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Interior models of earthquake damaged buildings for search and rescue

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ABSTRACT

Survivors trapped in void spaces formed when buildings collapse in an earthquake may be saved if search and rescue (SAR) operations are quick. A novel computational approach aims to provide building information that can guide SAR teams, thus minimizing their risk and accelerating operations. The inputs are an 'as-built' BIM model of the building before an earthquake and a partial 'as-damaged' BIM model of the exterior components after the earthquake derived from a terrestrial laser scan. A large set of possible collapse patterns is generated before the earthquake. After the event, the pattern with geometry most similar to that of the 'as-damaged' exterior BIM can be selected rapidly. This paper details the selection methods, which use least sum of point distances and Modal Assurance Criteria (MAC) algorithms, and illustrates their operation on a series of simulated computer models of collapsed structures, thus demonstrating the potential feasibility of the proposed approach.

1. Introduction

Collapsed buildings are the most significant direct cause of death and injury in earthquakes in urban areas. Search and rescue is hampered by the difficulty of locating victims; a recent review of the state-of-the-art in technology for search and rescue identified the need for development of new tools to locate victims [1]. Survivors are most likely to be found in void spaces (triangles of life) that are formed naturally in damaged buildings [2]. They can be saved only if search and rescue (SAR) operations are quick and efficient, because the probability of survival decreases rapidly over time. Tunneling from void to void to reach a trapped occupant, a common rescue method, is slow and dangerous work but frequently required in order to reach trapped occupants [3,4]. Information about the structural elements and other large building elements, their original sizes, composition and material, and their new locations in the damaged building, would enable SAR teams to search selectively and thus minimize the risk and accelerate the search process.

However, with existing technology, no information about the existing voids or the state of the internal structural system of the damaged building can be provided, making it difficult for decision makers on site to choose the safest and most efficient void from which to begin. The authors propose a technological approach that can provide this information during SAR operations.

As the literature review below reveals, most existing automated damage assessment methods provide broad classifications of the damaged state of entire buildings, with only generic, descriptive information about the possible conditions within a building. Existing applications of laser scanning for earthquakes, for example, can only determine the location and damage type classification of each building [5]. Kashani et al. [6] used terrestrial laser scanning to survey homes damaged by a tornado and succeeded in identifying damage to roofs and walls of individual buildings. A promising procedure is that of Zeibak-Shini et al. [7], which provides information about the exterior components of a damaged building using terrestrial laser-scanning and a pre-existing Building Information Modeling (BIM) model. However, it too cannot reveal anything about the interior components.

In response to these limitations, this research explores the use of BIM technology and simulation tools for estimating potential collapse patterns to rapidly derive detailed information about the interior geometry of a damaged building, its systems and its contents, for the use of SAR teams. The proposed method relies on two sources of information: (a) detailed definitions of the state of a building before an earthquake event, embodied in an as-built BIM model and (b) a partial BIM model of the visible exterior components of a damaged building, compiled using the procedure developed by Zeibak-Shini et al. [7]. The research objective is to demonstrate the proposed method and its potential feasibility, which is dependent on rapid processing of information after the earthquake event. The information includes the potential collapse patterns, which are generated *before* the earthquake event. After

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the event, the information is screened and filtered to select the most likely pattern(s).

The background and literature review section that follows reviews existing automated approaches to acquire information about buildings in the period immediately after an earthquake event. It also provides the necessary background to BIM and the simulation technologies that are needed in the proposed solution. The third section outlines the proposed process, placing the structural simulation and model selection components that are covered in this paper in the context of the overall process that includes laser scanning and derivation of the exterior as-damaged model. The collapse engine and the selection (screening) algorithms are the subjects of the fourth and fifth sections respectively. Following the layout of the process components, the series of tests conducted to illustrate the basic feasibility of the concept are described in Section 6. The discussion and conclusion Sections 7 and 8 highlight what has been achieved and what remains for future research and development.

2. Background and literature review

2.1. Damage detection and determination of damage type

After an earthquake in an urban area, the number and location of collapsed buildings are unknown, as is the number and medical state of the people trapped inside these buildings. For efficient disaster recovery response SAR teams need information about the location and state of damaged or partially or totally collapsed buildings in the affected area [8]. Therefore the need arises for rapid and reliable information gathering [9–12]. Remote sensing techniques for data collection (such as airborne or terrestrial laser scanning [8,13]) and other sensor-based technologies (such as accelerometers [14]) are especially suitable for obtaining large scale information about the damaged area after a disaster. The data collected by sensors can be processed using methods such as error-domain model falsification to overcome uncertainties of residual structural resistance that arise from incomplete data [15].

