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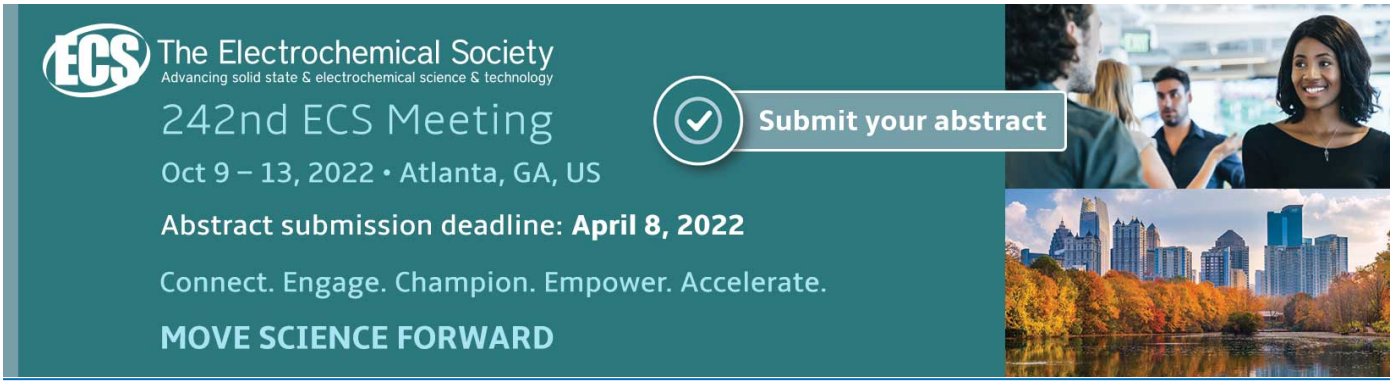

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BIM authoring for an image-based bridge maintenance system of existing cable-supported bridges

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Abstract. Infrastructure nowadays is increasingly become the main backbone for the metropolitan development in general. Along with the rise of new facilities, the demand in term of maintenance for the existing bridges is indispensable. Recently, the terminology of "preventive maintenance" is not unfamiliar with the engineer, literally is the use of a bridge maintenance system (BMS) based on a BIM-oriented model. In this paper, the process of generating a BMS based on BIM model is introduced in detail. Data management for this BMS is separated into two modules: site inspection system and information management system. The noteworthy aspect of this model lays on the closed and automatic process of "capture image, generate the technical damage report, and upload/feedback to the BMS" in real-time. A pilot BMS system for a cable-supported bridge is presented which showed a good performance and potential to further development of preventive maintenance.

1. Introduction

Building information modeling (BIM)-based technology increasingly becomes the most innovative trend in the global construction industry. BIM presents in the process of generating and managing construction data during its life cycle [1]. The term BIM was popularized as a common name for these capabilities offered by several technology providers or vendors. On the other hand, BIM digitally represents the building process in terms of facilitating exchange and interoperability of the model information. It covers all geometric and non-geometric information, spatial or geographic constraint, quantity and physical characteristic of the structure [2] [3]. For the existing facilities, it has hardly been applied for the purpose of maintenance, refurbishment or deconstruction. This condition premises the huge benefits in terms of efficient resource management through development a solution to overcome uncertainties of building condition, as well as solving the problem of deficient documentation in existing facilities.

The conducted literature review of several (over 180) publications presented the state-of-the-art implementation and research of BIM in existing buildings, which focus on maintenance and deconstruction stages, highlighted the intensifying research approaches to harness BIM application in existing facilities as well as capturing and integrating data into the entire information system [4]. It also shows an increment of maintenance interfaces and new functionalities, however, it reveals that three major challenges which need to pay more attention from researchers: the automated data capturing and BIM creating, the timely update and completely maintenance of information, and the controlling of uncertainty data.

