Ramalytique: Augmented Reality in Architectural Exhibitions

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Abstract:

Architectural heritage is difficult to present in museums. We identify major issues visitors face in conventional exhibitions, discuss precedents, and propose a solution that uses augmented reality (AR) technology. A low-cost prototype with marker-based sensing method on a common handheld device is demonstrated. A building usually is too big to fit in an exhibition room, and removing architecture from its site to display in a museum would lose some essence since its design is tied with surrounding context. Alternatively, use of traditional scale models, photographs, and drawings is a way of translating the original into useful representations deployed by professional architects. But these methods fragment the building into isolated forms of different media, and ordinary audience is often left clueless about the original architecture. Our human test confirmed that locating the vantage of a given photograph, elevation or section on the floor plan is a demanding mental task for anyone, and is especially difficult for novices without architectural backgrounds.

What are almost lost in this translation and cause difficulties are the spatial relationships amongst architecture and various forms of its representations. To resolve this situation, we built Ramalytique, an AR-based prototype, and loaded it with digital contents about a Renaissance villa designed by Andrea Palladio. The installation exhibits a scale model on a table, and audience use a handheld device for viewing it with selectively superimposed representations, which includes a photogrammetric model sampled on the site, geometric models illustrating the base floor and roof tectonics, animated figures, as well as plan, section and elevation drawings depicted in The Four Books on Architecture.

This system capable of simple synchronization of a building's visual representations allows a curator to select and align them in multiple meaningful combinations, and provides an effective, intuitive means to help audience minds integrate diverse forms of exhibits.

Keywords: Augmented Reality, Architecture, Exhibition, Spatial Representation, Mental Rotation Test

Introduction and Motivation

This paper discusses challenges in representing architectural heritage in exhibition settings today, and describes a solution that uses augmented reality technology for interactive and selective viewing of a variety of visual information such as drawings and models in both digital and conventional formats. We propose this system as means to create a carefully crafted digital exhibition inside a handheld device by condensing multitude of available visual representations about a building, organizing them into cohesive spatial context, and choreographing the on-demand experience of viewing them in proper combinations. A prototype (Fig. 1) was developed and installed a part of our digital heritage project on Palladio under investigation in collaboration with Daniel Tsai and Howard Burns, and we named it Ramalytique after analytique, a traditional Beaux Arts compositional method for describing antique architecture in drawings.



Fig. 1 - Ramalytique (Nagakura and Sung, 2013) in an exhibition setting. (Copyright: Nagakura and Sung)

Background Project

Architects produce a large amount of visual representations when they design a building. And when it is constructed, the built heritage itself offers opportunities for scholars to study it and produce any additional amount of representations about it. For instance, the author's group recently is studying notable buildings designed and realized by Andrea Palladio near Veneto region of Italy in Renaissance. Those villas, palazzos, and churches were documented originally by the architect in the Four Books on Architecture (Palladio, 1570), and later by his studious follower, Bertotti Scamozzi (1796). Their documentation includes representations of each building in plan, elevation, section, sketches and other drawings of various details. Scale models, perspectives and paintings have been made since by many who studied Palladio's designs, including excellent wood models we see in Palladio Museum of CISA Palladio located in Vicenza. Besides these conventional representations deployed by architects for centuries, contemporary digital technology has helped producing other useful kinds (Fig. 2). Scholars and visitors to his buildings make photographs and video recordings of the space. Google Map includes satellite view of the buildings and its site context. Many versions of synthetic 3D models are posted on internet sites including that of Palladio Museum. Our group has studied Palladio's buildings on site, and produced numerous photogrammetric

models of their parts as well as panoramic walk-through and drone-based aerial video recordings. Some of these recordings are stereoscopic. Other advanced tools available lately include a laser scanner that creates measured point cloud data and motion capturing tools such as Kinect. We can use them, for example, to accurately capture the site context or to track people moving in and around the building.



Fig. 2 - Examples of conventional and digital representations of Palladio's architecture.

