An Augmented Panoramic Environment to Access Building Information on a Construction Site

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A panorama is a continuous wide view of a real or virtual environment that provides the viewer with a natural feeling of being in such an environment. Panoramas can provide the visual backdrops and contexts for any augmented information such as audio, text, video, or 3D objects. This augmented panoramic environment can create an interactive space to provide information and bring the panorama to life. Having a panorama of a construction jobsite, and superimposing the building information models on it, would provide construction personnel with a simple way to access their required information in a natural and interactive environment. In this research, a workflow was developed to access building information augmented over the panoramic view of the real-world physical environment of the construction jobsite. A prototype was developed based on the created process and a user participation case study was conducted to test this system on a construction renovation project. The results show that, an augmented panorama can provide a location-independent virtual reality experience, which is not significantly different from a pure-augmented-reality setting.

Keywords: augmented panorama, augmented reality, building information modeling, human-computer interaction, user-centered evaluation, case study

Introduction

Panorama is defined as "an unbroken view of the whole region surrounding an observer" (Oxford Dictionary 2008). "The sense of presence, of being there" (Bourke 2014) is one of the key reasons to use panoramas. In other words, motivation for an immersive visualization of the environment is the main reason to use panoramas. A panorama captures everything visible from different positions, increases the capabilities of the human visual system, gives a sense of immersion, and can create highly realistic and detailed representations of the environment (Bourke, 2014). Panoramas have been used in very different domains from 19th century in mainly depicting patriotic moments of wars or scenery of distant lands, historic cities, or exotic places (Comment 1999) to more recent applications in creating satellite photographs, (Moffit et. al. 1980), virtual environments (McMillan et.al. 1995; Szeliski 1996), virtual travel and architectural walkthroughs (Chen 1995), and even for educational purposes (Black & Heatwole 2011; Gheisari et. al. 2015). Nowadays footprint of panoramas in forms of virtual tour galleries and videos can be found in variety of websites and mobile applications and have been used for a variety of purposes such as walking through museums, viewing hotel rooms, visiting different cities or exotic locations around the world.

Panoramas have also been tested in different ways by researchers in the construction domain. The majority of these research projects have used panoramas of the real environments as a backdrop to augment mainly 3D models on them (Côté et. al. 2011a, 2011b, 2012, 2013a, 2013b; Wither et al., 2011). For instance, Côté et al. (2011b) used panorama of the surface of a street to augment a virtual excavation and illustrated underground utilities on it (Figure 1-a). Furthermore there have been many examples of augmented panorama used in Architectural and Real Estate domains for creating virtual walk-throughs of real environments for clients. In such application, panoramic images or videos taken from interior, augmented with various types of information (e.g. virtual 2D signs, audio, or 3D models), would create a natural tour of the building for potential buyers (Figure 1-b). Augmented panorama is capable of simulating an immersive experience of walking inside the real space for users.

In this research project, adding layers of information on offline view of the environment is defined as augmented panorama. Augmented panorama, because of its static and offline characteristics, has been considered as an

opportunity to cover the limitations of a pure augmented reality (AR) experience. This is because augmented panorama does not superimpose the virtual layers on the real worldview but to a captured skybox virtual representation that is offline but looks similar to the real environment. Both AR and augmented panorama have their own imitations and advantages. The main difficulty with AR has been the issue of registration: properly matching the augmented 3D model or other type of virtual data over a physical object in reality. Augmented panoramas do not suffer from this registration problem but they provide a natural and intuitive semi-AR experience that is also location-independent. Location-independency means that in an augmented panoramic environment the user would not need to be present at a specific physical location to experience the virtual augmentation. The main disadvantage of an augmented panorama is that panoramic images or videos cannot be updated in real time (Côté et. al. 2013b; dos Reis et. al. 2014). But the same limitation might be considered as an advantage for situations and applications that would require location-independent experience of real environments, which cannot be achieved through an AR method.
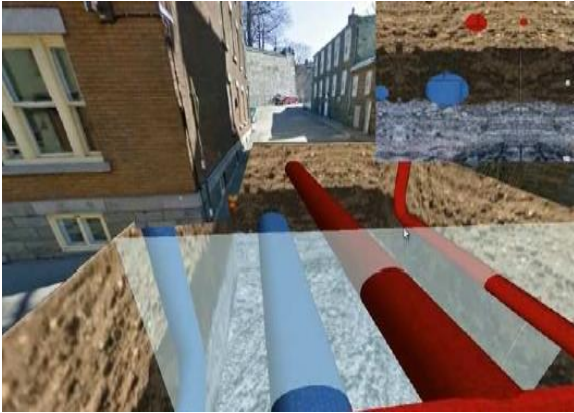
<table>
<tr><td>(a) Virtual excavation for subsurface and utilities (Côté et. al., 2011b)</td><td>(b) Panoramic tours for real state applications (URL 1)</td></tr>
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Figure 1: Panorama applications examples for construction and real-state domains