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Bridge maintenance system (BMS) was paid special attention last decades. In the developed countries who are facing the aging of infrastructure, there are various BMSs adopted [5]. It engenders the demand in term of developing a national bridge inventory [6]. For existing bridges, in order to distinguish the difference between repairs and strengthening, estimating the progressive deterioration of performance for bridge members needs to be taken into account. Also, a balance between quality-maximization and maintenance-cost-minimization needs to be considered as the rehabilitation strategy for the bridge [7]. Automated system for bridge maintenance has always been a difficult problem for engineers. The first aspect lies in the way to generate 3D digital information model from modelers. In this regards, parametric modeling has been widely applied as an effective methodology to embed BIM expertise into the construction industry. Although the use of parametric modeling solution is not unfamiliar so far, it is still challenging and has some limitations in term of capturing and interpreting a tacit knowledge into computer-readable geometric and relationships. In an automated system, if the input/output data judgment and responsibilities are not strictly controlled, it increases the risk of propagating errors. System performance degradation also needs to be considered when large numbers of parameters and geometric constraints are included (Lee et al. 2006). The second aspect in order to automate the function of generating data for a BMS lies in the inspection process. Several researchers have been proposed the automatic workflows for the bridge inspection work which are based on the image processing technology [8] [9]. Adapting a good machine vision concept, nowadays engineer can detect the structural damage in real time and also has advanced utility functions for remote supervision. Among all inspection objectives, crack detection is the most important achievement and increasingly be paid significant attention [10] [11] [12]. Inspection data can be observed and directly uploaded onto the server by the aids of mobile device or UAV, or other wearable/AR devices, and timely analysis to find out the crack profile, width, and length, also propagation direction, significant support for decision-making process from a remote office.

2. Information requirement

2.1. Maintenance strategy and objectives

Recently, preventive maintenance has increasingly become the most important trend for operation and maintenance (O&M) phase of infrastructure system from worldwide developed countries. Comparing to the traditional O&M process of existing facilities, where the maintenance work presents as a "reactive activity" and be performed only when the structural deterioration and damage becomes dangerous to the safety in general. Consequently, the owner/government often faces a big hesitation in term of decision making for the repair/rehabilitation work. Nowadays, by a good cost-effective proactive strategy for maintenance purpose from the beginning of the project, it is possible to prevent unexpected risk during service-life of the structure, leading to minimizing the extra cost in O&M. Infrastructure is very diverse, depends on different types of bridge, the structural objective should be defined and highlighted as the main criteria when authoring the BMS. Maintenance work is the kind of continuous and repeated process, starts with the inspection and monitoring system, evaluates the structural behavior, proposes and performs the appropriate repair/rehabilitation work if needed, and finally, upgrade/feedback to the database. The following figure describes the configuration for a management system with consideration of BIM standard.

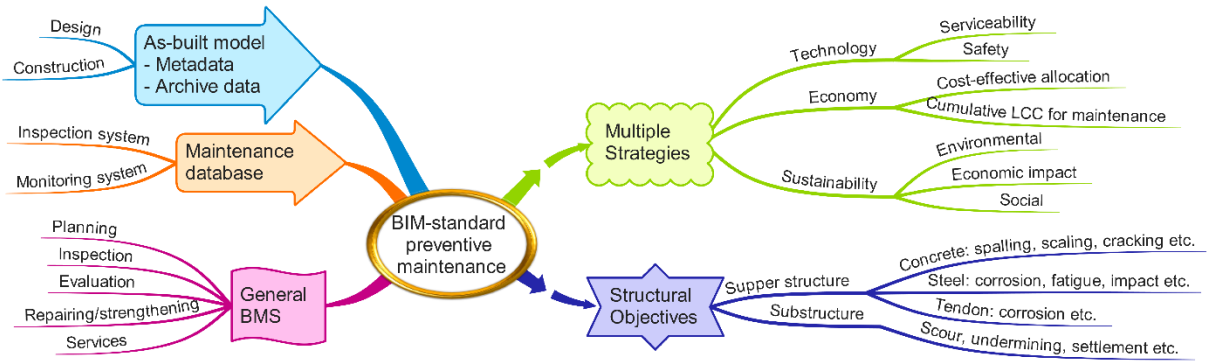


Figure 1. Configuration system for BIM-standard preventive maintenance.

