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BRIM IMPLEMENTATION FOR DOCUMENTATION OF BRIDGE CONDITION FOR INSPECTION

Firas A. Al-Shalabi[1], Yelda Turkan[1, 2] and Simon Laflamme[1]
[1] Department of Civil, Construction and Environmental Engineering, Iowa State University, USA
[2] yturkan@iastate.edu

Abstract: Bridge condition inspection data provide critical and rich information for assessing structural condition. Currently, the majority of bridge inspection methods use printed checklists, and their interpretation is labor intensive, subject to personal judgment, and prone to error. To realize the full benefits of bridge inspections, there is a need to automate the data management process. This study implements Bridge Information Modeling (BrIM) technology for bridge inspections and compare it to the conventional approach of paper checklists. The environment combines a 3D representation of the infrastructure, and allows the integration of inspection data, such as the presence, type, severity, and localization of damage and previous maintenance decisions. In this paper, we use the acronym BrIM to refer to the database that integrates a 3D bridge model and bridge element condition data. In order to validate our approach, we obtained 2D drawings and previous inspection and maintenance data from two bridges located in Ames, Iowa, and modeled them using Revit. We then synced both models using cloud-based solutions so that we could access them from tablet computers on-site. Then, we tested the BrIM based inspection methodology with Iowa DOT engineers and bridge inspectors, who confirmed that BrIM can be used to automatically query, sort, evaluate and send information to decision makers. Furthermore, we conducted a short survey with several DOT engineers and bridge inspectors regarding with possible expected benefits of using 3D BrIM based solutions for inspections. It is concluded that this methodology will substantially improve bridge assessment and maintenance operations, resulting in reduction of costs associated with bridge assessment, and improvement structural resiliency by enabling more effective maintenance and repair operations.

1 INTRODUCTION

The Federal Highway Administration (FHWA), according to Federal-Aid Highway Act of 1968, requires all states to perform a biennial inspection for each bridge to document its condition. Current bridge inspection and assessment methods rely heavily on a reiterative process of manual data entry and extraction, which are subjective, error prone and time consuming. Data collected during site inspections provides the foundation for maintenance and rehabilitation actions. Bridge Information Modelling (BrIM) is a fairly new technology that is still in its infancy in terms of its adoption in the industry. BrIM technology enables storing all bridge data, including its drawings and models, material specifications, inspection notes and others, in a central database that can be accessed both from the office and the field. This gives an opportunity to adopt BrIM to develop an automated bridge inspection method. BrIM has many proven benefits such as reduced construction duration and cost savings when implemented during design and construction. However, the benefits of adopting it for inspection purposes are still uncertain. In this paper, a novel framework that employs BrIM and cloud computing technologies for bridge inspection and assessment is introduced. The framework was tested to determine its applicability and impact on bridge inspection. The test/mock inspection was conducted on a bridge located in Ames, Iowa with the collaboration of Iowa DOT personnel to evaluate and compare the current and proposed inspection practices. Furthermore, a survey was conducted among eight other DOTs in order to better understand current and possible future BrIM applications at their institutions. The survey included questions regarding 3D modelling, BrIM applications in general, as well as BrIM adoption for bridge inspections.

This paper is organized as follows: Section 2 provides a literature review on information technology and modelling applications in heavy-civil sectors. Section 3 presents the research methodology by detailing the BrIM based bridge inspection framework and by providing the details of the survey. Section 4 presents the results of the mock inspection and the survey. Section 5 draws conclusions and discusses future research needs.

2 LITERATURE REVIEW

The U.S. economy depends heavily on its road network and bridges. Any failure in maintaining this network can cause substantial economic losses (Elbehairy 2007). In order to keep this network maintained, all states must perform a biennial inspection for each bridge to document its condition. This requirement puts a cumbersome responsibility on state DOTs to manage their assets. As a result, standalone Bridge Management Systems (BMS) (e.g., AASHTOWare PONTIS and VIRTIS) were adopted to satisfy DOTs needs such as: the operational requirements, planning and program management, e.g. load rating, permitting and routing. However, those systems do not satisfy the need to coordinate management tasks of all phases of a bridge life cycle i.e. design, construction, operations and program management (Shirolé 2010). Furthermore, they require re-entry and transformation of data, which is a cumbersome, redundant and error prone process. On the other hand, comprehensive asset management solutions such as BrIM could improve the deployment of services and maintenance resources, reduce maintenance costs and increase the quality of services (Zhang et al. 2009). BrIM benefits are being recognised by DOTs and asset owners (Howard and Björk 2008). While the current BMS do not satisfy the need for a more comprehensive solution covering the entire life cycle of a bridge (Shirolé 2010), BrIM can offer an integrated comprehensive solution for life-cycle bridge management (Chen and Shirolé 2006; Chen and Shirolé 2007; Shirole et al. 2009; Shirolé 2010).

