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POST-EARTHQUAKE DAMAGE ASSESSMENT OF BUILDINGS: AN OVERALL OVERVIEW

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Abstract: Present act of post-earthquake damage assessment mainly depends on visual inspections. This paper aims to introduce the application of advanced field data acquisition technologies (e.g. Laser Scanning and Radio Frequency Identification) instead of time consuming and error-prone reports produced as a result of inspections. First, an overview of the past researches is presented in the area and outlines the processes required to implement these tools. It provides a discussion on information about damage, and how it could be captured using laser scanners and processed for a more objective and information-driven damage assessment practice. In addition to damage information, the paper suggests an outlook for integrating these systems and Building Information Modeling (BIM) for real-time project information management to streamline the damage assessment process. Aim of this research based on representing crack information. Compiling this information with BIM approach and a damage modeling software, results as-damaged instance models using Industry Foundation Class (IFC) exchange schema. In order to support damage assessment, three activities have to be taken into account: I) necessities recognized based on accepted damage assessment specifications; II) abilities of IFC explored for expressing crack parameters; III) recommendations provided for using existing concepts in IFCs for representing cracks.

Keywords: Earthquake damage assessment, Building Information Modeling, Industry Foundation Classes, crack.

1 INTRODUCTION

Architecture, Engineering and Construction (AEC) industry experiences low gainfulness rates, that is significantly related on how those project majority of the data is figured out (Eastman et al. 2008). Because of the way that the AEC industry, is one of the largest industry in the world (about 1.1 trillion in 2002), a small change in the resource allocation and utilization could greatly affect the supporting enterprises and general economy as well. This paper aims to prepare a platform for the AEC industry to improve current project information management practices, by using field data acquisition systems and building information modeling (BIM) to increase industry's productivity (Teicholz et al. 2001). All these systems provide a roadmap for research into the area of construction automation and damage assessment.

General practices in itemized assessment of structural damages due to earthquake require manual inspection of buildings and interpretation of results by experts (FEMA

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1999; Menches et al. 2008). Clarification of inspection reports and hand outlines requires expertise and understanding of the structural behaviour of elements (e.g., beams, columns, and walls making up an assembly). In addition, several challenges exist in the process of identifying damage severity. Firstly, damage severity is not solely a function of the detected damage (e.g., crack widths). Observed damage could be interpreted when the damage mode (e.g., shear, flexure, etc.) is known. More precisely, two cracks with the same width and orientation can correspond to dissimilar damage severities of different behaviour modes. Secondly, identifying damage modes of components necessitate understanding on how different components composing an assembly interact to withstand earthquake forces (FEMA 1999). Visual observations, manual reporting and interpretations have been shown that accompanied by disadvantages (Kempton et al. 2001; Menches et al. 2008). Addressing these challenges, necessitate accurate methods of collecting, storing, and processing damage information.

2 Field Data Acquisition Systems

Remote sensing techniques for field data collection such as airborne or terrestrial laser scanning (Torok et al. 2014), photogrammetry (Brilakis et al. 2010), Radio Frequency Identification (RFID), and other sensor-based technologies such as accelerometers (Goulet et al. 2015) are especially suitable for addressing valuable information of damaged area after earthquake.

2.1 Laser Scanning

This method often called 3D laser scanning (or laser radars, LADARs: Laser Detection And Ranging, LIDARs: Light Detection And Ranging) is used to capture shapes of objects, buildings and landscapes and deliver the Cartesian or spherical coordinates of thousands of points in the scene called "point cloud". Terrestrial laser scanning (TLS) is a ground-based, active imaging method that rapidly acquires accurate, 3D point clouds of object surfaces (Olsen et al. 2010). The deliverable, which is registered as point clouds, could be processed to 2D or 3D AutoCAD and BIM-based softwares. In order to have CAD or BIM outputs, point clouds that are containing extensive amount of information need to be taken through a series of process including data processing, registration, and modeling. Some studies have been done on integrating photogrammetry and 3D laser scanning to alleviate difficulties in point data processing like edge detection and object recognition (El-Omari et al. 2008). Laser scanning data is no longer sufficient, and a BIM model is recommended for providing information about the elements of the concerned building. The model contains information not only about the geometry, but also about the elements' properties and their spatial relationships. A semi-automated process has been developed that is capable of generating a BIM model that represents the post-earthquake damaged condition of the external façades of a reinforced concrete frame building (Sacks et al. 2015).