2.2. Data schema for BMS

Basically, the bridge maintenance system using BIM model needs configuration of structured data schema, aiming to orient and form the model-based information system on later. BIM concept is the kind of object-oriented authoring, therefore, the 3D information model is separately defined element-by-element, and finally assembled together by specific ID and individual orientation (coordinates & constraints). In this regards, each structural element should be categorized into an inventory system according to either role or service in entire bridge system. For example, it can be inventoried as a superstructure or as a substructure. Noteworthy that among a distinguished category, structural elements should have the similar characteristics and properties, otherwise it is necessary to further classified into detailer hierarchy category, to form the feature of each category.

Since the inventory system and ID definition system is defined, the BIM-oriented information model can be generated by adding the corresponding information into specified object ID. Two main characteristics: "attribute" and "archive" are the backbone of the information system. The individual attribute feature consists of all physical information such as geometric and material property, orientation and role, quantity/cost estimating is moreover indispensable. The individual archive data, on the other hand, consists all related information following the EIR's aspects, for example, inspection plan/manual, damage/repair record etc. which is continuously obtained during the bridge lifecycle, from design and construction, to O&M stage, and specified in a list.

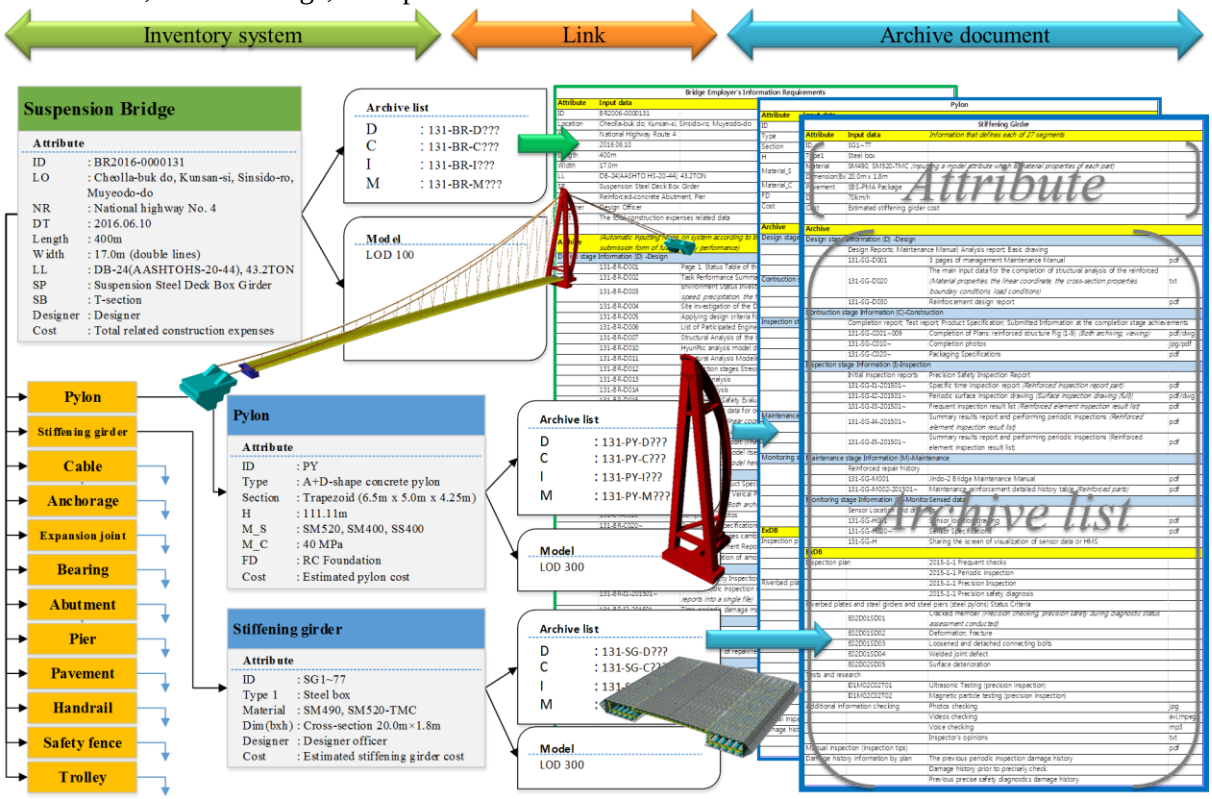


Figure 2. Shortened example for data-schema of a suspension bridge.