In this research project a workflow has been proposed to create an augmented panorama for construction purposes. This workflow then was used in a construction-related case study to create an augmented panoramic environment. The same case study was also created following a pure AR approach (Williams et al. 2014) and were both tested with construction professionals on the jobsite to investigate how different these two environments are considering the construction user perspectives. Attention to human factors and user requirements would yield successful technology development and integration in AEC (Architecture, Engineering, and Construction) domain (Wang et al. 2013). In this paper, the goal of the case study is to investigate how a panorama of a construction jobsite augmented with building information models would provide a semi-AR experience for construction workers to access their required information.

Architecture & Workflow of an Augmented Panoramic Environment

Creating an augmented panorama view consists of several steps. First, it's necessary to identify the location of a user since digital augmentations and panoramas are generated based on that position. Next, a sequence of photos of the environment is taken from a panoramic camera. After stitching individual images to an equirectangular projection, the panorama image needs to be converted into six square textures for rendering. Fig. 2 presents the augmented panorama architecture, which has three phases: data, reconstruction, and presentation. In data phase, panorama and 3-dimensional (3D) model are generated respectively as inputs to the next phase. Panorama of the environment is captured as six square images, which forms a skybox and then will be superimposed by click-able 3D models of building elements. The 3-dimensional (3D) model of the room is isolated from building information model and exported as a Collada file. During the reconstruction phase, 3D geometry are translated, orientated, or scaled in order to fit within the skybox. Each object is associated with material and BIM data as external referencing sources for graphic rendering and information retrieval. In the final presentation phase, handheld devices such as iPads or iPhones loaded with Argon 2, an open-standards augmented reality browser, enable the users to see and interact with digital augmentation on panorama. When orientation updates, Argon 2 will also update the virtual camera in the 3D environment to align with physical surroundings.
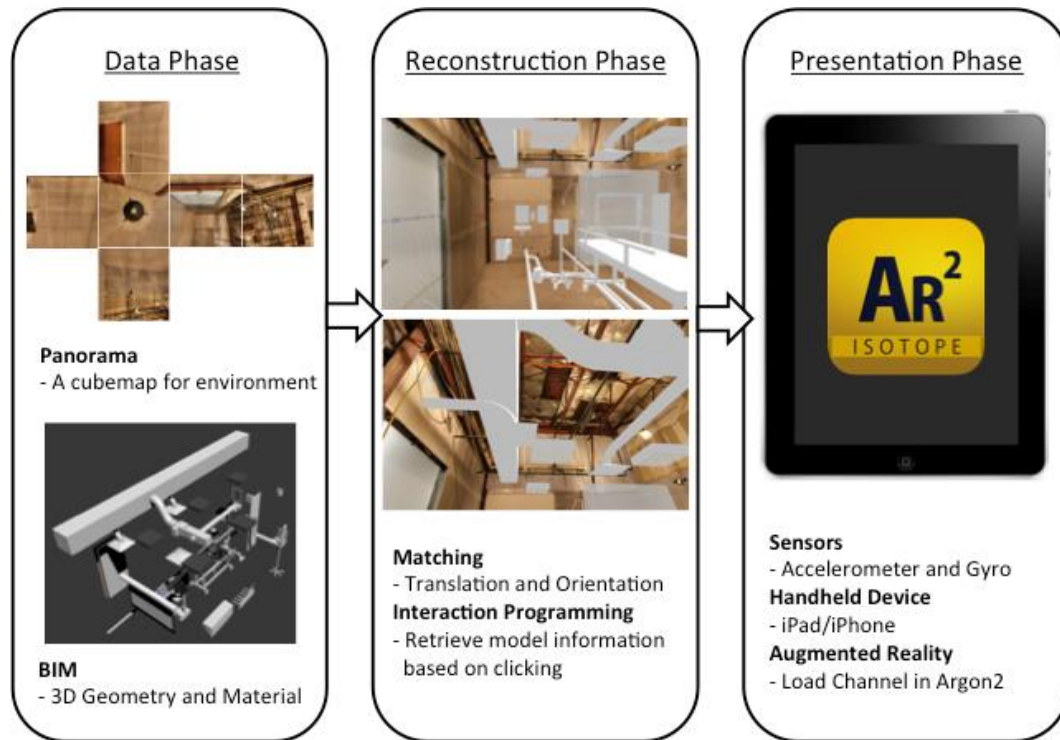
Figure 2: Augmented panorama architecture