2.2 Radio Frequency Identification

RFID is also a commonly used data-acquisition system that applies radio frequencies. This system consists of a transponder (tag), transceiver and antenna or coil. The tag is composed of a computer chip with an internal memory in which a limited amount of information can be stored. This technology aims to decentralize objects' information by making it available wherever the object exists, also the combination of RFID, GPS, and GSM technologies, as a powerful portable data-collection tool, enables the collection, storage, sharing, and reuse of field data accurately, completely, and almost instantaneously

(Majrouhi 2012). A new wireless RFID-based platform is presented for the damage detection in Structural Health Monitoring (SHM) applications (Lisowski et al. 2016).

2.3 Sensors

Sensors have various applications in AEC industry, mainly in the form of deformations and temperature gauges or accelerometers to provide engineers with data needed to analyse and monitor the structural health of infrastructures and buildings. Although their application in the AEC industry has been limited so far, recent advancements in structural engineering require implementing electronic products for structural health monitoring such as embedded sensors. Akinci et al. (2006) carry out a case study on using sensors to record the concrete temperature to monitor the structural strength of cast-in-situ concrete. Naiem et al. (2006) had shown that the proposed methods for automated post-earthquake damage assessment of instrumented building could provide extremely useful information regarding the status of a building immediately after an earthquake by simple and rapid analysis of sensor data and prior to any building inspections.

Many of the introduced field data acquisition systems can be utilized in a more automated fashion by using robotics as a platform to automate data collection process and reduce the need for human labour (Rezaeian 2010). A set of machines embedded together, capable of performing specific autonomous or semi-autonomous operations intelligently in the field like moving is referred to as robotics. Figure 1 shows how to implement robotics, laser scanning, and photogrammetry together for automatic 2D mapping and 3D model reconstruction of indoor environments. At the highest level of detail of the structure, airborne laser scanning technology has been applied in post-earthquake responses for identification of damaged buildings and for classification of the buildings according to the type of damage sustained (Dong and Shan 2013). Laser scanners have been shown to be efficient for detecting cracks and other damage indicators due to their long range, light independence, and accuracy (Anil et al. 2013).

3 Fragility Curves for Damage Assessment

Assembly-Based Vulnerability (ABV) is a framework for evaluating the seismic vulnerability and performance of structures on a building-specific basis, utilizing seismic analysis models to determine the structural response of a building. The approach, accounts for the detailed structural and non-structural building components and corresponding fragility curves, and subsequently applies BIM-based techniques to automate the generation of damage assessment (Christodoulou et al. 2010). An optimal procedure of FCs construction must be based on numerical simulations performed through NLDAs; the seismic action must been modeled by natural accelerograms. The damage model must been defined considering a representative limit states; they should be able to describe the different damage conditions (Mastroberti and Vona 2016).

Fragility curves quantify the vulnerability of the frame and provide understanding of the impact of different component failure mechanisms on frame vulnerability (Brilakis et al. 2015), and relate structural response with various levels of damage, producing the probability of a structure reaching or exceeding a particular damage level.

Additionally, for a detailed assessment, the quantities and details of re-bars, material properties, connectivity of components are needed (FEMA 1999). Therefore, the semantics of the building components, as well as mechanisms for processing the damage information and structural properties of the building is required to identify the damage severity of buildings.

