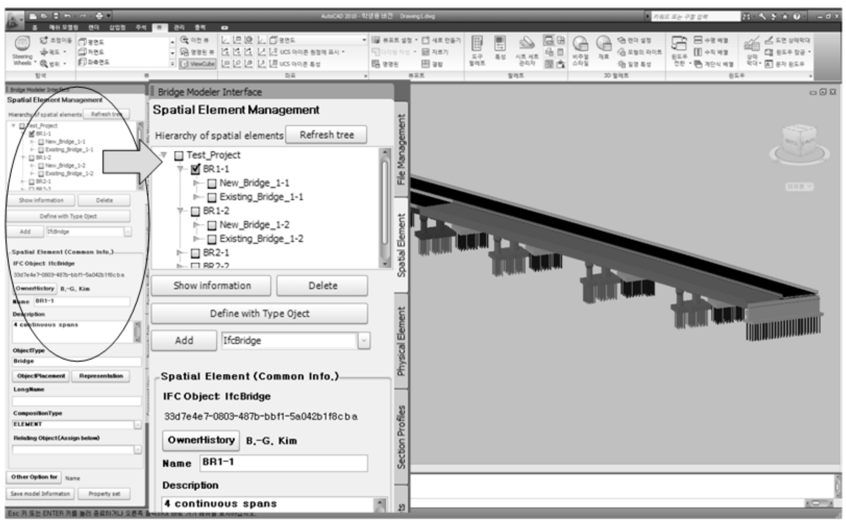


Figure 4: Elements in sub-bridge of the sample bridge

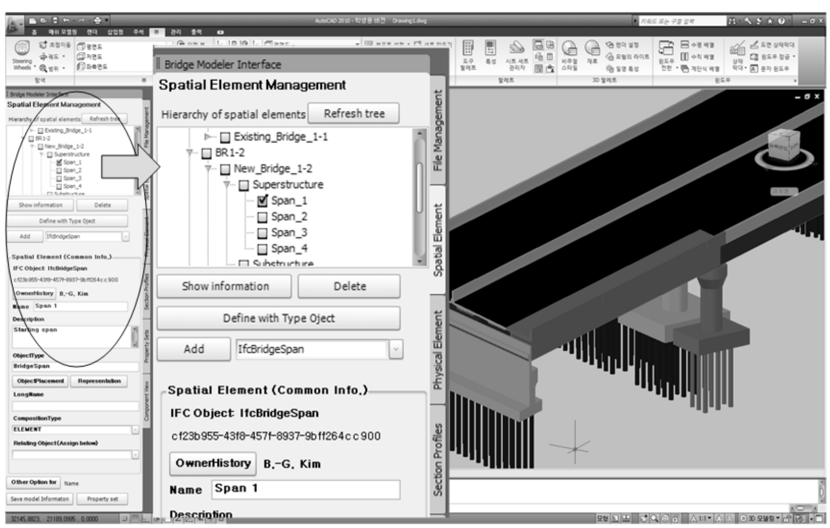


Figure 5: Elements in the first span of sample bridge section

5.2 Retrievals of document fragments

5.2.1 Query process for document retrieval from semi-structured documents

This study directly uses semi-structured documents that are generated by using developed module described in chapter 3. Names of tags of XML elements and text information (PCDATA of XML element) are used to match a specific component in a 3D bridge model to the corresponding document fragments. Figure 6 shows the application modules that were implemented to extract document fragments from semi-structured documents, and Figure 7 illustrates a query process that runs in the 'Query module For Model2Doc' shown in Figure 6.