2.3. Information specification

Depending on the level of development (LOD) of information requirement, only needed information is adequately provided. For the physical 3D geometric model, each structural element is described by a minimized number of parameters with pre-setting by a relative value. Furthermore, this type of imported information for each element should be generated by a spreadsheet data type, so that information can be easily imported into the different application from each partner. For the archive data, in order to make the computer-readable feature, the standard report form should be considered. In this regards, the primitive file format is suggested such as .jpg for photo checking reports, .avi for video checking reports, or .pdf/.txt for document reports etc. With advantages of information technology nowadays, input

information can be preserved, updated and stored throughout the project lifecycle, with the permitted access from rational stakeholders in each stage.

3. BIM authoring for the BMS



Figure 3. Modules of BMS using BIM model.

3.1. Module 1: Information management system using BIM-based model

3.1.1. 3D information model

In fact that almost existing older bridges which are in-use are based on 2D design, therefore generating the 3D digital model from 2D CAD-drawing is an important task in this regards. Moreover, for maintenance purpose, it is required a high interoperability such as linking the metadata, including all attribute and archive. Parametric modeling based on BIM technology was suggested and can be considered as the most innovative and modern technologies for designers. By the flexibility of design variables, all optimization and revision procedures can be automated and full-in-range controlled. During the design process, the geometric definitions or even conceptual definitions can be varied anytime. With the concept of parametric features, the design now can match more and more with the actual work as well as the manufacturing process. The following figure presents a flowchart for the concept of parametric modeling of the standard elements for a suspension bridge. In this regards, two types of the algorithm should be distinguished: one describes the shape and the other describes the position, orientation, or constraint of the geometric object. Corresponding to each parameter, a chain of the algorithm will be varied to decide the type of parameters. A geometric object is usually built from points, lines, and planes, and the parameters of only one type of these object features are used to specify the geometry. The algorithm to create the geometry of an object is based on linear equations of curves and surfaces in the Euclidean three-dimensional space, whereas most exterior orientation parameters are based on the matrix operations.

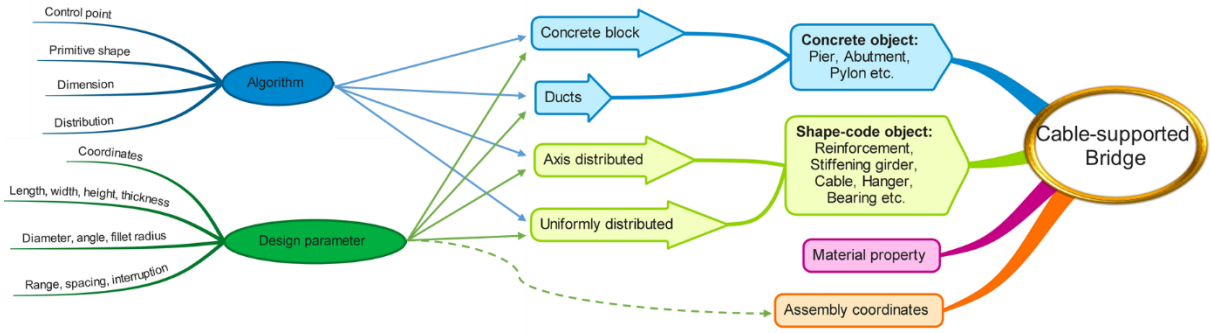


Figure 4. Parametric Modeling concept for structural element of cable-supported bridge.

