Challenges in Generation of As-is Bridge Information Model: A Case Study

V. Kasireddy[a*] and B. Akinci[a]

[a]Department of Civil & Environmental Engineering, Carnegie Mellon University, USA
E-mail: varunkasi@cmu.edu (corresponding author), bakinci@cmu.edu

ABSTRACT

Most of bridges in the United States (US) were constructed long ago, so they have only 2D drawings and sketches, depicting the design information, as part of their documentation. Moreover, since routine inspection is conducted once every two years, it is challenging for inspectors in terms of situational and spatial awareness in order to thoroughly recall past condition information, just by looking at the existing documentation. An as-is 3D model of a bridge can potentially offer an accurate and up-to-date repository and enable visualizing and interpreting bridge details and or previously undertaken maintenance actions.

With the advent and success of semantically-rich building information models (BIMs) for buildings, several researchers have been working on extending such a specification for bridges. However, there are several challenges for researchers and bridge practitioners who intend to create an integrated as-is model based repository. This paper discusses these challenges in detail through a case study on an overpass bridge.

The findings include challenges and lessons learnt during the case study in various phases such as information extraction from documentation, 3D modelling and updating, and 3D model augmentation, for creating as-is bridge information model (BrIM). This work can contribute towards advancing state-of-the-art knowledge for semantically representing defects in this domain, and towards formalizing an approach to use multiple data acquisition modes, such as laser scanning and imaging, as a means to triangulate as-is information of the bridge.

Keywords -

Automation; Robotics; Laser scanning; Bridge Information Modeling; As-is BrIM; Bridges; Bridge Inspection; Point Cloud; Deviation Analysis; Infrastructure Modeling; Semantic-rich bridge models

1 Introduction

The documentation of many existing bridges in the US mainly comprises of 2D drawings and sketches [1] [2] [3]. These 2D documentation does not always represent as-is bridge conditions due to the fact that geometrical and spatial changes made to the bridge structure over time are not always captured and updated in the corresponding bridge documentation. In the last decade, some state Departments of Transportation (DOT) in the US have utilized laser scanning to capture point clouds of the bridges, to generate a 3D as-built bridge record [2] [4]. However, a one-time documentation of geometric and spatial details of the structure, alone does not give an accurate and a complete understanding of the extent and reasons for changes in the structure over time.

Understanding changes in the structure is necessary to support decision making during a variety of activities over the service life of a bridge, such as inspection and maintenance [5]. These changes include periodic additions/removals of members, and possible increase and decrease in extent and severity of various defects.

Capturing raw point clouds of the structure frequently at different times and visually comparing them, by overlaying one over the other, will not be sufficient to comprehend changes over time. This is because, raw point clouds only have low-level spatial coordinate and colour information, and in addition, there are typically hundreds of thousands of points in a single point cloud and visually comparing several such point clouds is hard. To overcome this problem, it is important to be able to do high-level reasoning about the raw scan data, in order to identify and segment various bridge elements and defects present on them. Thereafter, to create an integrated as-is BrIM, the segmented element and defect information should be associated with corresponding elements in a 3D design model and combined with other non-geometric information such as condition ratings, maintenance actions and condition images.. Having such a model supports automatically retrieving defect and other information that might be required for decision making.

We conducted a case study on an overpass bridge with the goal of creating an as-is BrIM that would be useful for inspection and maintenance purposes. During this process, we have encountered several challenges associated with creating as-is BrIM using existing modelling software, as well as utilizing details available in the bridge documentation such as design drawings, inspection reports and site photos to update and augment the model. In this paper, we discuss these challenges and conclude with some of the lessons learnt during different stages in the case study process such as developing, updating and augmenting the 3D design model; and also with possible directions to automate as-is BrIM creation.