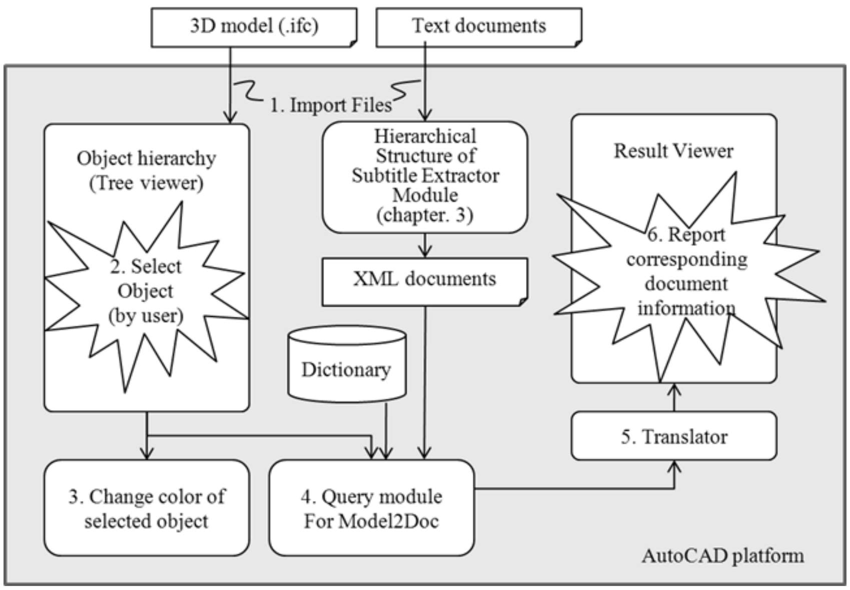


Figure 6: Embedded modules for retrieval of document fragments from the semi-structured document in a 3D model view

This study used the subsystem name as the document name of each superstructure. For the component of substructure, names of piers and abutments were used for each document. The unit of each document file was not intentionally reorganized for matching 3D model and document fragment.

5.2.2 Example of document retrievals

Figure 8 illustrates an example of 'Segment 1' whose profile type is 'Section 1'. With respect to the 'Segment 1', 3 of the element nodes were retrieved in the node name and 5 of text nodes contained the 'Section 1'. Figure 9 shows the document contents of retrieved nodes: sectional properties (Figure 9(a)) and member forces (Figure 9(b)) at the 'Section 1'. All of the retrieved nodes were contained in a structural calculation document because the document name could be matched to the name of the bridge.

The example shows that a 3D model and semi-structured documents can be operated together by using the integration approach proposed in this study. Especially, document files were not intentionally reorganized but used as they were generated in bridge design practice. In addition, the names of sub-bridges and components could be used to map to information objects in different information sets. The same names for subsystems and bridge components are generally used in bridge design drawings and documents. Consequently, it is believed that the described method can facilitate the construction of an integrated information environment for a 3D bridge model and structural calculation documents.

Two major limitations can be discussed. The translated documents for providing document fragments are semi-structured. That is the computer cannot recognize the specific meaning of data in the document. In order to overcome this limitation, the physical level of document schema can be used. As another drawback, the developed module cannot process the figures and shape of tables. Text information of tables, however, could be handled with a specific element node in a semi-structured document. This illustrates that figures and tables can be correctly provided with subtitles. This limitation can be overcome by using application programming interfaces (APIs) provided by the software development companies.

