Bridge Information Model Based on IFC Standards and Web Content Providing System for Supporting an Inspection Process

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Abstract:

Recently, ICT technology has been used to maintain civil engineering structures, such as bridges and dams, in order to increase the efficiency of the maintenance process. To support the inspection processes, the data model that has the information of design (Computer-Aided Design, CAD data) and inspection (measured data) is very important. Moreover, the data should be archived for a long time (more than 50 years) because of the long lifecycle of bridges.

Bridge life cycle management aims to perform the management functionalities related to bridges from the conceptual stage to the end of their useful life, through the design, construction, operation, and maintenance stages. Degradation data obtained by bridge inspections have to be retained stably for a long time. Hammad et al. discussed the requirements for developing a mobile model-based bridge life cycle management system. A prototype system based on the Building Information Model (BIM) standards, the Industry Foundation Class (IFC), was also developed. However, the system did not contain measured data and degradation data. Aruga et al. proposed the degradation model based on the IFC; however, the model still did not contain measured data. So far, there is no suitable data model for retaining degradation data together with measured data.

In this report, the information model for supporting the bridge inspection process is proposed. This model is based on the IFC and satisfies the requirements of inspection processes.

The bridge inspection information model for retaining several kinds of degradation data and inspection data is proposed. A web content providing system is also proposed to observe degradation data in the outside field of bridge inspection.

Keywords: bridge information model, bridge inspection, IFC Standard, Civil (Construction) Information Modeling, web content providing, geometric modeling.

1. INTRODUCTION

Recently, ICT technology has been used to support the product lifecycle of civil engineering structures, such as bridges and dams, in order to increase the efficiency of the supporting process. One of the key technologies in the Architecture, Engineering, and Construction (AEC) industry is Building Information Modeling (BIM). BIM is an intelligent process for product visualization, automatic fabrication/shop drawing, cost and material procurement, construction sequencing, conflict or collision detection, forensic analysis and facility management (Azhar et al., 2012). Rapid advances in BIM offer new opportunities to improve efficiency and effectiveness of the construction process and enhance the use of emerging technology throughout a project's lifecycle, not only in buildings, but also in infrastructures (Shou et al., 2015).

Bridge life cycle management aims to perform the management functionalities related to bridges from the conceptual stage to the end of their useful life, through the design, construction, operation, and maintenance stages (Hammad et al., 2006). To support the inspection and maintenance processes, the data model that has the information of design (Computer-Aided Design, CAD data) and measured data is very important. Moreover, these data should be archived for a long time (more than 50 years) because of the long life cycle of bridges.

In this paper, the information model for bridge maintenance is proposed. This model is based on the BIM standard to support the long life of the bridge and satisfies the requirements of maintenance processes. A web content providing system is also proposed in order to show the model in the outside field of maintenance.
The structure of this paper is as follows. In Section 2, related works about BIM for bridges are explained. In Section 3, the product life cycle of a bridge and information requirements for supporting the product life cycle are explained. In order to satisfy the information requirements, the information model for bridge maintenance is based on the Industry Foundation Class (IFC) model (ISO, 2013) adopted by the International Organization for Standardization (ISO). In Section 4, the structure of the IFC and IFC-Bridge (Lebegue et al., 2013), which is the extension for supporting the bridge, is explained. In Section 5, the proposed structure of the IFC-Bridge extension is explained. In Section 6, the web content providing system for bridge inspection and maintenance is explained. In Section 7, some conclusions are explained.

2. RELATED WORKS

The IFC (ISO, 2013) is a specific data format written using the EXPRESS data definition language, defined as ISO10303-11 (ISO, 2004) by the ISO TC184/SC4, and has been used to exchange data between applications in the AEC industries. The IFC is supported by many commercial BIM tools for building structures. IFC modeling has been applied to many areas of construction and engineering. For example, Yabuki and Shitani developed an IFC-based data schema for reinforced concrete and prestressed slab bridges, and developed a system that checks for interference after creating a 3D shape of the bridge (Yabuki and Shitani, 2003). Yabuki also proposed the IFC-based IFC-ShieldTunnel and included items for representing components, facilities, and geologic information targeted at shield method tunnels (Yabuki, 2008). Lee et al. proposed a 3D information modeling technique for road structures such as roads, bridges, and tunnels (Lee et al, 2011). These models are developed for mainly design and construction phases, not maintenance phases.

Bridge life cycle management aims to perform the management functionalities related to bridges. Bridge condition data are a major component of bridge management. Hammad et al. discussed the requirements for developing a mobile model-based bridge life cycle management system (Hammad et al., 2006). However, the system did not contain measured data and degradation data. Aruga et al. proposed the degradation model based on the IFC (Aruga and Yabuki 2013, 2014); however, the model still did not contain measured (as-built or as-is) data. Visual inspection becomes the primary method used to evaluate bridge condition (Yeum and Dyke, 2015). However, few works of research (Abudayyeh and Al-Battaineh, 2003) have proposed a model for measured data. BIM is not yet suited for as-built and as-damaged information mapping (Koch et. al., 2014).