2 Detailed Description of Case

For this research, we did a case study on a steel beam bridge, constructed in 1965, which had a suspended concrete deck passing over another roadway. One of the goals of this case study was to collect necessary data from multiple sources such as design and as-built drawings, inspection reports and site photos, to generate an as-is BrIM in support of current and future inspection and maintenance tasks.

This bridge had many known locations with deterioration that can be described by multiple instances of various defect types, such as section loss, concrete spalling and exposed reinforcement. We were given access to information sources, such as bridge as-built drawings and recent bridge inspection reports. Additionally, our collaborators from Northeastern University, supervised a team that spent half a day at the bridge site and collected point clouds using a ground laser scanner, took bridge condition photos, and also took size measurements of various bridge elements and defects using a micrometer for validation purposes. Considering the existing bridge conditions and availability of necessary information, this bridge is a good candidate for our study on as-is BrIM generation.

Apart from the time spent on the site for data collection during a detailed laser scanning activity, all other activities in this case study were carried out, over a span of three months in summer 2014. Those include scan registration, 3D model development, deviation analysis and model updating.

3 Approach

We initially built a semantically-rich 3D design model of the bridge using the existing documentation and then brought in the registered scans to perform a deviation analysis. Based on the results of the deviation analysis, we have updated the model and added the results from prior bridge inspections, such as defect information, into the model. The upcoming sections describe details of this approach and discuss the lessons learned in each step of this process.

3.1 3D design model development

3.1.1 Using details from design drawings

The design drawings were used to create an initial 3D model. These drawings included general plan and elevation details, road alignment and profile details, abutment details and pier column section details. Though we were able to create a preliminary model using these drawings, there are several issues associated with the usage of these drawings for as-is model generation that were discovered only in the subsequent stages of the overall approach. These issues relate to the presence of: (i) incomplete/misleading details (e.g., Figure 1) and (ii) missing details (e.g., Figure 2).

Figure 1. Missing railings from the bridge, however, drawings do not reflect the situation on the ground

(a) (b)

Figure 2. Two types of bracings (encircled in red) were present between girders at various spansof the bridge, however, their design details were missing from the drawings

The set of drawings provided for span details, contained only a typical span cross-section including girder details.. Providing only this detail in the drawings mislead us to an assumption that all spans in the bridge had the same number of girders with similar sizes. Another example of missing details is that of railings. The drawings did not indicate that the railings were removed, so we ended up modelling the railings, However, these were proved to be wrong when we later performed deviation analysis using point clouds and also corroborated with additional site photographs. Similarly, as shown in Figure 2, bracings are clearly visible in the structure, but their details were completely missing in the drawings. Due to missing details, all diaphragms were wrongly modelled as having the same type. The photos taken at the time of laser scanning, for later reference, did not cover each and every type of span, and those revealed the presence of only the bracing type, as shown in Figure 2(a), but not the other type which is shown in Figure 2(b). This mistake was identified during deviation analysis and was corroborated by subsequently collecting additional photographs from the site. Details about the corrections related to these issues are provided in section 3.2.3.

3.1.2 Using 3D modelling software systems

A bridge typically carries a roadway. The roadways maybe curvy in three planes, thus adding complexity to the design model. Accurately modelling this complexity is not a straightforward task.

Autodesk Civil3D is a convenient tool to model the centreline of a roadway [1]. However, an important limitation of Civil3D software is its inability to create intelligent and parametric 3D objects. To overcome this limitation, using Autodesk Revit can be handy. Revit can not only support 3D modelling, but also allows assigning non-geometric attributes, such as material information and connections. Also, Revit can generate IFC 2X4-compliant code that is useful for interoperability of information between 3D modelling software systems and other custom software that might be developed as per research needs.