3.1.2. API-based modeling

In order to enhance design performance, smart algorithm-based 3D information models should be possible to reuse for different construction practices from conceptual design to analysis, estimation, multi-dimensional simulation, and maintenance etc. This paper proposes an essential strategy for 3D simulation of the information system. An integrative work between a CAD program and a programing language was launched by the aided of application programming interface (API). The common API can ease the work of programming graphical user interface components by accessing databases system. It also can facilitate the integration of new features into existing applications especially if using an open-source programming language which strong and fundamental enough for the integrated purpose.

Moreover, an API is able to assist otherwise distinct applications with sharing data, which can help to integrate and enhance the functionalities of the applications.

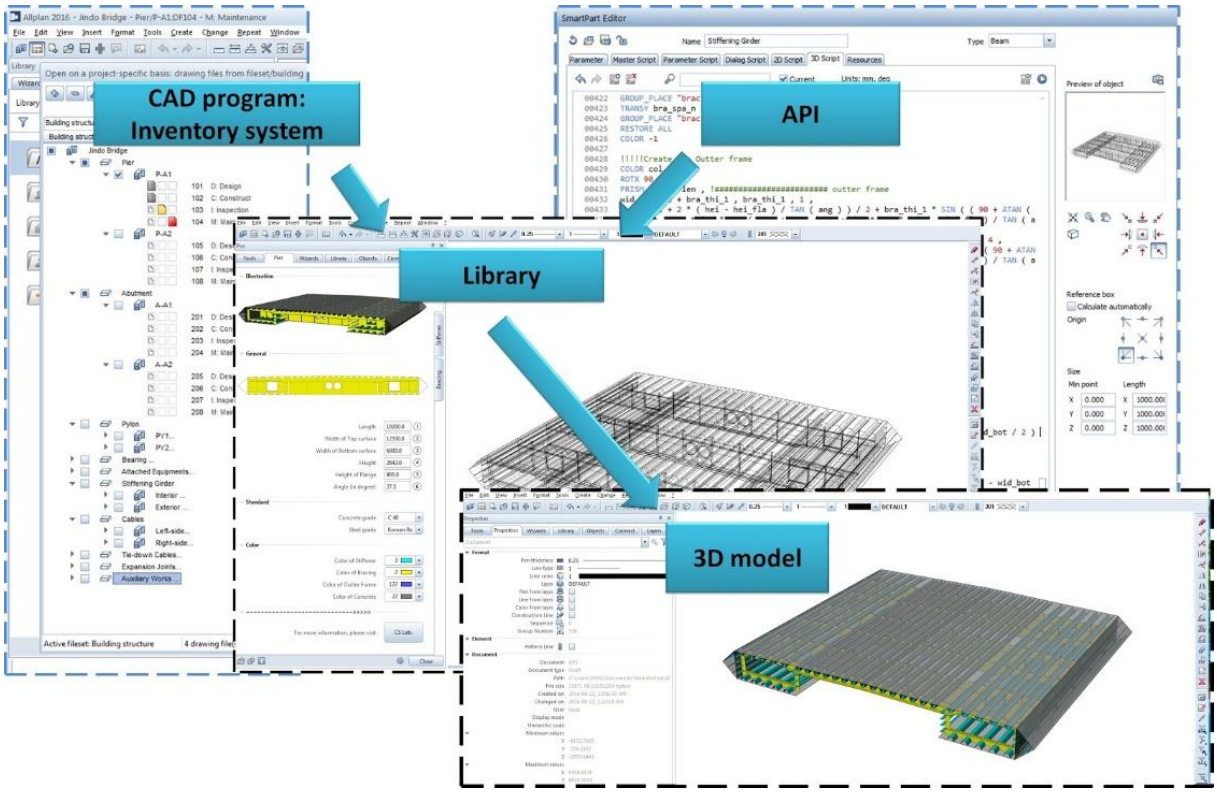


Figure 5. Concept for Digital mock-up by application programing interface.