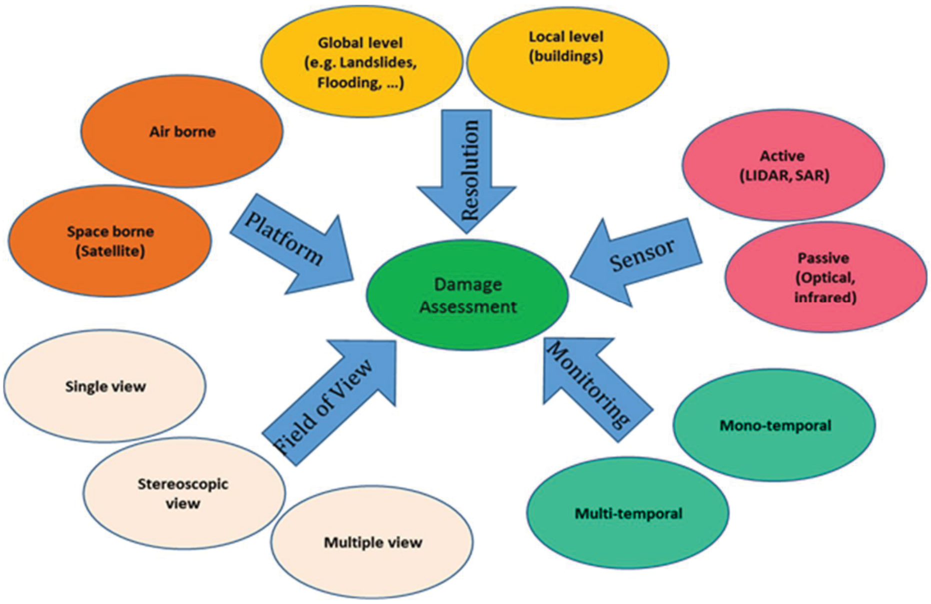

Figure 1: Remote sensing methodology for damage assessment

BIM models can handle both illustration and inquiring of the required properties of building components as well as topological connections between components (Paul and Borrmann 2009). However, current BIM approaches do not support representation of damage facts. Hereafter this paper concentrates on representing crack information obtained from laser scanners to support identifying damage severities of elements. The paper probes several methods for representing important crack characterization using existing capabilities of IFC. Only elementry properties of cracks, such as width, location, orientation, and path were considered. These properties can be distinguished and analysed by automated algorithms (Tsai et al. 2012). Use of texture maps and association of raw crack information to building components through the utilization of external documents is discussed as well.

Design and implementation of developing reasoning mechanisms, and representation of other damage indicators are ongoing research tasks. This paper presents the preliminary results in the representation of raw crack information using Matlab (2014) software.

4 Information Requirements and Research Approach

In current practice, primarily, crack constitutes the first visual damage assessment of structures. Crack is the initiation and the most important sign of damage intensity from minor to moderate level. Damage progress, will be intensified by further causes, such as concrete spalling, re-bar deformation, crushing of core concrete and in fills, and splitting of the concrete cover due to lap splice slips (FEMA 1999).

Detection and identification of damage to building components becomes possible by using terrestrial laser scanning (TLS) or photogrammetry with less than 1 m resolution. The damaged shape and state of a distorted component depends on the sequence in which local sections of the structural element bear displacement, cracking and eventually failure. The progress of damage at any given section is relied on other sections, due to yielding of re-bars, cracking or crushing of concrete at those locations where the applied stresses, exceed capacity. As a result, the component behaviour changes from the original structural design intent (Ma et al. 2015).

The damaged modes are categorized as below:

- Surface cracking
- Spalling and delamination
- Bending and buckling
- Shearing and breaking

A designer uses relative locations (respective to the component geometry and to each other), orientation, length, and width of cracks on a component to classify damage (FEMA 1999). For instance, horizontal cracks on a vertical sturctural element (e.g., column) indicate a bending and buckling type of damage, whereas diagonal cracks designate a shearing type of damage. Vertical cracks along the sides of the components may specify spalling and delamination of the cover concrete due to slipping of lap splice. Focus of cracks at corners of walls may point out crushing and widths of cracks indicate the severity of the damage for different damage modes.

A few representation schemas can be conceivable relying upon the usage and the reasoning mechanism, which works on the model. For instance, it is likely to derive some fundamental features utilizing crack patterns, orientation, and width as a first step of crack classification algorithms (Tsai et al. 2012). Specifically, this paper concerns the representation of the crack path, width, and relative location of cracks on a given component surface (Figure 2).

(a) (b)

Figure 2: Sample of crack paths and point classification.

This research considers the latest officially released IFC4 schema (BuildingSmart-tech.org 2017) for storage and exchange of building information over the entire life cycle of a building. However, the IFC schema cannot be considered as complete, since there is a continuing need for new features to enhanced data definitions, especially for specific domains within the construction industry for representing some of the required crack information. Enrichment of the IFC schema has been suggested to extend its ability to model elements of all structures. Although the current IFC schema comprehensively covers a building's designed and as-built models, but it lacks some of the parameters needed to model as-damaged building elements. Following the damage process described above, the first missing concept is the representation of cracks. In some cases, it may be sufficient to represent a superficial crack as a feature on the surface of an element; this can be done using the "IfcSurfaceFeature" entity and its associated relationships and geometry.

For identifying the cracks, an application can be used to distinguish surface points (Figure 2). In this manner, a plane is fitted to a region of fixed size, around each area using a robust method, such as RANSAC, and thereafter an elective method is used to organize points. In every region, if the number of points that are within "2s" distance from the local surface are greater than the number of points that are farther than "2s" distance, then the point is classified as being a crack point. Here "s" indicates the standard deviation of range measurements.

An assumption of 10 cm can be used for an accurate neighborhood size. This method is sensitive to other off-surface points, such as joints, voids or mortars (Figure 2).

5 Representation of As-Damaged Building Models

The original motivation for this work was to introduce two applicable concepts for signifying basic crack information as follow:

- Surface maps to link crack information to component surfaces using presentation methods after minimal modification to IFCs.
- All crack information will be stored in an external file, which are readable by storing crack information to the model and linking the external file to components using "IfcRelAssociatesDocument" object.