In the early versions of Revit, however, the centreline of a roadway could not be modelled if it consisted of multiple line segments [1]. In recent versions, a Revit extension: Civil Structures, is available, that can import the centreline of a roadway from Civil3D into Revit. Apart from the centreline import feature, this software extension has features that can enable the user to incorporate greater details related to layout, element configuration and geometry, into the model. For instance, the user has the flexibility to assign a taper angle to the roadway deck apart from being able to set several discrete station locations and station elevations where important substructure elements, such as pier, abutment, and footings, are present. This extension also comes with a group of parametric bridge families covering abutment, pier, girders, guardrails, bearings, deck etc., which cover most of the required elements in concrete deck bridges. Instances of these parametric families are placed at appropriate station locations, and default attributes specified by the software relating to geometric and material properties of these instances can be modified.

For the bridge in our case study, the decks from two adjacent roadways merge together at a certain location into a single roadway. However, the available deck families are suitable only to model individual roadways and they do not have adjustable attributes to facilitate merging of two or more individual decks in order to generate a merged deck structure which we needed in this case study. Hence, we used “Mass” family available in Revit to model our custom geometry, which was just an object with just 3D shape information. Another limitation with the available bridge families is the missing semantic relationship information between instances of different families. For example, railings are hosted on the roadway deck, and bearing joints on the pier, much like light switches are hosted on the walls in a building model. Often, during a condition assessment of bridge elements, it is necessary to check for the condition of their connected joints. In such situations, it is useful to have semantic information about these elements available. As these are currently not defined, we had to manually define geometric parameters and constraints, and other non-geometric parameters for each and every family individually.

In a nutshell, some of the challenges that we have encountered associated with using the existing software systems are: (i) multiple software systems with complementing features were needed to successfully come up with the bridge design model, (ii) the default bridge design families available in current software systems can be parametrically customized only to a certain extent in the aspects of geometry, and cannot accommodate varied unique shapes that sometimes arise in bridge projects, such as the merged roadway deck case described earlier in this section. For such cases, new element families are needed to be created from scratch which can be tedious, time consuming and requires a skilled modeller, (iii) the instances of provided families do not automatically identify and support semantic relationships, such as topological connections and element host, concerning different bridge elements. Manually embedding such information is again a tedious process.

3.2 Improving 3D model using registered point clouds and on-site photos and model updating

A sequence of three steps is performed in this approach. They are (i) scan registration; (ii) deviation analysis; and (iii) 3D model updating.

3.2.1 Scan registration and subsampling

Typically, as a bridge presents complex geometries and are of massive sizes, detailed capturing of the entire bridge site is not possible from a single scan location. Therefore, multiple scans are acquired from various locations on the site. These scans are registered into a single spatially-rich point cloud representing the entire scene.

We used Faro SCENE 5.3 to register the collected scans (18 in total). During laser scanning, several spherical targets (17 in total) were spread over a maximum distance of 30 m, and there was redundancy in target overlap over multiple scans. Therefore, automatic registration of scans using Faro SCENE was sufficient to generate a complete 3D image of the bridge site along with error statistics, without requiring to manually select target features. All the individual scans were within a mean placement error of 1.6-5.6 mm. The registered scan had an overall mean error of 3.3 mm and standard deviation of 3 mm.

Each scan was at least 480 MB or more. Registering several of such big scan files together would make the process computationally intensive and sometimes even not viable depending on the user's available computational resources. So, we subsampled the point clouds by considering only 1 sample out of every 2 rows and 2 columns, and then registered the point clouds. As a quick validation test, we checked if the subsampled was still able to show 0.505" inch cracks, which was the smallest defect we measured on site with a micrometer. However, there is a possibility of existence of cracks smaller than the ones measured in this case study, at other locations in this bridge.

3.2.2 Deviation analysis

As a first step towards performing deviation analysis, we imported the point cloud into Revit and aligned it properly with the 3D model. Then, we used a useful extension in Revit – ScanToBIM, to perform deviation analysis between a point cloud and a 3D model

In order to bring a point cloud into Revit, it should be indexed into Autodesk Recap formats, i.e. either .rcp or .rcs format. At the time of this case study, i.e. June 2014, the latest Faro file version that could be supported for indexing by Recap was version 5.1. Since, we registered the files using Faro SCENE 5.3, indexing in Recap was not possible. We had to redo the registration process by converting each subsampled Faro .fls into .ptx format and then using them .ptx being a neutral format across many softwares, could then be indexed into Recap formats and thereafter brought into Revit.