3.1.3. Data management system

The common data environment (CDE) for a bridge stores all information related to the physical features of that bridge, which can be gathered from design and construction phase, and upgraded from inspection and repair records. As mentioned above, according to the information requirements in EIR, the database system is classified by structure element and their constraints, which is represented by element ID. The database system can be distinguished into three types: asset database, inspection database, and repair database. The BIM-based parametric model now can demonstrate its outstanding features in term of archiving, exchanging as well as delivering information, which absolutely preserves the accuracy of information. The inspection database can be collected primarily from regular or major inspection through an inspection contractor and synthesized into the bridge condition evaluation reports, which used as a basis for the proposed plan of maintenance work. After repair works, the repaired database including the date of repair works, repaired as-built model etc. will be upgraded to the initial asset information.

3.2. Module 2: Site inspection system

3.2.1. Damage classification

Depending on different types of a structural member of the bridge, the damage type of each member should be classified at first. For a concrete member, the regular damage type is surface crack, leakage etc. meanwhile the steel member commonly suffered rust, failure, loosening of bolt or damage to weld etc. Additionally the negative effect of abrasion or deformation, coating separation probably affect both.

3.2.2. Damage detection (image processing)

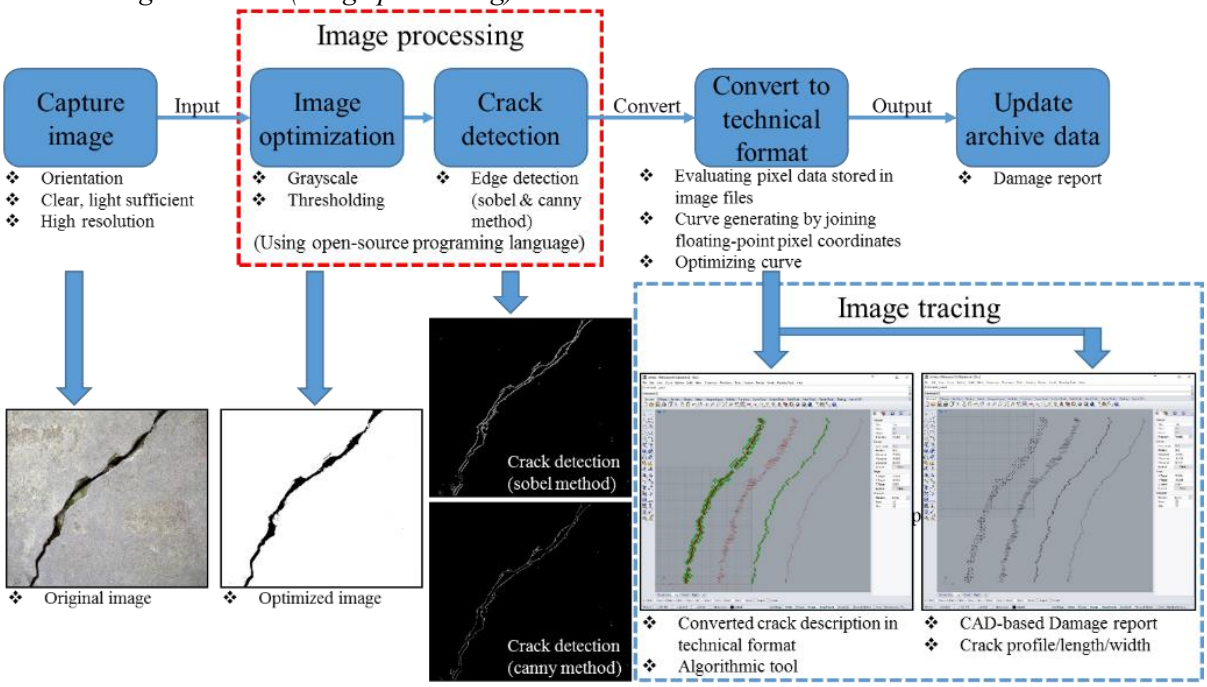


Figure 6. Concept of surface damage detection based on image processing.