3. INFORMATION REQUIREMENT FOR PRODUCT LIFE CYCLE OF BRIDGE

The product life cycle of a bridge is shown in Figure 1. The life cycle stages of the bridge are design, construction, inspection and maintenance, and disposal. Bridge construction takes more than one year. Measured data need to be obtained and stored in the product database because the shape of the bridge after construction is usually different from the design shape. After construction, the life of the bridge is more than 50 years. The inspection task is performed every 5 years and measured data are obtained in this task.
Information requirements for supporting the product life cycle of a bridge are shown in Figure 2. The requirement for over-all life cycle is to realize long term data archiving. In order to satisfy this requirement, the model should be based on international standards, which are independent from any implementation technologies. For a long lifecycle product, an international standards based approach was proposed in the Long Term Archiving and Retrieval (LOTAR) consortium, which is comprised of many of the aerospace companies worldwide (LOTAR, 2015) (Brunsmann et al., 2012). The shape and structure of a bridge is defined in a standard format. On the other hand, measured data and degradation data should be represented in a formal manner. In order to satisfy the requirements, the extension of the international standards is proposed in this paper.

4. STRUCTURE OF IFC AND IFC-BRIDGE

The basic structure of the proposed model is based on the IFC model (ISO, 2013), which is shown in Figure 3. It is registered with ISO as ISO16739 (ISO, 2013).

![Figure 3. Structure of the IFC 4.0](image-url)
There are three fundamental entity types in the IFC model, which are all subtypes of an IfcRoot. They form the first level of specialization within the entity hierarchy. An IfcObjectDefinition is the generalization of any semantically treated thing (or item) within the IFC model. An IfcRelationship is the generalization of all relationships among things (or items) that are treated as objectified relationships between different entities. For example, the assignment relationship (IfcRelAssigns) and the decomposition relationship (IfcRelDecomposes) are subtypes of the IfcRelationship. An IfcPropertyDefinition is the generalization of all characteristics that may be assigned to the IfcObjectDefinition.

An IfcContext is a specific kind of the IfcObjectDefinition as it provides the project (IfcProject) or library context in which an IfcTypeObject and an IfcObject are defined. An IfcTypeObject defines the specific information about a type.

An IfcObject is the generalization of any semantically treated thing or process (IfcProcess). An IfcProduct is an abstract representation of any object that relates to a geometric or spatial context. An IfcProduct occurs at a specific location in space if it has a geometric representation assigned. The geometric data is represented in subtypes of an IfcRepresentation entity via an IfcProductRepresentation entity. The details of the geometric data are subtypes of an IfcRepresentationItem. The elements of the geometric data are almost the same as ISO 10303.

An IfcElement is a generalization of all components that make up an AEC product. Then, the IfcElement is a physically existent object, although there might be void elements, such as holes. An IfcCivilElement is a generalization of all elements within a civil engineering work. An IfcSpatialElement is the generalization of all spatial elements that might be used to define a spatial structure (IfcSpatialStructureElement) or to define spatial zones. Main elements within the spatial structure are a site (IfcSite), a building (IfcBuilding), and a storey (IfcBuildingStorey). These entities are all subtypes of the IfcSpatialStructureElement. An IfcProxy is intended to be a kind of a container for wrapping objects that are defined by associated properties.

The IFC-Bridge (Lebegue et al., 2013) is an extension of the IFC model for a bridge and another base model of this paper. Scopes of the IFC-Bridge model data are the general structure of bridges, geometry, materials and technological definitions, prestressing information, and process control. The structure of the IFC-Bridge is shown in Figure 4.

![Figure 4. Structure of IFC-Bridge](image-url)
An IfcCivilStructureElement, which is the subtype of the IfcSpatialStructureElement, is an abstract entity to describe spatial elements for civil engineering structures. An IfcBridgeStructureElement, a subtype of the IfcCivilStructureElement, is an abstract entity for all bridge spatial structure elements. An IfcBridge entity, one of the subtypes of the IfcBridgeStructureElement, is a top entity of the bridge products. It has a StructureType attribute of the type IfcBridgeStructureType, which is the type of bridge structure, such as an arched bridge or a slab bridge. Another subtype, IfcBridgePart, is a subassembly of a bridge with a specific structure type (IfcBridgeStructureElementType), such as a deck or a pier. An IfcBridgeElement is the supertype for all bridge structure components, which have geometry and associated materials. Subtypes of the IfcBridgeElement are a prismatic element (IfcBridgePrismaticElement) and a segment (IfcBridgeSegment). The IfcBridgePrismaticElement has a PredefinedType attribute of the type IfcBridgePrismaticElementType, which is the type of prismatic element, such as a solid slab or a web.