In our approach, to align the scans, we identified elements with large outer surface area with minimal obstructions to the line-of-sight of these elements with the laser scanner. Typically, piers column walls, abutment surface walls and underside of the deck are good candidates to examine for large outer surface areas. Then, we finalized the surfaces whose surface normal pointed (almost pointed) towards one of the nearby scanner locations. This will filter out the occluded surfaces and ensure higher point density on the outer surface of the element, which in turn will result in a better surface-mesh fit. Next, we fit a reference flat surface to the dense point concentration representing outer surface of the identified element. Thereafter, we moved the model and made adjustments to minimize the deviation between the reference flat surface and the 3D model object representing the actual element. Precisely, in our case study, couple of outer walls of piers had high point concentration, so we fit a reference flat surface to these outer walls. After this alignment was completed, we shifted our focus to other elements in the 3D model and iteratively checked for model deviations with the point cloud using tools such as deviation map and deviation histogram provided by ScanToBIM extension inside Revit. These details are provided in section 3.2.3.

In this analysis, we realized that small number of deviations will always appear on the map and histogram, regardless of efforts to get rid of those. This is because point cloud is the representation of a real surface – that potentially is not flat and might also contain defects - which are impractical to model using existing 3D modelling software systems. Hence, small deviations are inherent and cannot be removed. To overcome this problem, we stopped iterative improvements to the 3D model immediately after majority of the deviations (roughly 80% of them) are within the 0-0.5 inches range as can be seen from the histogram (Figure 4). This is based on the assumption that such smaller range deviations do not significantly impact representation accuracy while modelling defects in this bridge. Also, major deviations (3-6 inches) were mainly near the connections. The reason being, to join together the elements modelled using structural beams family in Revit, we need to connect their anchor points (Figure 3). However, the actual beam boundary does not align with the anchor point, thereby causing an overlap in the 3D model, which consequently shows up as a point cloud deviation.

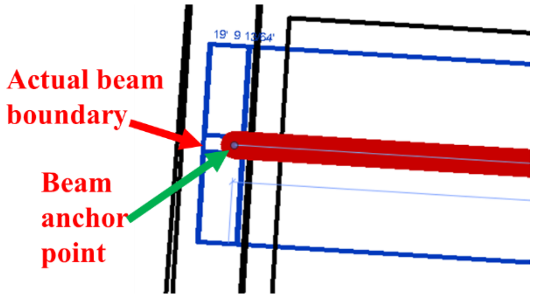

Figure 3. Actual beam boundary and beam anchor points are at different locations which can be a source of error while modelling connections

During our case study, we tried to perform deviation analysis for the whole bridge in a single operation. As there were several elements in the bridge, the software could not complete the analysis, instead it crashed. Later on, we excluded one of roadway i.e. 4FH with spans 4FH-1, 4FH-2 and 4FH-3 and all the elements under these spans (Figure 5) from the deviation analysis and proceeded with the rest of the elements (100 in total excluding the footings which are anyway underground). Still, the process took five and half hours to finish, on a computer with 64-bit Windows 7 OS, i7 processor (3.4 GHz) and 32 GB RAM. Therefore, this is a time-and-computationally-intensive exercise and current software systems are having difficulties in handling the whole bridge in its entirety or even half of it. Therefore, it is better to cluster small sets of bridge elements and addressing deviations pertaining to them separately, before moving over to another set till all the elements are covered.