Building Information Modeling (BIM) is an emerging technology that has gained increasing popularity among designers and contractors in the civil, architectural, and construction industries. BIM is the development and use of a 3D digital model to simulate and represent the design, construction and operation of a facility. This model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, where data appropriate for various users' needs can be extracted and analysed in order to generate useful information for decision makers in a facility and improve the process of delivering a facility (Eastman et al. 2008; AGC 2006). Despite a variety of definitions, the agreement is reached that BIM is a digital representation of a facility. Also, it is widely accepted that BIM is not only a modeling software, but an integrated design and construction process providing a collaboration and communication platform for various parties throughout the project lifecycle (Carmona and Irwin 2007).

Bridge Information Modeling (BrIM) is the specialization of BIM to bridge projects. Other similar terms in the field include Heavy BIM, Horizontal BIM, Virtual Design and Construction (VDC) and 3D Engineered Models for Construction. Heavy civil construction projects such as bridges have unique characteristics compared to a typical building construction project. Various land contour, changing site conditions over the long span of a project, existing infrastructure segments and traffic coordination during construction are some of those unique characteristics that impact the design and construction of a new project (Cylwik and Dwyer 2012). Previous research has highlighted many benefits that can be obtained from implementing BrIM for bridge maintenance and operations. (Shirolé 2010) summarised the benefits that can be obtained from adopting BrIM in bridge management as follows: 1) satisfied data needs at project level; 2) elimination of repetitive manual transcription of data; 3) improved data quality, reliability and speed of bridge inspection; 4) easy access to bridge safety related data so that it can be extracted and updated in an efficient manner; 5) improved communication between inspectors and bridge engineers by providing virtual models which would eliminate the need for re-inspections and improve well inform the decision makers; and 6) cost effective bridge life cycle management (Shirole et al. 2009). Possible benefits of BrIM for bridge management are acknowledged both in academia and industry. However, its implementation and possible benefits for managing existing bridges is still unclear (Marzouk and Hisham 2011). This paper aims to create a better understanding of bridge inspection needs and how to meet them using BrIM. A novel framework is created and tested with cooperation of Iowa DOT, and then their feedback in addition to other DOTs was recorded.

3 METHODOLOGY

BrIM can be considered a comprehensive bridge management system as it enables managing bridge information from design through maintenance and operation phases. In this paper, a BrIM based bridge inspection workflow is presented. This workflow involves using a mobile device such as a tablet computer that enables inspectors to access an accurate, up to date 3D information model of the bridge via cloud data storage services. This 3D model contains all bridge elements including their maintenance history at object level. This environment allows entering and storing inspection data such as sketch drawings and measurements. The proposed workflow allows direct access to inspection data from home office. This BrIM based inspection workflow is tested with Iowa DOT inspectors and bridge engineers. In addition, a survey with several DOTs was conducted to evaluate the applicability of the proposed framework.

3.1 BrIM enabled inspection framework

This study has taken an existing bridge located on highway US 30 spanning the Skunk River in Ames, Iowa as a case study. Two dimensional (2D) plans and historical inspection data of the bridge were provided by Iowa DOT to the research team in electronic document format. The research team then combined all this data in an intelligent 3D model, i.e. 3D BrIM.

In the traditional way of inspection, a bridge is divided into three groups i.e. deck, super structure and sub-structure. Usually the inspection team divides the main three groups between the team members and each group is inspected using a separate inspection sheet. The other method is doing a loop by starting with one group to the next until they finish. The condition of each element at the time of inspection is documented to the best judgment of the inspector and according to the measurements that are taken from the damaged area, - e.g. in concrete structures, the inspectors look at the integrity of the bridge, specifically corrosion, spalling, concrete cracks and paint cracks. A crack comparator scale is used to measure the width of the crack. Any crack that is at least 1/16 inch wide should be watched. The depth of the crack is not measured, however if rust was found this is taken as an indication that the crack is deep and further inspection is required. Then, the inspection team draws manual sketches to document the size, severity, depth and location using true dimensions of the problem. Finally, the report and the sketches are taken to the office and re-entered again into the BMS to update the current status of the bridge condition. Then bridge engineers do a comparison with the previous inspection, and actions are taken to fix problems, if any existed.