Challenge in Designing an Architectural Exhibition

While we have such multitude of rich visual representations about heritage buildings, designing an architectural exhibition in a museum is a challenge. A building itself usually does not fit in an exhibition room, and removing architecture from its site to display in a museum would lose some essence since its design is strongly tied with surrounding context. Therefore, a typical exhibition of architecture relies instead on its representations. For instance, Figure 3 is a scene from an architectural exhibition on Palladio. At the center of a gallery where a Palladio's church design is introduced, a large, exquisitely detailed wood model is placed on a table. On adjacent two walls richly placed are building plans, section and elevation drawings, painting, photo, and portrait of the architect.

One limitation of the traditional way of arranging these physical architectural exhibits is that individually framed pieces of exhibits are often placed separately and without explicit association with each other. A visitor looks at a beautiful elevation drawing, and it is up to his or her mental effort to figure out which side of the scale model it corresponds to or where in the floor plan that facade is viewed from. Accordingly, the elegance and preciousness of individual piece of exhibits may lose its deserved significance and attraction to puzzled visitors. And the multitude of those exhibits in a corner of a gallery could eventually become a source of their frustration, without an opportunity to make a sense out of these representations as a set and mentally constitute them in a cohesive interpretation of one building.



Fig. 3 - A scene from Andrea Palladio Exhibition (2009) at Royal Academy of Arts. (Photo copyright by Eric Parry Architects)

To alleviate a similar problem, illustrations in architectural publications are often laid out in attempts to establish simple spatial associations and help their readers. Figure 4 shows examples of Palladios's elevation drawing aligned directly underneath the floor plan, his chopped column with its plan and adjacent elevation details, and Galli's interior perspective drawing placed in explicit connection to the floor plan.



Fig. 4 – Aligned architectural drawings (left and middle) by Palladio (1570, p128, p232) documenting Temple of Mars The Avenger, and another (right) by Galli (1711) depicting a stage design for a scena par angolo.

The use of these conventional drawings and models as well as digital representations produced by contemporary modeling, capturing, and recording technologies is a way of translating the original into convenient representations, that are commonly deployed by architects, preservationists, and other professionals. But these methods fragment the building into isolated forms of different projections on different media. Therefore, without proper arrangement, ordinary visitor looks at each piece individually in an exhibition and can be left clueless about the original architecture. What are almost lost in this translation and cause difficulties are the spatial relationships amongst architecture and various forms of its representations. In an interview on digital museums, Mitchell (1998, p.43) once discussed the difference between the real and the virtual museum, and pointed out a dilemma of an exhibition in a traditional museum.

"The obvious advantage of the traditional museum is that you get to directly confront the original work. Now, there are two disadvantages; one is that it takes objects out of context by definition. It removes them from their context and places them in a special display. And the second thing is that you can arrange objects only in one way. "

If we replace his objects with visual representations of a building, his remark retraces the situations we often encounter in architectural exhibitions. And it also underscores that even a set of very carefully arranged exhibits has a limitation because their placement helps the visitors to notice explicit references between objects only in one fixed way as intended, while the same set of exhibits could be rearranged and combined differently to help visitors making other senses out them. A floor plan may be useful as reference when you figure out the interior organization by looking at an adjacently aligned section drawing, but the same plan may be helpful when you examine a scale model as well as an interior perspective or exterior photograph, with each favoring a specific spatial alignment to the plan. And the scale model describing the building's geometry would make a sense in direct comparison to another aerial photograph showing the built reality. It is impossible to design one fixed arrangement of physical exhibits that establishes explicit references between every possible meaningful combination of a multitude of representations.

View Locating Experiment on Human Subjects

How actually difficult is it for people to put building's images into context? To evaluate it, Nagakura has conducted a simple mental experiment of locating a view. It was modeled after typical methods established in cognitive psychology, such as the mental rotation test by Shepard and Metzler (1971) as well as the Image transformation test by Shepard and Feng (1972), where the subjects were shown images of objects for imagining its rotation or transformation and their response time was measured.



Fig. 5 – Mental test of locating a view in a plan (left). The correct answer for this image pair is H. Shepard and Metzler (1971) used the illustrations on the right for their mental rotation test.