3.2.3 3D model updating

Performing deviation analysis overlaying point clouds with the 3D model is an essential pre-cursor to accurately updating geometric and spatial details in the model. With the aid of feedback from useful tools, such as deviation map and deviation histogram in Scan-To-BIM extension, it is easy to iteratively adjust the 3D model components to fit closer to the point cloud, in order to minimize deviations. Table 1 gives details on some geometry and spatial updates which were made on the model for a specific bridge span.

Then, we corroborated the changes with available photos and hand measurements taken on the bridge. Photos, in particular, were helpful in identifying if missing points in a certain region were due to occlusions or were representative of actually missing sections (Figure 6).

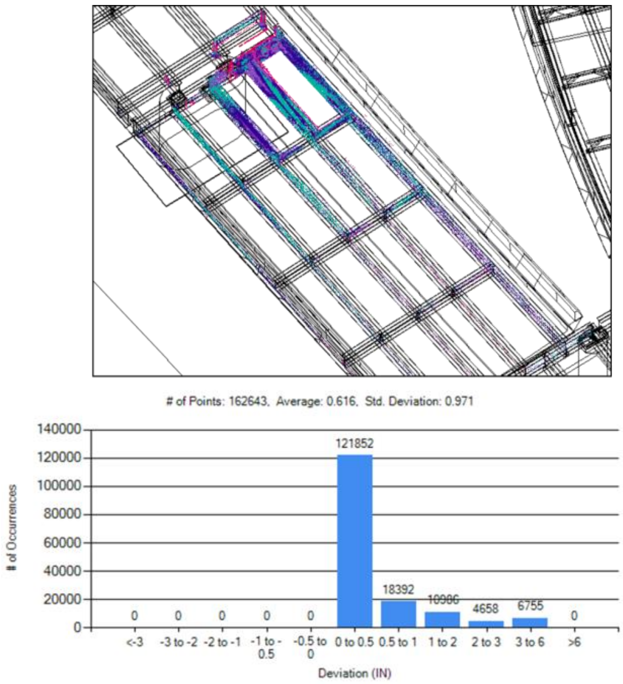

Figure 4. In the deviation map above, dark blue color indicates least deviation and red color indicates high deviations (> 6 inches). Below is the deviation histogram

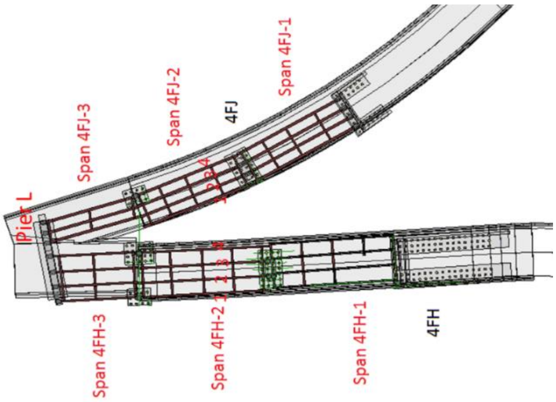

Figure 5. Prominent locations where model adjustments were necessary

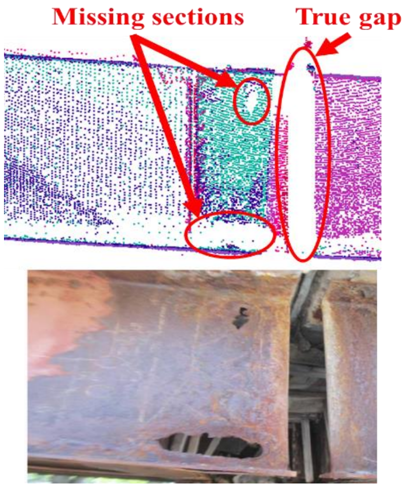

Figure 6. Point cloud overlay (above) on the model showed missing points (encircled in red); Corresponding image showing instances of missing sections as well as true gaps which were otherwise indistinguishable using only the point clouds