The 3D BrIM model was built by mimicking the traditional way of bridge inspection. Model elements were divided into similar groups such as deck, super structure, sub-structure, channel and piers in order to mimic the traditional bridge inspection method. Each of those categories is downloaded as a separate model to the tablet application, and they can be merged again easily using the 3D modeling software application in the office. Then, each group is given a specific color, and each element is provided with details that are pinned to that element. Those details include previous inspection information with technical details. The BrIM-enabled inspection framework concept, as shown in Figure 1, consists of three major elements; data cloud, mobile devices and home office computer interface. The data cloud can be accessed both from home office and from the site, which enables data sharing with all stakeholders simultaneously. This procedure would help increase the speed of communication and eliminate any re-entry of the inspection data. It would also prevent any possible data loss during data transfer. Having a better representation of the field conditions and instantaneous access to inspection data would enable decision makers to make better informed decisions since they would have a better idea of the problem and direct feedback from other stakeholders such as bridge engineers and inspectors.

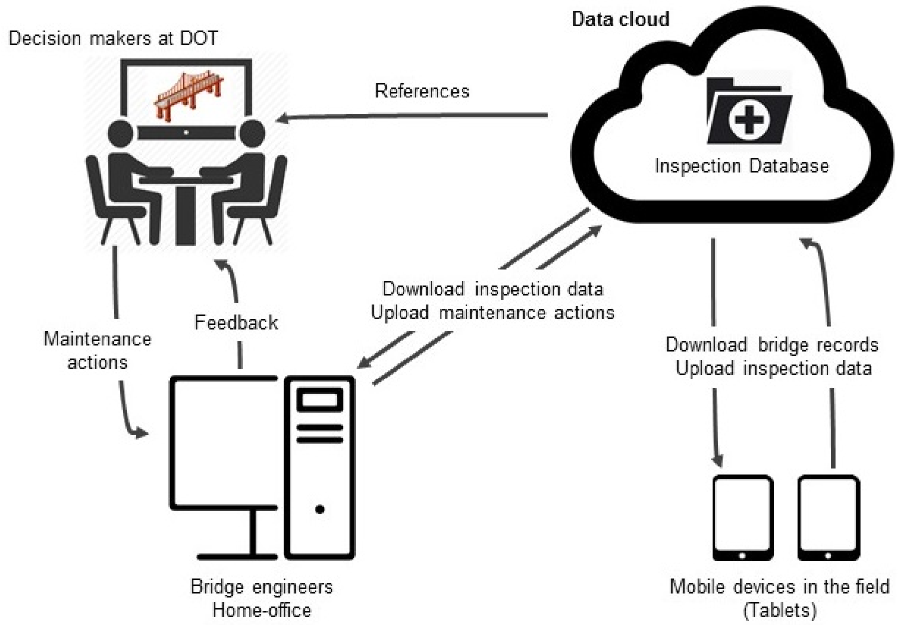

Figure 1: BrIM-enabled inspection framework

3D BrIM models can be downloaded to data cloud from home office where they can be accessed by inspectors in the field. Inspectors then choose an element that has a deficiency and by freezing the model they create an image where they can document the problem and enter all data that is required and upload all the inspection data back to the data cloud (Figure 2). This enables bridge engineers to access the inspection data from home office where they can conduct further analysis.