5.1 Surface Maps

IFC is an object-oriented data schema and supports annotations, such as text, hatching, tiling, colouring, and texture mapping. These annotations can be attached to semantic objects or can be isolated, such as grid lines. IFC allows representing the geometric specifications and shaping information. Surface maps, in particular, can be in the form of 2D images attached to surfaces.

A coordinate mapping exists between the 2D images and 3D space. The kernel of the proposed data schema extension is shown as a diagram in (Figure 3). Shaping information is attached to surfaces using the "IfcStyledItem" object. By using the surface mapping mechanism, images containing the crack information can be mapped to the component surfaces. IFC permits controlling the appearance of the elements under different contexts and views using the "IfcSurfaceFeatureContext" and its sub-context "IfcSurfaceFeatureSubContext" as shown in Figure 3.

The UserDefinedViewTargetView attribute can be assign to “Surface_Crack_Map” or any other unique entity to distinguish the crack information from other indentifiers. Some objects, such as "IfcbuildingElement", are abstract, which means that they serve as parent objects in the inheritance hierarchy, but they cannot be instanced.

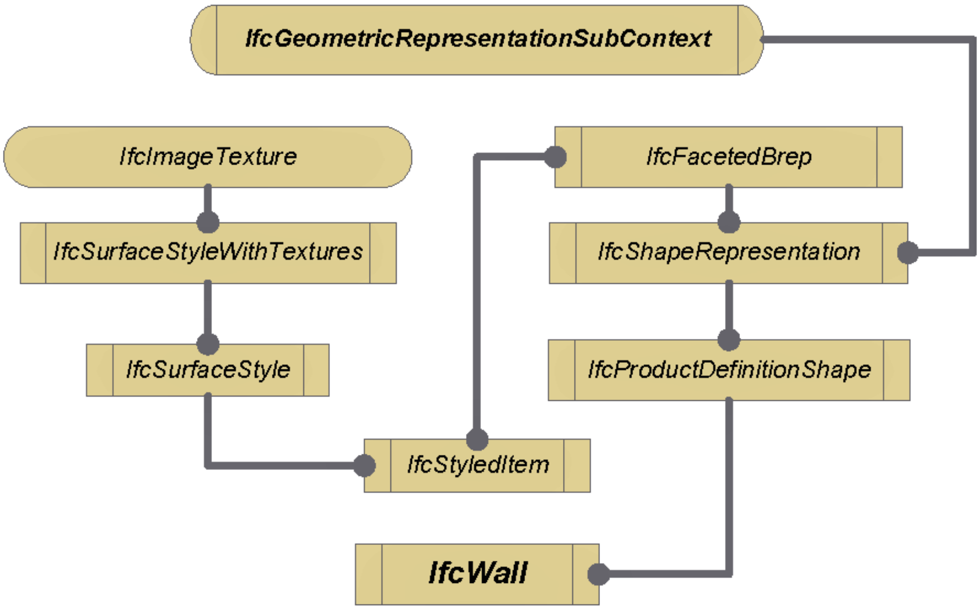

Figure 3: Class diagram of objects related to surface mapping.

IFC allowing specific building object entities like "IfcWall", "IfcBeam" and "IfcDoor" to share common property definitions.

5.2 Recognition and Storing of Propagative Cracks

According to the identified damage modes, a crack is an intermediary of the propagative damage process. Crack information will be stored in an external file, which can be linked to the building components using "IfcRelAssociatedDocument" relationship. The file can contain all components information, and as an advantage will be directly linked to the raw point cloud. One potential benefit of the external file is that it can be linked to all components and in addition to process the information. If necessary raw point cloud can be useful for later processing. In this approach, the crack information can be exported as text files, where a crack is represented with a polygon determining the crack path, its width and orientation (Table 1). Similarly, the raw point cloud can be linked to the components.

Table 1: Detected crack paths and widths can be stored in an external file.

#X	Y	Angle	Crack Width
-2.450	-2.93	44	5.22
-2.457	-2.80	86	10.2
-2.461	-1.90	5	3.1

6 Conclusions and Future Work

This paper presents a review on field data acquisition systems and an introduction to damage models, which conducted to explore how to identify basic crack information. The crack properties included crack path, width and its orientation. By minimal changes to the IFC specification, two concepts developed in this research. One is to represent, the crack information surface map and the other is externally linking crack information to the building components. Both of approaches require a minimal change to the IFC schema to support representation of crack information linked to building components. However, future research is required in order to validate whether the two techniques suggested here can support identification of damage levels and severities of the components. Also or more representation of cracks is needed within IFCs to simplify and possibly automate the reasoning about cracks. Future research can be conducted to develop as-damaged building models for both structural and non-structural elements as a full record that include the explicit damage sequence data.

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