Inspection works commonly based on the visual observation and the main activity is describing the damage of the structure by technical format. From the process of visual observation and hand-draw description or photograph, there may some inconsistent error occurred. In order to enhance the productivity of this work, the concept of image processing is proposed to make an automatic site inspection system. The above figure shows an example of surface-cracking inspection work, with the use of digital information in the whole process of inspection activities. The inspection engineers check the structure's conditions, whenever damage such as cracking is found, engineer captures the damage by camera or a mobile device. Damage data is sent to the site inspection system and the process of image processing is conducted. Starting with the original image, it can be optimized by transferring into grayscale and apply thresholding algorithm. This work aims to make a clear and edge-detectable input material. Hereafter, edge detection algorithms are used through an open-source programing language, which integrated into the site inspection system. The different approachable method is applied, the final result is chosen depending on the type of damage, e.g. canny method usually applied for crack detection whereas fuzzy-logic method used for area damage detection. Finally, by image tracing conversion (as so-called raster-to-vector conversion or vectorization), damage report is generated without any discontinuity or deficiency

3.2.3. Technical report (image tracing)

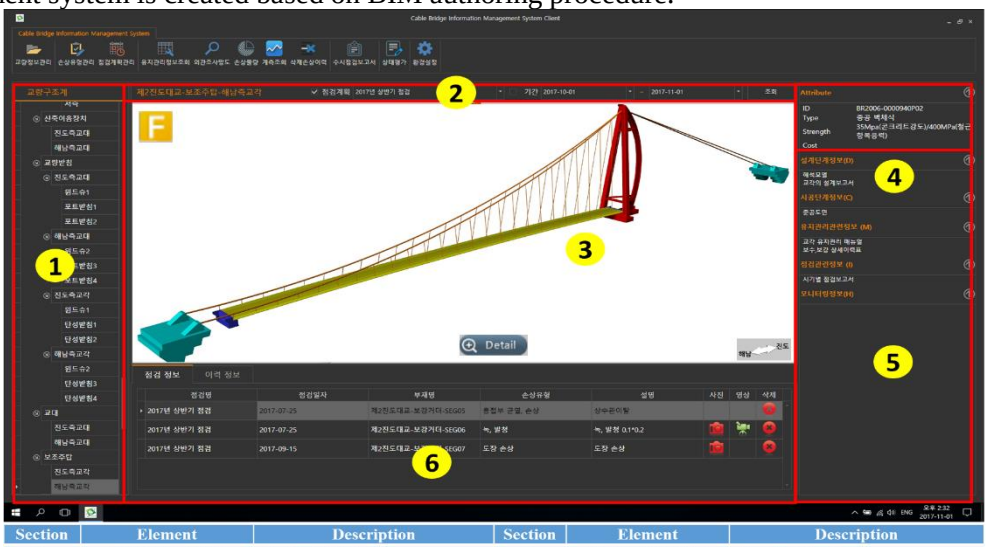
Since this kind of digital technical information in the vector graphic format is created, it is easy to collect the crack profile as well as calculating the length as well as the maximum width of cracks. The surface where crack occurred can be found from the initial 3D model by known specified object ID. Finally, the technical drawing of crack will be mapped into the target surface and update inspection information back to the initial 3D model in digital format. The site inspection system moreover can automatically generate inspection reports for bridge elements in 2D drawings. Noteworthy that, nowadays with the aid of mobile/wearable devices which integrated the data processing features as a mini-computer, e.g. an augmented reality device (or even a tablet with appropriate software), with one unique device but engineer now can perform all the inspection task easily. On the other hand, damage report in technical format can be quickly generated and upgraded back to the management system at the same time.

4. A pilot BMS application

This research is performed by BMS research team in Korea. The developed BMS is in the stage of installation to a cable-supported bridge in Korea. All the models and information were linked together and will be utilized for future maintenance work.

4.1. Module 1

From the proposed data schema and established data management system, the module of Information management system is created based on BIM authoring procedure.