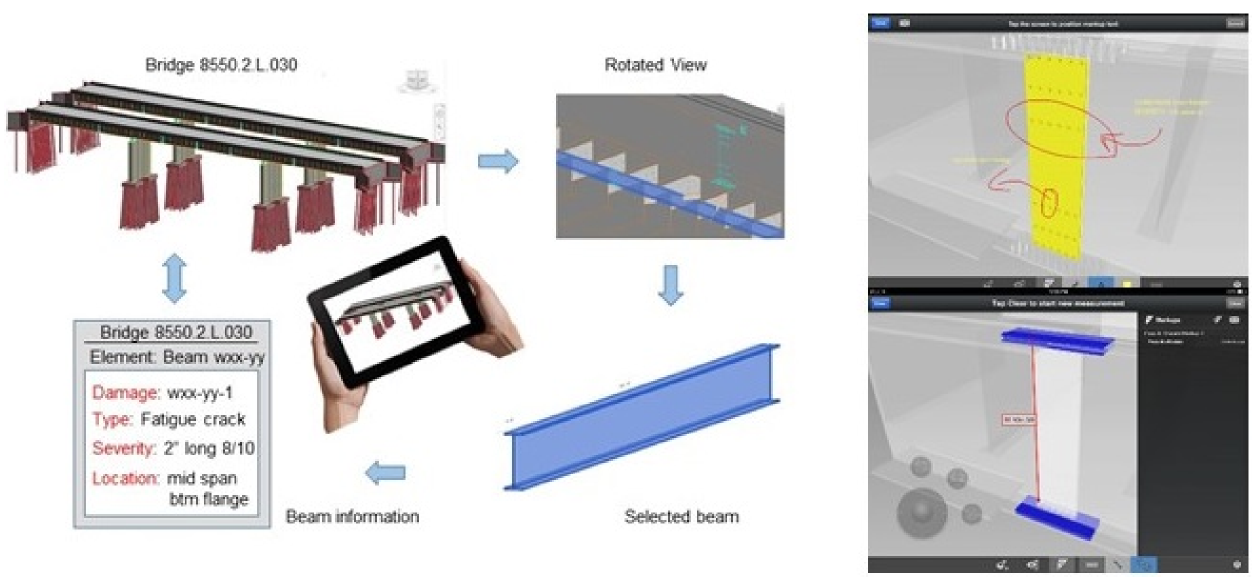

Figure 2: BrIM inspection process

3.2 DOT Survey

A web-based survey, using the Qualtrics survey tool, was conducted in order to evaluate applicability of BrIM for inspection purposes in other states outside Iowa. The survey was sent out to eight DOTs in the Midwest in addition to New York and Pennsylvania DOTs to obtain their feedback on implementing BrIM technology for bridge inspection and maintenance. DOT personnel ranging from bridge engineer to a director of bureau of structures from eight different DOTs participated in the survey.

The questions varied between open format questions where DOTs personnel provided their feedback, and closed format questions that varied between Dichotomous questions and Likert questions. The questions were directed to understand three key aspects; the first one was whether the DOT has any experience in using BrIM technology and how they are using it. The second one was to find out whether they are facing any problems with the current bridge inspection practices. Finally, the third one was to determine the potential of the proposed BrIM based framework for inspections.

The surveyed DOTs acknowledged the benefits of BrIM and showed interest in using it. However, they expressed several difficulties and challenges they are facing when implementing it during design and construction phases. Furthermore, most DOTs acknowledged that BrIM would be beneficial for bridge inspection. The detailed findings of this survey are summarized in Table 1.

4 RESULTS AND DISCUSSION

According to the survey, the number of qualified bridge inspectors range from 10 to 50 among the states surveyed in this study. This number can reach up to 650 when consultants and freelance inspectors are included. Typically 2-4 inspectors are required for inspection of a regular bridge. The number of inspectors can reach up to 7 for inspection of special types of bridges such as over water bridges. The yearly cost of inspections varies among states as the number of bridges and the size of the states vary. When asked what means are being used for bridge inspections in the current practice, 71% of respondents said that they use the paper based method. And the other 29% of the respondents stated that they are using mobile computing technologies such as Personal Digital Assistant (PDA), tablets and laptops. About 50% of the surveyed states responded that their DOTs use 3D information models and information technologies during design and construction of civil projects, and 33% of the respondents stated that they are using it specifically for bridge design and construction. This result is compatible with the opinion that states that large asset owners are moving towards more comprehensive tools to manage their assets (Howard and Björk 2008; Zhang et al. 2009).

The DOTs who participated in this survey recognized BrIM as a beneficial tool for bridge inspections. However, they are not planning to adopt it in their bridge inspection practices in the near future. The reason for this maybe the invalidated benefits of BrIM for the inspection process (i.e. BrIM must prove its ability to improve inspection process over current practices). In this study, while conducting the mock-up inspection, the time needed for inspecting each element as well as signing and dating the inspection documents were reduced significantly. This is mainly due to the user friendly sketch drawing and input recording functionalities of the software.

The surveyed DOTs predict several challenges that maybe faced when implementing BrIM technology for bridge inspections. One major challenge mentioned by most survey respondents was the concern of damaging portable electronic devices during the inspection process. They stated that electronic portable devices used for inspection tasks must be durable in rain, sunshine and extremely cold weather conditions. And they need to be sturdy enough so that they do not break down if dropped; should be small enough to fit in inspector’s harness, and large enough for sketching and visualization. This problem was also stated in the literature (Chen and Kamara 2008; Tsai et al. 2014), and can be overcome as mobile devices are being improved continuously; e.g. their mobility, durability, hardware compatibility and battery life being improved constantly to satisfy the needs of construction job environments. Moreover, a variety of accessories are available to protect tablet computers in harsh outdoor environments.