Figure 3 illustrates the process of bringing augmented panorama into mobile augmented reality. The developed method involves several hardware and software tools. Gigapan EPIC Pro (URL 2) was used to take photos due to ease of generating panorama and shooting automation. The Gigapan Stitch application (URL 2) was used due to the multiple formats it supports and its built-in vignette correction. BIM information was exported from Autodesk Revit. Revit was used because it's widely adopted in AEC environment. Finally, Argon 2, an iOS based AR web browser, was utilized due to integration of Vuforia and Three.JS. Vuforia is a robust and efficient vision-tracking library and Three.JS is an open-sourced 3D library with ease of implementation.

This process begins with converting panorama photos from the stitched image to six square images (Figure 3). The transformation is done via Panorama Converter for Argon, a web-based tool for generating skybox images. The images are in PNG format and will be used as textures in Argon 2. On the other hand, building information model in Revit needs to be isolated to match the environment from perspectives of the user on the panoramic spot. A Revit plugin is used to translate BIM geometry to the Collada format, a XML-based schema that supports interchangeability between various software programs. The goal of the implementation is to place a 3D model inside of a skybox, which is identical to the physical environment. To achieve this goal, the method requires three steps before running on Argon 2. First, the 3D model should be loaded with an origin at the panoramic spot and then a 3D cube should also be created as the skybox with six square textures inverted inward. Second, the model and cube should be matched considering their translation, orientation, and scale variables. Finally, virtual camera should be placed on the panoramic spot with a similar height of a user. All the coding has been done in JavaScript, HTML5, and CSS3 therefore the files can be accessed via a HTTP request similar to requesting a web page on an Internet browser. After loading the main page in Argon 2, the virtual camera will update immediately according to physical orientation, which creates an augmented panorama experience.
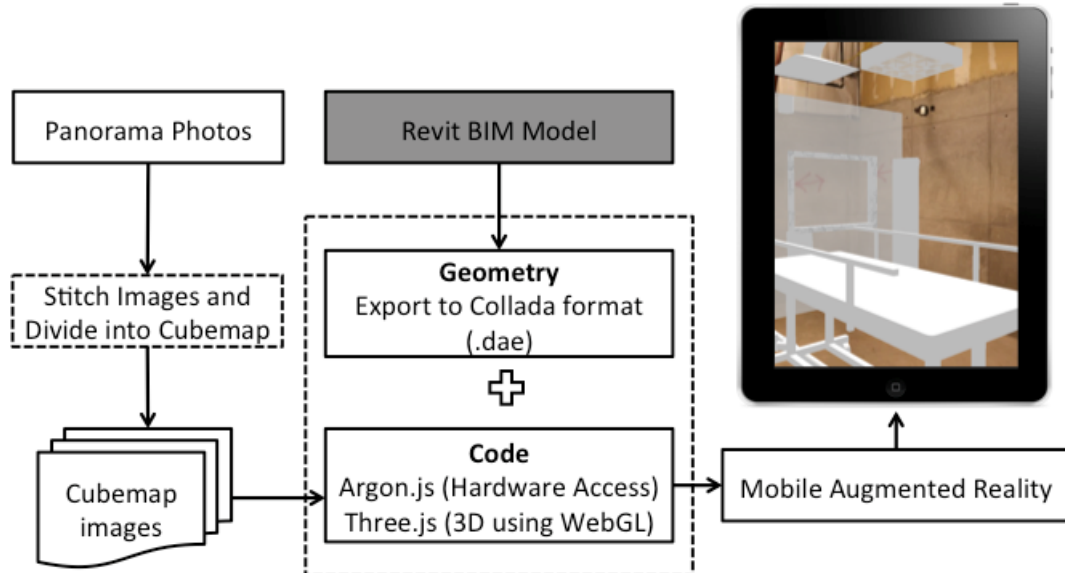
Figure 3: Augmented panorama workflow

Case Study; Implementing Augmented Panorama Workflow in a Construction Project

The case study was conducted in a living laboratory setting (Intille et al. 2005) within an indoor environment of a construction renovation project. This test location was chosen as an example of a complex and dynamic environment where construction workers are constantly required to locate/visualize different building components. Building information model of this facility was created using Autodesk Revit and provided by general contractor to the research team. Since this was an active facility, the research team was restricted to one room for conducting the case study (Room X). A Gigapixel Panoramic Camera Mount device (URL2, Figure 4) was used to create the panoramic picture of Room X (Figure 5) and was then superimposed by some components of the building information model of the same room (Figure 6).