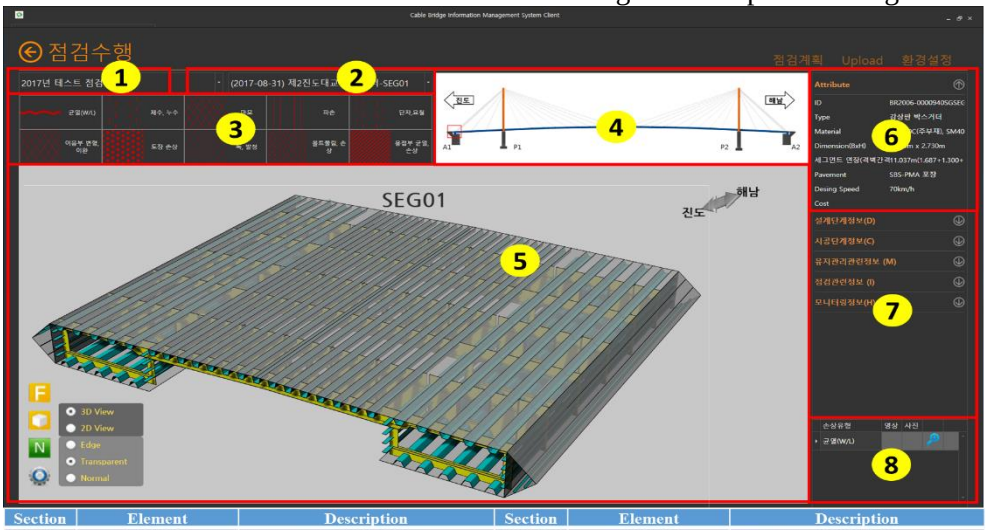


Section	Element	Description	Section	Element	Description
1	Inventory system	Structural element	4	Basic Information	Structure attribute
2	Inspection browsing	Selecting inspection case	5	Archive Information	Attached archive list
3	3D Viewer	3D model display	6	Inspection Detail	Inspection history with damages

Figure 7. BIM-based Information management system (Software interface).

4.2. Module 2

The second module focuses on the real-time data generation and utilization. Real-time collaboration between field engineers and office engineers is provided by this system. Robotic or drone-based inspection in the future was considered in the real-time sharing of the inspection image.



Section	Element	Description	Section	Element	Description
1	Inspection Browsing	Selecting inspection case	5	3D Viewer	3D model display
2	Segment Browsing	Selecting inspection parts	6	Basic Information	Structure attribute
3	Damage Remarks	Damage to apply	7	Archive Information	Attached archive lists
4	Key-Map	Approximate location of segment	8	Input Data Screen	Inputting data viewer

Figure 8. Automatic inspection system on site (Software interface).

5. Conclusion

In this research, a new framework for bridge maintenance system is developed using BIM concept with considering all aspects of maintenance task. One part of research work including a BMS application is applying into an existing cable-supported bridge in Korea and shows good potential for performance-enhancing of maintenance work. The bridge data management system was generated without any limitations by using the proposed BIM authoring and data schema which derived from EIR. Inspection work now can be easily performed and timely reported/upgraded the database in digital technical format, leading to significantly help engineer for saving time and cost. Moreover, the proposed framework can be adapted for various bridges or types of bridge. Based on this paper, the following conclusions were derived:

- In order to build up a bridge maintenance system, the data schema should be defined at first. By using the open-source BIM platform, all O&M manager or other stakeholders can easily access and handle any information within the BMS through object ID. Interoperability of 3D bridge information model should be considered. Information specification and data exchange need to be early specified. Parametric modeling has seen a key-refine for the object-based information system. By using only a few fundamental parameters and algorithms to build up some unique structural member as well as bridge alignment, the designer now can generate the entire bridge model with thousand members with the desired LOD.
- Inspection work needs to be a closed digital process. Surface damage inspection can be performed with just a few engineers through the aids of mobile/wearable devices. Damage report in technical format can be quickly generated and upgraded back to the management system in short time, which is more efficient than conventional one. Development of communications technology allows engineers to browse data wherever they have accessibility to BMS. BMS consists of two modules, one is main management module and the other is inspection module. Two modules can simultaneously share and exchange inspection or stored data. They are possible to handle their own work and to make decisions, even if they are not in the same place. Moreover, it helps to avoid work duplication and loss of data.

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