Table 1: Survey Results

Task	Results	Remarks
Inspection Means	71% paper based 14% PDA 14% others	
Number of Inspectors	15 – 75	The number can reach up to 650 with all qualified consultants
No. of inspectors in each inspection	2 – 4	Can reach 7 for major over water bridges
BrIM usage in design & construction	33% using it	
Challenges in the current practice	60% have challenges	• Close observation and management to stay on compliance • Training inspectors • Inadequate staff • Aging staff • New problems with new bridge designs.
Future use of BrIM in inspection	71% denied any future plans	
BrIM staff knowledge	62% poor – fair 13% good 25% V.Good - Exc	
Usefulness of BrIM for inspection	71% neutral	29% sees it as useful
BrIM Improve the speed and precision of inspection	71% disapproved	
BrIM implementation challenges		• Damaging portable electronic devices • Cell phone signals • Sturdy equipment to handle rain, sunshine and extremely cold weather. • Initial cost • Time invested in creating models
Institutional barriers		• Training • Digital signatures issues • Integrity of data during transmission. • Confidential information

Another critical challenge mentioned was cell phone signals. There are many bridges located in rural areas where no cell phone service is available. The authors and other researchers (Tsai et al. 2014) suggest an offline BrIM approach to overcome this challenge. An offline BrIM tool for inspection enables downloading all models before arriving to the site. The inspector can record and save all inspection data on the device while offline and upload them to the data cloud when he/she has a wireless connection. This procedure was tested during the mock-up inspection with Iowa DOT inspectors where no cell phone signal was available under the bridge. Another challenge mentioned was related to the initial costs of implementing a new technology, along with the software costs, cost for keeping them up-to-date. In addition, initial investment in time and money to build 3D information models of existing bridges needs to be taken into consideration. The authors suggest that this barrier could be overcome by adapting new technologies into current practices gradually. In addition, case studies from institutions that received benefits from implementing new technologies in their projects would help and encourage other asset owners adopting new tools and technologies into their practices. For example, (Cox et al. 2002) documented that using mobile devices such as PDAs reduce costs and labor time during data collection.

While many DOTs listed lack of resources and initial investment cost as an institutional barrier to implementing BrIM for inspections, others listed human factor as a barrier, such as inspector's education and training. And some DOTs were concerned about legal issues such as digital signatures of inspectors, integrity of data during transmission and the critical details that must be kept confidential for security purposes.

When asked about the current inspection practices, around 60% of the responses admitted that DOTs are facing many challenges with the current inspection practices. The main challenge is to conduct inspections on time in order to comply with the federal law. Furthermore, challenges in training inspectors, inadequate staff, aging staff and new inspection problems with newer bridge designs were also mentioned. Overall, the current inspection practices challenges DOTs in their bridge management practice as there are problems with effectively processing and integrating inspection data with bridge management databases (Agrawal et al. 2009; Lee et al. 2008; Shirolé 2010).

The surveyed DOTs stated lack of knowledge in using 3D information modelling. On a five level Likert scale ranging from poor to excellent, 62% of surveyed DOTs considered themselves having fair or poor knowledge; while 13% considered themselves as good and 25% ranged between very good and excellent. Finally, 71% of the surveyed DOTs did not think that uploading inspection data to the data cloud directly would increase the speed and precision of the inspection. This might explain the small percentage (28%) of the surveyed DOTs that indicated having future plans for implementing BrIM in their bridge inspection process.

5 CONCLUSIONS

Bridge inspection is considered a time consuming and redundant task in the traditional way. Errors are likely to occur depending on the way the inspection is conducted and based on the inspector's experience and personal judgment. This study shows the possibility of extending the benefits of BrIM technology for bridge inspections. DOTs are recognizing the benefits of BrIM as a comprehensive solution for managing their bridge assets. BrIM based inspection would help eliminate redundant data collection, data re-entry, and minimize possible errors that may result from inspector's personal judgment or limited experience. It would also help reduce errors and improve overall inspection quality and safety by reducing the time needed for inspection. Furthermore, it can also help reduce the time needed for each inspection by improving the way sketches are drawn on site, as well as reducing the time needed for signing and dating each inspection paper. Bringing mobile devices and BrIM to the bridge management practice is applicable. However, its sought benefits need to be validated for its adoption. For future research, the research team would recommend validating the benefits of BrIM for bridge management through several case studies.

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