In all, 59 changes were made for the whole 3D bridge model out which 24 were *major* changes. The major changes included all types of changes such as moving elements, resizing elements, adding missing elements, and deleting initially-modelled elements that were based on wrong assumptions. Overall, changes were contributed by those made on girders (41%), beams (14%), piers (11%), bearings (11%), bracings (10%), railings (6%), deck (4%) and abutment (3%). Meanwhile, among the *major* changes, distribution is as following: on girders (50%), beams (14%), piers (7%), bracings (7%), railings (14%), and deck (8%). Looking at the percentages, sum of the number of changes involving girders and beams forms major proportion of all the changes. Additionally, most of the *major* changes were also from these two types. This could be attributed to the fact that assumptions regarding number of girders per spans and beam continuity were completely wrong due to misleading information in the design drawings. Similarly, proportion of contribution of deck and railings to the major changes is more than that to the overall changes. This implies that most of the changes needed to these elements were major.

3.2.4 Augmenting 3D model with object semantics and as-is conditions

After updating geometric and spatial aspects in the 3D model using approaches described in Section 3.2, we added semantic information, derived from the inspection reports, to the 3D model. The inspection reports, spanning several pages, contained information about bridge location, meta information such as identification number and intersecting features, and site inspection details. Besides these, we also found element condition ratings, condition descriptions given in text, defect sketches and photos of various elements in the bridge. It is necessary to embed this information into the 3D model to create an integrated information model that is a repository of condition information and semantic relationships between different spatial containers such as superstructure and substructure, and physical elements of the bridge such as beams, girders and piers. Using such a model, we can spatially and temporally reason with such an information-rich 3D model (Figure 7) to answer user-specific queries about as-is conditions.

Another aspect of information representation is the interoperability of such information with other commercial/research software, i.e. to organize them in an exchangeable format. IFC is a standard typically adopted used for interoperability of building information across software from different vendors [6]. Similarly, IFC can be applied for bridge domain, however, several bridge-specific components and their related attributes do not have formal representation in IFC standards, and should be represented using general IFC entities such as *IfcBuildingElementProxy*, *IfcPropertySet* etc. For example, in representing a bridge pier or abutment, it is necessary to model them as *IfcElementProxy* since the concepts of *IfcBridgePier* or *IfcAbutment* do not exist in IFC 2X4. Bridge-specific formal representations are envisioned to be included in IFC-Bridge, which is still under development, with several researchers across the world collaborating on this project. Nevertheless, as it is yet to be officially accepted as a standard for bridge information exchange, commercial software used in our case study was not compatible with IFC-Bridge.

Embedding relevant information into the model can be accomplished by adding expressions in a proper STEP format within the model's IFC file. For example, connection information between different bridge element objects in the 3D model can be manually defined in an IFC file in the following manner:

#216420=IFCRELCONNECTSELEMENTS('',#41,'','',$, #148580,#168507);

#216421=IFCRELCONNECTSELEMENTS('',#41,'','',$, #148580,#168563);

Here, *#148580* represents a bridge pier, *#168507* and *#168563* represent bearings. Likewise, "*IFCRELCONNECTSELEMENTS*" specifies the connection relationship between these elements. Similarly, spatial container relationship can be specified using "*IFCRELASSIGNSTOGROUP*". Other functional relationships involving the element, and meta information about spatial and physical entities can be represented using "*IFCPROPERTYSET*" and "*IFCRELDEFINESBYPROPERTIES*" [7]. Furthermore, Engin et al. [8] proposed the idea of using geometry as a representation of defects/damage in buildings. The defect representation and its context can be captured by "*IFCREPRESENTATION*" and "*IFCREPRESENTATIONCONTEXT*", respectively. Therefore, as-is condition information over different inspection and maintenance contexts can be associated with the 3D model.