5. PROPOSED STRUCTURE OF IFC-BRIDGE EXTENSION

5.1 Information Requirements for Supporting the Inspection Tasks

Information requirements for supporting the inspection tasks and measured data are shown in Figure 5. A degradation element and a measured region are the primary elements of the model. In a single inspection task, there are several measured regions and degradation elements. In Figure 5, one measured region and one degradation element (red line in Figure 5) exist in the inspection task of the date (2010.11.10). In the inspection task of the other date (2015.12.12), two measured regions and one degradation element (gray line in Figure 5) exist. These degradation elements are time variations of the degradation, and the information model for the bridge maintenance should have a relationship between these degradation elements. The relationship between degradation and civil elements (bridge piers), and the relationship between civil elements and the measured region should be defined. The degradation element and the measured region are also related in the inspection tasks. The measured data file is also connected to the measured region.

![Figure 5. Information requirements for supporting the inspection tasks of the bridge](image)

5.2 Proposed Structure of IFC-Bridge Extension for Satisfying the Information Requirements

An overview of the proposed model structure is shown in Figure 6. In order to satisfy the requirements, an IfcMeasuredRegion for representing the measured region, an IfcDegradation for representing the degradation and an IfcDegradationElement for representing the time variation of degradation are introduced in this paper. In order to represent the relationship between the IfcDegradation and the IfcBridgePart, which is a subpart of the bridge, the IfcRelAggregates entity in the IFC 4.0 is used. The IfcRelAggregates is a special type of the general composition/decomposition (or whole/part) relationship (IfcRel Decomposes). The relationship between the IfcDegradation and the IfcDegradationElement is captured by a new IfcRelConnectsToTimeVariation entity. An IfcRelConnectsToMeasuredRegion entity is also introduced to represent the relationship between the IfcMeasuredRegion and the IfcBridgePart or the IfcMeasuredRegion and the IfcDegradationElement. The IfcMeasuredRegion and the IfcDegradationElement are connected to an IfcTask, which represents the inspection task. The IfcTask, which is the subtype of an IfcProcess, has an attribute that has a representation structure of
time information, such as start time and end time. The IfcRelAssignsToProduct entity, which is the subtype of the IfcRelAssigns, captures the relationship between the IfcTask and the IfcProduct. Using this relationship, the IfcProduct and its subtype are considered as the output of the IfcProcess and its subtypes.

The information about the measured data file is represented in the IfcDocumentReference via the IfcRelAssociatesDocument entity. The IfcRelAssociatesDocument, which is the subtype of the IfcRelAssociates, handles the assignment of items of the select type IfcDocumentSelect to subtypes of the IfcObject. An IfcDocumentReference represents a reference to the location of a document. The reference is given by a URI string where the document can be found.

The proposed data structure is shown in Figure 7. An IfcMeasuredRegion relates to a geometric or spatial context. However, the IfcMeasuredRegion and the IfcDegradation are not types of components that make up an AEC product. Then, the IfcMeasuredRegion and the IfcDegradation are the subtype of the IfcProduct entity. The IfcDegradationElement is the subtype of the IfcElement entity.

Figure 6. Overview of the structure for supporting inspection process

Figure 7. Proposed extension model structure
In Figure 7, the IfcRelConnectsToMeasuredRegion and the IfcRelConnectsToTimeVariations are the subtypes of the IfcRelConnects entity. The IfcRelConnects entity is a connectivity relationship that connects objects under certain criteria. The IfcRelConnectsToMeasuredRegion entity connects from the IfcProduct (a RelatedProduct attribute) to the IfcMeasuredRegion (a RelatingRegion attribute). The IfcRelConnectsToTimeVariations entity connects from the IfcProducts (a set of RelatedProduct attribute) that represents time variations of the RelatingProduct to the IfcProduct (a RelatingProduct attribute).

6. WEB CONTENT PROVIDING SYSTEM FOR BRIDGE INSPECTION AND MAINTENANCE

The structure of a web content providing system is shown in Figure 8. The system consists of the product data, the data converter, and the webserver. The design data from the CAD system and measured data are stored in the database. In this paper, Revit, a commercial system built by Autodesk, is used to generate CAD data. The converter generates the triangular mesh from the IFC data file. The converter is based on an ifcengine.dll (ifcengine.dll, 2015) library. The webserver is implemented using a Python programing language.

To display the 3D objects in a web browser, the three.js library (three.js, 2015), which is the wrapper library of the WebGL, is adopted. Using these technologies, 3D data can be utilized with tablets in the outside field.

The browser output using three.js is shown in Figure 9. In Figure 9 the browser shows the design data with degradations (red points) and the measured data. The measured data are obtained from measuring technologies such as a laser scan and Structure from Motion (SFM).
When degradation point is clicked, the close-up image is shown in other windows. Inspection date, element information (element ID, element description), and degradation information (degradation size, degradation description) will be described in the window.

7. CONCLUSION

In order to support the maintenance processes, the data model, which contains the design and inspection information, is very important. In this paper, the information model for bridge maintenance is proposed. This model is based on the IFC and IFC-Bridge, which is the standards for BIM, and is extended to satisfy the requirements of maintenance processes. The proposed IfcMeasuredRegion and IfcDegradation entities can bring information about inspection tasks and inspection results using the entity attributes and the property set attached to these entities. A web content providing system based on the WebGL is also proposed in order to show the model in the outside field of maintenance. Future works may include verifying the validity of the model and evaluating the usability of the system through utilizing in the actual bridge inspection process.

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