Testing Method using Image Pairs

In our method, a subject looks at a pair of images about a building. The image on the left is a major floor plan or roof plan, and includes a number of labeled arrows indicating possible vantage positions and directions, i.e., viewing angles. The image on the right is an elevation, section, perspective, or photograph. A subject's task is to find the arrow in the left image that most closely corresponds to the vantage position and direction for the right image. (In case of a section, a dotted line indicating a cutting plane was attached to each arrow.) For instance, in Figure 5, the correct answer is H. To measure the reaction time, the subject was given brief pauses at 4, 12, 28, and 60 seconds after starting to look at the image pair, which was briefly removed during each pause while the subject wrote down an answer before the pair reappeared to resume. The experiment conducted used three buildings of different styles and popularity, including Villa Malcontenta (Andrea Palladio, 1549, Italy), Haus Gericke (Mies vander Rohe, 1932, Germany), and Kaufman House (a.k.a. Falling Water, Frank Lloyd Wright, 1935, USA). Each building is presented by one of three different pairs of images (Fig. 6). For instance, the main floor plan of Villa Malcontenta was presented with each of an interior photo, exterior photo, and a longitudinal section. In total, 24 participating subjects volunteered near our university campus in Cambridge, Massachusetts, during October of 2014. Among them, 12 had previous background in architectural design as either student or professional. The other 12 were control group who did not have the same level of expertise. After each test, a subject was also asked if he or she knew the particular building that was just presented in the test.





Haus Gericke (Mies vander Rohe, 1932, Germany),



Villa Malcontenta (Andrea Palladio, 1549, Italy),



Fig. 6 – Images used for the view locating experiment. Each of three buildings is presented by a pair of its plan and each of three other images.

Observations of the Test Result

The Figure 7 shows the overall result, where the vertical axis is the percentage of subjects with correct answers and the horizontal axis is the time spent on observing each of the image pairs. The followings are our observations and interpretations.



Fig. 7 – Result of the view locating experiment. Percentage of correct answers is plotted against time spent for observation of each of the image pairs. Architects and novices are compaired. (Copyright: Nagakura and Sung)

1. Associating an Image to its vantage position and direction is a mentally consuming task

The images used against a plan are common illustrations such as casual photograph, perspective sketch, and a simple building section. Yet the recognition of its vantage position and direction in plan was not instantaneous. The more time is spent for the subject to examine an image pair, the more subjects reached the correct answer. Nearly a minute was required for subjects to identify the correct vantages in some image pairs, and a subject was not able to figure them out at all in some other pairs

2. Architects did generally better than novices.

Architects had an advantage because they casually practice a similar task during both studying a building and designing it. In other words, this mental task seems improved by practicing. A related issue is the graphic conventions some drawings use to describe objects. For instance, plans have marks for openings, columns, and mullions, and line weights distinguish structure from outlines of other objects. The conventions used in this experiment were not the kinds which require more than common sense to understand a real estate advertisement, but architects may have better and instantaneous idea about what those marked objects would look like in reality and using those as references to find correspondence in image pairs.

3. Familiarity with a building did not produce noticeable influence.

Some subjects in our experiment said identified a photograph of Frank Lloyd Wright's Falling Water building, but the identification did not seem to help them much in making a correct answer for the test.

4. Media type makes difference but the result is inconclusive.

A plan was paired with a different type of media such as section, sketch, perspective, interior photograph, and photographed model, and subjects took more time to figure out the vantage for some medium than others. However, the number of our samples was too small to identify any definite factors. Also the rotation amount of the plan counts. For instance, subjects performed very well if an exterior photograph shown is

taken from the position at the bottom of its paired plan towards its center. With a bigger rotation of the plan, subjects would need more time to reach a correct answer as the experiment on mental rotation by Shepard and Metzler (1971) suggests. An experiment to follow up on this specific factor would be interesting.

Previous Work and Examples

In the interview previously quoted on the dilemma of exhibiting artifacts in a traditional museum, Mitchell (1998, p.43) continued on to make a comment on a digital museum.