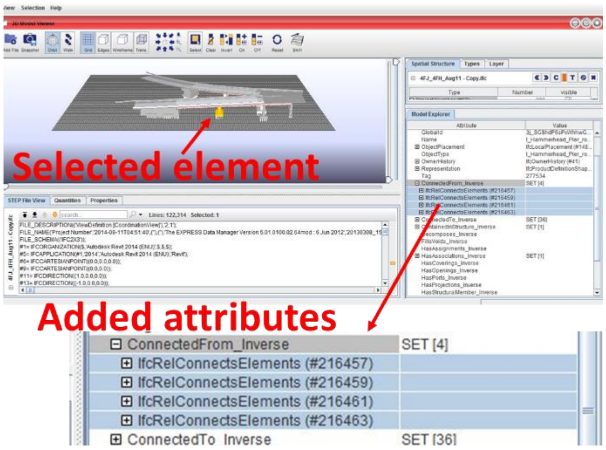

Figure 7. Prototype implemented using IFC Tools project [9] to demonstrate as-is BrIM

Major drawback of this approach is that, manually adding several of these properties concerning each and every bridge element to the IFC file can be tedious and error prone. In this case, adding just the connection information (222 in total) to the STEP file took about 20 person hours. Another drawback with the manual approach is that, all the additions to the STEP file will be lost if we make changes in the 3D model and re-export it back in IFC format. This is because line numbers in a STEP file, such as *#168563 (in the above example),* are randomly assigned, each time it is generated. On the other hand, automating the task of gathering custom model parameter values and mapping those values directly into an IFC file requires user's proficiency in programming, and Revit API and Extensible Storage concepts.

The challenges we encountered while augmenting the 3D model are: (i) lack of a higher-level interface to conveniently input geometric representation of defects as well as topological associations related to different elements in a 3D model, (ii) inability to reuse manually added semantic information after changes are made to the 3D model and re-exported to IFC format, (iii) inability to automatically map user-given information into relevant entities in an information exchangeable format such as IFC.

4 Conclusions

In this paper, we discuss a case study that we conducted to investigate challenges encountered in generating as-is BrIM. Some of the challenges are related to (i) available 2D design and as-built bridge drawings, which do not reflect the current conditions; (ii) lack of readily available parametric element families to model complex and unique geometry that varies from bridge to bridge; (iii) requirement of computationally intensive resources to support pre-processing of reality data; (iv) occasional lack of version and file format support between reality capture and 3D modelling software to effectively and efficiently capture and pre-process as-is data; (v) inability to automatically segment bridge elements and defect conditions from raw point clouds for high-level reasoning; (vi) occlusions during reality capture of bridges; and (vii) lack of flexibility to parametrically represent and exchange information about different types of defect/damage conditions using currently available software.

In relation to these challenges, some of the lessons learnt are: (i) bridge drawings potentially contain incorrect, obsolete and sometimes even missing details, hence the details should be corroborated with multiple information sources; (ii) modelling errors could be due to initial inaccurate assumptions about the design details based on the drawings or due to modelling constraints imposed by the software (iii) apart from programming skills, familiarity is required with strengths and shortcomings of various design software that support data exchange between one other, in order to devise workarounds in situations where a single software is not providing all the bridge modelling capabilities required for the project; (iv) while subsampling point clouds and deviation analysis, it important to understand the tradeoff between keeping all the relevant condition data intact/addressing minor point cloud deviations with the model, and squeezing all the computational and time resources available at hand; (iv) as of today, there is no available software system that facilitates automatic processing of as-is bridge information, as well as automatic mapping of that information into exchangeable format. This is necessary to be efficient and ensure less error-prone creation of as-is BrIM.

The findings from this study can help researchers in their efforts to advance state-of-the-art knowledge for semantically representing damage in bridge domain, and also towards formalizing a triangulation approach to generating as-is BrIM, using multiple data acquisition modes, such as laser scanning and imaging. This work can also help the bridge practitioners in making them aware of the bottlenecks in the process of as-is model generation of bridges, and also to plan better for carrying out a similar exercise.