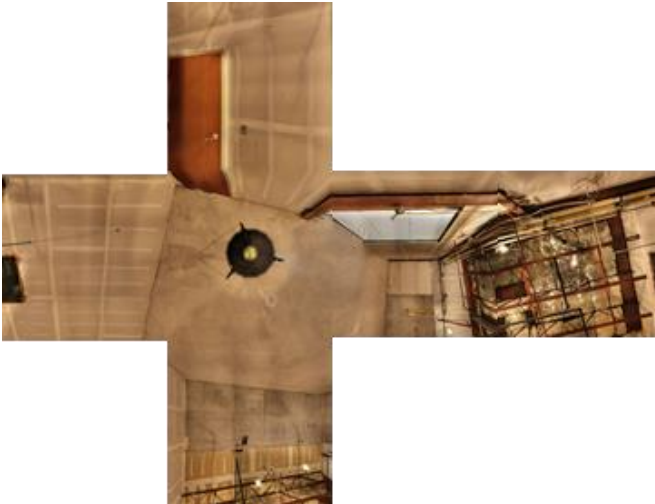Figure 4: Use of Gigapixel Camera Mount for taking images in 360 degree
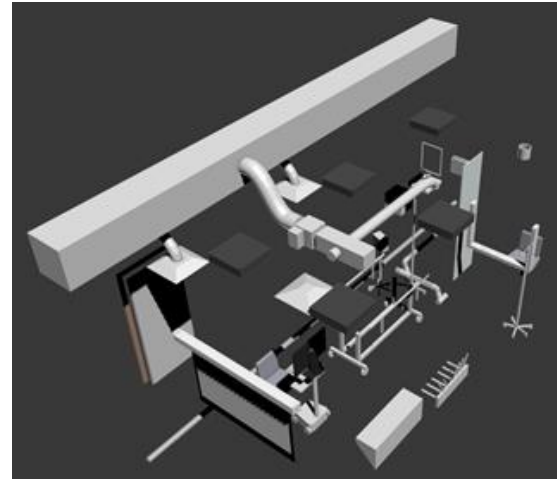
Figure 5: A cubical panorama of Room X

Figure 6: Building information components of
Room X created in Autodesk Revit

Then attributes were customized for several objects in the project and only the associated objects were left visible for interaction within an augmented panoramic environment (Figure 7). Augmented panorama process described in previous section was used to create the augmented panorama experience and BIM2MAR (Williams et al., 2014) process was used to develop a pure AR experience for the very same case study. The purpose of creating the same case study using these two different methods was to investigate how AR and augmented panorama experiences are different.

Figure 7: Building information model of Room X

Additionally, information spots were selected to indicate where the users of the AR system could access the properly registered geo-located augmentations. Subjects under the augment panorama condition didn't actually need to stand on the geo-spots since their experience was location-independent. Subjects could see the real-life view of the room through a mobile phone or tablet device (iPad in this case), and each object in the room was highlighted using augmented 3D geometry of the same object from the model. On the interface of user's mobile device, the target component in the room appeared in grey while showing the associated information of that specific component from BIM (Figure 8.a) and objects associated with completed tasks were then displayed to the user with green shading (Figure 8.b).

This within-subjects case study consisted of using a tablet computer device (an Apple iPad) as a mobile tool to explore once the augmented panorama condition and then pure AR version of Room X. Under both conditions, the users were interacting with augmented models to collect their required information to do their tasks. The participants had to speak their thoughts aloud, and an observer made note of all critical errors or mistakes as well as participants' comments or concerns. Before starting the case study, each subject was presented with an informed consent form for him or her to read and express agreement to participate in the case study. Institutional review board (IRB) had evaluated and approved the study protocol. To investigate their experiences under each condition, the subjects were also required to complete a post-study questionnaire after the case study.

