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Original article

Context-aware risk management for architectural heritage using historic building information modeling and virtual reality

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ABSTRACT

This research proposes a data structure for context-aware risk management for architectural heritage using Historic Building Information Modeling (HBIM) and Virtual Reality (VR). In cultural heritage domain, risk management plays a key role in the preservation and intervention of the heritage. For effective risk management, it is important to share enriched data between people who monitor and diagnose heritages and people who recognize the context of information. The 5W1H (what, when, where, who, why, and how) model-based metadata structure for context-awareness and the framework for linking the HBIM with VR environment which enables sharing and retrieving of risk management information are proposed in this research. Two prototypes were created; an on-site VR application for the heritage managers and a remote VR application for the conservators. The effectiveness of the applications was verified through an experiment including a user survey to compare the paper-based and the VR-based methods regarding on-site VR application, and a focus-group interview regarding the remote VR application. This study enabled to integrate risk management information scattered across a variety of sources and formats, provide contextualized information. Thereby it shortens the time and effort spent to find and share information by heritage managers and conservators.

1. Introduction

In the architectural risk management field, researches on methods and tools to help conservation and management planning decisions have been carried out by many cultural heritage organizations. Risk management can be defined as the process of identifying, assessing and analyzing possible damage or establishing a strategy to reduce the damage of cultural heritage [1]. However, risk management of architectural heritage is more complicated due to the combination of structural instability and component degradation [2]. So, new methods and tools are necessary to assess, analyze and establish a strategy to reduce damages for risk management of architectural heritage.

In this research, a new form of metadata and a risk management framework that use Historic Building Information Modeling (HBIM) data in a virtual environment for risk management of architectural heritage is suggested. For this purpose, it is important to share enriched data between the people who monitor and diagnose heritages and people who recognize the context of information. Our method enables efficient risk management by connecting HBIM and VR, and providing contextualized information. Specifically, it consolidates risk management information scattered across a variety of sources and formats, provides contextualized information, thereby shortens the time and effort spent to find and share information by people monitor and diagnose heritage.

There have been several problems in the field of risk management of architectural heritage. First, HBIM, a tool for managing information on architectural heritage, could not utilize enriched data. Information that can be stored and managed by HBIM has recently become enriched with non-geometric data, but its use is limited due to the proprietary issues with external systems [3]. Second, metadata for cultural heritage information management does not provide information appropriate to the user's context [4]. The existing metadata does not reflect the context of risk management because it is intended to archive and manage information [5]. Third, the on-site heritage manager and the conservator who diagnoses the risks were not able to share information efficiently.

In this study, we proposed following method to overcome the limitations. We present the 5W1H (what, when, where, who, why, and how) model-based metadata structure for context-awareness, and suggest the framework for linking the HBIM with VR application which enables sharing and retrieving of the risk and historical information. The use of metadata in this research provides contextualized information that is relevant to the context of the subject,

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the user, and the interaction in the virtual environment. In particular, we defined metadata based on the 5W1H model, describing a situation that uses sensors, service, and the user's points of view for generic purposes [6]. Therefore, the model can provide the basis for context-awareness and for secure extensibility to provide further contextualized information [7].

We developed two prototypes, an on-site VR application for heritage managers and a remote VR application for conservators, and conducted a user survey to verify the effectiveness of the applications. Our findings can be summarized as follows. First, the VR method proved to reduce the time to perform risk management tasks compared to the traditional paper method. Second, the VR method also showed that it reduces the frustration of the user compared to the traditional method. Third, the VR method had some difficulties navigating in a virtual environment but proved to be more effective than diagnosing risks on site.

2. Related works

2.1. HBIM for risk management

The HBIM system is a management system that integrates the historical information of the architectural heritage and builds the risk information into a database linked to the 3D model. Although the data structure of HBIM is not fully suitable for browsing risk management information and updating conditions of cultural heritages on site [8], the HBIM system has an advantage in the integration of heritage information such as historical documents, monitoring data, structural data, and conservation states for use in conserving and monitoring works [9]. So far, researchers have tried to apply HBIM to support conservation and monitoring works related to architectural heritage [10].