Acknowledgements

The project is funded by a grant from the National Science Foundation (NSF), #1328930. NSF's support is gratefully acknowledged. Any opinions, findings, conclusions or recommendations presented in this paper are those of authors and do not necessarily reflect the views of the NSF. The authors also acknowledge the kind support from collaborators in our project, Prof. J Hajjar, Dr. B Guldur and Y Yan from Northeastern University for sharing the data collected from field studies, and Dr. D Huber and M Song from Carnegie Mellon University for their valuable suggestions.

References

[1] Johansen J. BIM in Bridge Design, *Masters thesis*. Norwegian University of Science and Technology, 2013.

[2] Drogemuller R., Yum K K., Froese T., Aranda-Mena G., Sher W. and Goodman N. Model Based Estimating System for Civil Concrete Structures, *Final Report*, Research Project No: 2005-0008-C-01. Cooperative Research Centre for Construction Innovation, Australia, 2007.

[3] Ross, R J., Brashaw, B K. and Anderson, S J. Use of laser scanning technology to obtain as-built records of historic covered bridges. *Research Paper* FPL-RP-669, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, 2012.

[4] Bui, T., Ravani, B., Rasky, T A. and Hiremagalur, J. Standards and Specifications for 3D Laser Scanning in Caltrans Projects. *Report*, AHMCT

Research Centre, the University of California, Davis, CA, 2007.

[5] Jahanshahi, M R. and Masri, S F. A new methodology for non-contact accurate crack width measurement through photogrammetry for automated structural safety evaluation. *Smart Mater. Struct.*, 22(3), 12 pp, 2013.

[6] Akinci, B., & Boukamp, F. Representation and integration of as-built information to IFC based product and process models for automated assessment of as-built conditions. *NIST SPECIAL PUBLICATION SP*, 543-550, 2003.

[7] Ghaznavi, M., and AbouRizk, S. An Integrated Multi-Dimensional Information Model Framework for Tunneling Projects using IFC Data Model, *CSCE 2013 General Conference*, Paper No. 128, pages 1-12, Montreal, QC, Canada, 2013.

[8] Anil, E., Akinci, B., Garrett, J., and Kurc, O. Representation of Damage Information for Post-Earthquake Damage Assessment of Reinforced Concrete Frames. In *Proceedings of ASCE International Workshop on Computing in Civil Engineering*, pages 825-832, Los Angeles, CA, USA, 2013.

[9] Tulke, J., Tauscher, E., Theiler, M., and Thomas, R. Open IFC Toolbox. On-line: http://www.ifctoolsproject.com Accessed: 30/01/2015.

Table 1 Model adjustments related to Span 4FJ-3

Compon-ent type	Location	Type of change needed (Move/ Resize/ Add/ Delete)*	Reason for change
Girders	Span 4FJ-3	**Add**	Initially assumed three girders based on drawings, but point clouds confirmed that four girders were present
Deck Joint	Span 4FJ-3/ Span 4FH-3	**Add**	Lack of details of Pier L under the roadway joint in the design drawings, relating to number of bearings and their types, angle of the joint etc. This part was left out of initial modelling efforts, and was completed with the help of point clouds
Beam	Span 4FJ-3/ Span 4FJ-2	**Delete**	Beam is continuous for these two spans. Initially, as the details were not clear in the drawings, beams were modelled separately for different spans
Bracings	Span 4FJ-3	**Delete**	Missing details in the drawings led to wrong assumptions about the type of bracings on this span. These bracings had to be replaced by a new type (Figure 1(b)) after taking measurements with the help of point clouds
Bearings	Pier-L	Move/ **Add**	With the addition of new girder, new bearing was added and previously modelled bearings had to be moved slightly to minimize deviations with the point cloud
Pier L	Pier-L	Resize	Elevation details for this pier had to be assumed in the initial model due to missing details. Point clouds revealed that the height of the pier column is more than what was assumed.

*__Bold__ font indicates **Major** change