(a) All task-objects highlighted in grey   (b) Selected task-objects highlighted in green

Figure 8: System User Interface (UI)

Under both augmented panorama and AR conditions, the subjects were questioned about several objects (e.g. HVAC system, interior furniture) inside the room which had been 3d-vizullay augmented on the real object in the room. Based on any question, participants had to look around the room through the iPad and locate the correct object. They had to touch the augmentations and answer the question using a table of information that had been associated to that targeted object. Subjects were not required to write down any answer, but they had to state right answer aloud for the observer to verify. This was a simple case study to observe how user would interact with virtual augmented information within both augmented panorama and pure AR environments. To reduce learning effects due to the order of presentation, half of the subjects started their tasks with augmented panorama and the other half with AR condition.

Case Study Results and Discussion

Five participants (4 males and 1 female) took part in the case study. They were two project engineers, one superintendent, one quality control manager, and one virtual design/construction coordinator. They all had more than 6 years of construction experience and four of them had not previously used any type of virtual or mixed reality applications at their jobs. Four of them owned a handheld tablet computer (e.g. iPad, Nexus) that they were mainly using to explore different types of electronic format files (e.g. video, PDF, MS Word, MS Excel, 2D plans) at their jobs.

The users were thinking-aloud while doing their assigned tasks in the case study and all their activities were observed by one of the research team members. Several sections of the IBM Post-Study System Usability Questionnaire (PSSUQ) (Lewis 1995) were combined with NASA Task Load Index (Hart and Staveland 1988) to develop a new After-Scenario Questionnaire (ASQ) for this case study. The new questionnaire consisted of 13 qualitative questions with questions 1 to 7 extracted from PSSUQ and questions 8 to 13 based on NASA Task Load Index. The items asked participants to express their levels of agreement with the statements presented using the 7-point Likert Scale provided.

The results indicated that items were not scored significantly different than each other under either condition. Individuals' comments in the after-scenario questionnaire, as well as issues declared by subjects in the thinking-aloud process during the case study, also supported the findings. In terms of the qualitative after-scenario questions, the users were strongly satisfied with the ease of completing the tasks under both conditions (1=Strongly Disagree to 7=Strongly Agree, Mean=6.50). Subjects also indicated strong agreement that it was easy and quick to learn and use both approaches (6.4) and these systems could make them productive in conducting the tasks (AR: 6.6 & augmented panorama: 6.4). If subjects made a mistake while using the augmented panorama system, they believed that they would recover slightly easier and faster as opposed to the AR approach (AR: 5.6 & augmented panorama: 6.4). In terms of finding the information, subjects indicated strong agreement that it was easy for them to find the information required

to locate the correct object in the test room under both AR (6.2) and augmented panorama (6.4) conditions. Overall, subjects were satisfied with both AR condition (6.2) and augmented panorama conditions (6.4). Subjects' workload was measured using the NASA Task Load Index questions and they rated all those questions either identical under both conditions or slightly in favor of the augmented panorama condition.

Getting similar results from subjects under both conditions might relate to the very similar intuitive and natural experience that both panoramic and AR environments have provided for the users. Under both conditions 3D geometry of targeted building components were augmented to the view of the users. The difference between two systems is that under the augmented panorama condition, the users view is actually a static panoramic picture of the environment while in the augmented reality version, the augmentation happens on the real worldview of the users. None of the users in the case study recognized this difference while performing their tasks under both conditions. Although both systems were scaled similar, the majority of the subjects made several comments about drift problems under AR condition. One subject stated, "… there was disconnect between model and reality …", another one noted that "[the AR system is] usable but actually objects are not sitting on the model", and the other one mentioned that "… sometimes something is wrong that model and object are not fit". In the augmented panorama version, since the augmentation was happening on the static panoramic image of the real environment, there was no drift or registration issues, therefore users did not made any comment about drift. Because of not experiencing any drift in augmented panorama condition, the users made several comments in favor of the augmented panorama. One subject clearly mentioned this difference by saying "this one (augmented panorama) is more stable since pieces (real objects and 3d augmented models) move together better". Based on the users' comments, both conditions provided the users with a similar natural experience, which was easy to perform and had a smooth learning curve.

Conclusion

Location-independency, interactivity, and providing natural immersive experiences of the real and virtual environments are the most important features of augmented panoramas that would make them an appropriate option where the users are not required to be present at a specific physical location to experience the virtual augmentation. The proposed workflow together with the case study and the effectiveness-usability evaluation provided a foundation for understanding the user requirements and human computer interaction (HCI)-related issues for practical application of augmented panoramas in the construction domain. This research project shows that rigorous study is required not only on the computational side but also on the HCI side of the mixed reality environments to successfully use them for construction applications.

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