By comparing undamaged, pre-event, scanning data with data collected after the earthquake, information about the location and damage characteristic of each building can be retrieved [16]. The information derived from data collected by scanners or photogrammetry will include the location and even the damage type of each affected building which are the main factors in deciding the needed SAR resources for each partially or totally collapsed building. Yet the most important information about the internal condition and the possible locations of trapped occupants in each building is not available and cannot be derived from the scans.

Another approach that has been proposed is to collect video and/or photo images of the damaged building and to recognize cracks and other damage in structural components using image recognition algorithms [17,18]. Cameras may be mounted on unmanned aerial vehicles (UAV) [19]. This has the advantage of speed, but it too cannot provide information about the internal conditions.

Schweier and Markus [5] developed a classification system of collapsed buildings based on analysis of a large data set of post-earthquake damage reports and photographs. This "damage catalogue" includes ten different damage types of entire buildings typically occurring after earthquakes. Each damage type has specific geometrical features that can be detected by comparing pre-event scanning data with post-event scanning data. The damage type of each affected building can be determined.

Identification of damage type allows fast and efficient allocation of SAR teams and resources, but cannot provide enough information to enable a more efficient search inside each damaged building. The 'disaster management tool' (DMT) is a software application that was developed to try to provide complementary information about potential survivors. One part of the DMT consists of casualty estimation based on building stock and residential data together with estimation of damage type based on laser scanning data. Another part of the system is based on the augmented reality (AR) technology which provides a three dimensional view of the building before damage superposed with the actual image of the damaged building [20]. The comparison of the real collapsed building view with the view of the building before damage, from different perspectives, can help discover areas with possible voids and possible locations of trapped survivors. Nevertheless, the view of the internal geometry, which ultimately defines the void spaces, is revealed only when physically going into the ruins.

The motivation of this research is to provide this needed information with minimum risk to the SAR team. Providing this information before going into the ruins can help decision makers and enable a selective, more efficient, and less dangerous search.

2.2. Current SAR tools and technologies

Situational awareness of the search site is crucial for decision makers in SAR operations [1]. The need for new technologies, or improvement of existing technologies, for searching an urban disaster area for survivors is a key driver for research such as the EU "Second Generation Locator for Urban Search and Rescue Operations" project (EU-SGL) [21], which identified that the first information priority needed is general and quick assessment of victim location [1]. Various tools are available for locating trapped victims in the rubble of collapsed buildings each has advantages and disadvantages [22]. Electronic devices like small diameter search cameras are used to penetrate into void spaces to provide information about the trapped victims, but often visibility is limited due to dust or smoke. Infrared systems (IR) are used in a similar way, detecting sources of heat. They are especially effective in smoky environments, although the information they provide is often inaccurate due to sources of heat other than from the human victims. Acoustic devices are also used to detect victims but their use is severely limited in noisy search sites. Another disadvantage is the inability of such devices to locate unconscious victims. Another new method is the use of microwave life detection systems which can detect breathing and heartbeat signals of human subjects through rubble or a construction barrier of about 10-ft thickness [23].

More recent developments include the use of robots, equipped with different sensors, that can explore voids deep inside the rubble, going through spaces that are too small for a human to crawl through, areas of fire or areas without breathable air. Research in this area poses many challenges, such as the need for many different sensors to be mounted on a small sized robot, and mobility issues of the robots [24,25].

Canine search is often used together with the electronic tools to locate survivors (trapped or unconscious) and bodies. The search dogs are trained to find the scent of a human and indicate a find to their handlers, by barking for example. Although the dogs are well trained their abilities are affected by many environmental conditions and the search process is quite slow. It should also be noted that the number of trained search dogs is limited [22] and that the training process is long.

While all of the above mentioned methods and technologies improve the situational awareness of the SAR teams, they are not able to provide complete or accurate descriptions of the interior of the building. Information about the formation and location of the voids inside the rubbles is limited as the different sensors can only provide visualizations of small areas. Information about access holes and rescue paths is also very limited.