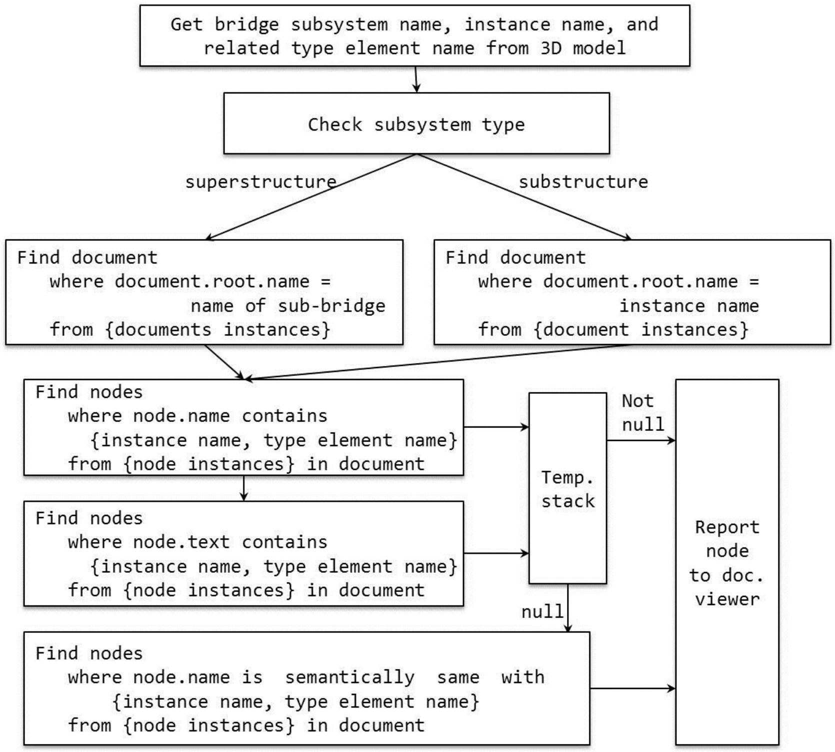


Figure 7: Query process for extracting specific nodes from the semi-structured document in a 3D model view

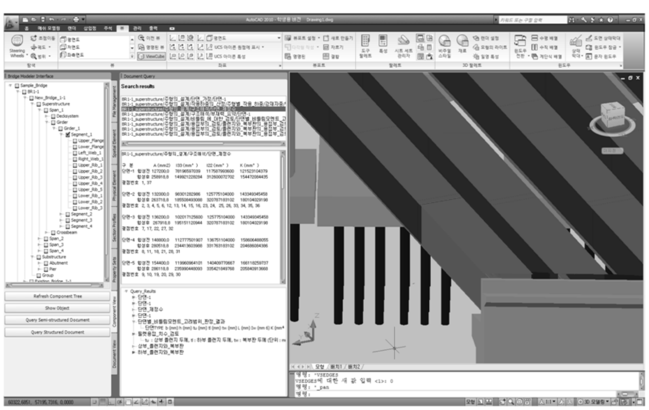
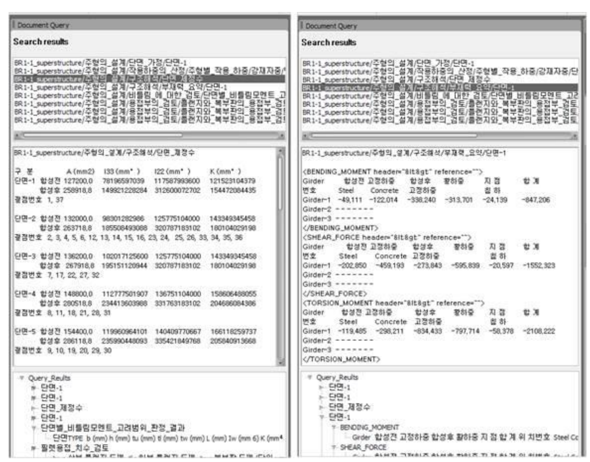


Figure 8: Example of doc. retrieval for Segment 1



(a) sectional properties (b) member forces

Figure 9: Contents of the retrieved document fragments for Segment 1

6. CONCLUSIONS

An idealized and integrated product data model may include most records manipulated in engineering processes because the process analysis is a starting point for the development of the product data model. However, so far, no product data model that can describe all engineering records has been developed. In contrast, an engineering document contains various records manipulated in the engineering process, which are seldom included in the product data model. This study focused on the document information to build an integrated information environment for the construction industry. Although the scope for engineering documents was limited to the structural calculation document of steel box girder bridge in this study, most developed definitions for structuring document information are expected to be used for the other types of the bridge and other engineering documents such as bridge inspection and assessment reports, hydraulic calculation records, and geological survey reports.

A major scientific contribution of this study is that a novel approach has been proposed for building an integrated information environment for a 3D bridge model and engineering document through direct structuring of the document information. A user interface and a query algorithm for retrieval of document fragments were implemented as embedded modules in the 3D modeling tool. The example of document retrieval on major members and segments have shown that document fragments on the specific object in a 3D model can be found in a 3D model view. This complementary information in engineering document can be provided to users in a 3D model view. The developed techniques for integration of a 3D bridge model and structured engineering document were tested in a limited environment of information resources.

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