Initially, HBIM was used for archiving and visualizing geometric and non-geometric information. Several researchers have used a parametric library of HBIM to convert architectural heritages' point cloud and photogrammetry data of into 3D models [11–17]. Because geometric information alone lacks the diversity of information available for cultural heritage management, it has recently included non-geometric information. Researchers have suggested the integration of non-geometric information to utilize HBIM in architectural heritage management; this has enabled data enrichment [18–23].

In order to take full advantage of HBIM's rich information, it needs to be connected to an external system, which has been difficult due to the proprietary issue of HBIM software. Several systems have connected with BIM through GIS and semantic technology [3,24]. Dore (2012) imported the HBIM model into GIS and converted it to CityGML [24]. And Quattrini (2017) used semantic technology to enable HBIM data to be used in web-based browsing systems and VR application. [3].

These existing systems contained contextual information essential to information management but did not reflect contextual information in terms of risk management. It is because the systems were intended for the archiving and browsing of information on the web. However, contextual information in risk management is critical for understanding and judging the state of a risk. In order to retrieve and provide context information suitable for risk management in a system connected with HBIM, a specialized data structure is needed.

2.2. Metadata for context-awareness in risk management

Metadata can be defined as structured information that makes it easy to search, describe, use, and manage information resources [25]. So far, many European governments and institutions have defined their own metadata and accumulated monument records accordingly. For example, The CARARE metadata schema includes 3D models in its digital resources related to architectural heritage [4].

However, these existing metadata have three limitations. First, the metadata of existing digital applications cannot guarantee that these applications will have suitable features for the virtual management of 3D models and information [26]. Second, the metadata lack descriptions of users and situations because they are mainly designed for the documentation and management of heritage information [5]. Third, the metadata cannot reflect local features and problems related to regional diversity and variation. Therefore, a unified context model is necessary to define the metadata structure for information management and for context-aware information retrieval.

Context is defined as any information that can be used to characterize a situation of an entity. The Entity means a person, a place, an object and an application that is relevant to the interaction [27]. Until now, various context-aware applications have emerged based on this definition and have been categorized as one of the following: the presentation of information and services to a user, the automatic execution of a service, or the tagging of context for later information retrieval [28]. However, most ways of modeling context were specific to the service or give undue value to particular information [6].

Therefore, to overcome this limitation, the metadata structure and the metadata is proposed for the risk management of architectural heritage using a unified 5W1H model in a context-aware application design. Context-awareness, such as recognizing the spatiotemporal background of a risk, is important in the risk management of architectural heritage because it enables an effective response to the given status of risks. Therefore, context-aware application in the risk management domain should include metadata that describe various contexts to ensure the effective presentation and retrieval of information.

The 5W1H unified model supports applications that perceive the users' situations in various environments by sorting complex contexts into six categories (what, when, where, who, why, and how). The unified context has several advantages for context-awareness. First, it provides a basic set of elements with a user-centric context. Second, it enables the generation of various situations involving the sensor such as GPS, the user, and the service according to the 5W1H semantic structure. Third, it has a context hierarchy for dynamically generating context. Finally, it is easy to utilize when developing all application in any environment, because it has structured elements [6,7]. These advantages of 5W1H model are beneficial for redefining and organizing information structures in systems such as VR applications.

2.3. VR for risk management

In the construction domain, VR technologies have been used for visualization of geographic data to support decision making and management of maintenance data in real time [29,30]. In the architectural heritage domain, VR technology is a valid cognitive tool and is a fundamental medium through which a user can interact with virtual heritage and heritage information in a virtual environment [31]. VR applications in the architectural heritage domain are meant for preservation, documentation, research, education, reconstruction, and exploration [32]. In these applications, VR technology has been primarily applied to intuitively share and visualize information and to provide the latest 3D model information for heritage buildings [33–37].

In detail, the use of VR technology in the field of risk management of architectural heritage also has some advantages; first, it allows to people to interact, intuitively share critical information