"Now the digital museum is exactly the opposite, you don't confront the original. But, it has the great advantage that it can place objects in a very rich context. And the other thing is that you can rearrange, in principle, the virtual museum in any way you want. So, you need both, because of the complimentary advantage and disadvantages, one does not replace the other. "

The contextualization of objects in his comment means associating plan, section, model and other visual representations in an architectural exhibition. And for ordinary people, our view locating experiment confirmed that this association is not a trivial mental task. In this 1998 interview, Mitchell did not mention any specific means that enables his vision, but such a means would be helpful to those who visits a traditional exhibition of architectural heritage and are frustrated in front of precious drawings carefully framed on the wall and beautiful scale models sitting gently on isolated podiums. So, what could that means look like?

Analytique Drawings in Beaux Arts Tradition

One inspirational source to tackle this inquiry is found in the analytique, a presentation method developed through Beaux Arts tradition of education since nineteenth century. It makes a single composite drawing about a building in which component illustrations are carefully scaled and positioned with alignment. French students awarded with traveling fellowship to Rome originally deployed and elaborated this method, and submitted their drawings describing their findings of antique architecture surveyed during the trip. American Beaux Arts schools later succeeded the style and produced similar presentations of student design projects.



Fig. 8 - Analytique depicting Temple of Hercules from the compilation by d'Espouy (1905).

Many spectacular works by French students are found in the compilation published by d'Espouy (1905). professor of ornamental design at the École des Beaux-Arts in Paris. It includes one of the best known analytique drawings depicting the Temple of Hercules (Figure 8). Analytique drawings typically use graphic principles such as framing one component illustration in another and ordering close-up details and distant views from bottom upwards. But what is particularly unique and well-crafted about this example is the way component illustrations are scaled, positioned and seamlessly merged together inside a rectangular frame. For example, the front elevation of the gable's left half is placed next to its side elevation showing the roof tiles. Its right half is replaced by a hollow section, which continues to the embellished interior wall farther right and the Doric column elevation beneath. Behind the row of flanking columns are framed a plan, overall façade, and other details in different scales. This way, the entire drawing embeds a web of spatial relationships among its components, and each component is rigorously contextualized. From the perspective of design of architectural exhibitions, analytique drawings underscore the power of spatial arrangement. The Temple of Hercules drawing includes only orthogonal projections of plans, elevations and sections with no perspective or oblique view. But by combining them properly, a person who examines the drawing would constitute a good mental image of the entire three dimensional form of the building, with additional sense of tectonics, details, and nearby context. In other words, the whole really is more than just the sum of its parts.

Nagakura's Previous Works

The alignment approach similar to the method demonstrated in the analytique drawings in ink on paper was previously explored by Nagakura and his collaborators (Fig. 9) with digital contents. The Space Barcoder installation (Nagakura, 1998), an early attempt used in an exhibition of a building of his own design, has small barcode tags pinned on physical architectural model. When the viewer shoots at a tag with a laser beam of a barcode reader gun, the display monitor placed near the model shows a view of the building from the point of the tag in the form of computer graphics rendering or video recording of the live space.



Fig. 9 - From left to right, Nagakura's Space barcoder (1998), Digitarama (1997), and Deskrama (2006).

For his installation at Virtual Architecture Exhibition in Tokyo, he developed Digitarama (Nagakura, 1997). This large mechanical device places a small 3D printed model of Hagia Sophia in the center, and has an extended aluminum arm holding two digital screens, one in front of the model and the other in its rear. When a visitor rotates this arm around this model, the rear screen shows the image of the main interior space adjusted as viewed from inside the model towards the screen, while the front screen shows the digital models of the building viewed from the visitor towards the physical model. The digital models cycle through representations of the entire building, foundation, structural system, and volume assembly of its domes. Following those, a smaller system, the Deskrama (Nagakura, 2006), was designed for his exhibition of synthetic visualization of unbuilt modern architecture. A sheet of a building's floor plan is placed on a table, and a visitor moves a screen, either projected or on a LCD panel, directly on the plan. Then the image in the screen interactively changes as if a virtual scale model of a building is on the plan, and cut by the plane of the screen. By changing the floor plan sheet, different buildings can be presented on the same table.

Augmented Reality Precedents

The analytique drawing method was an inspiration for composing and making sense of individual illustrations as a set, and the common thread for the design of Nagakura's previous works is an idea to use contemporary technology to similarly create a spatial composition by interactively synchronizing a variety of conventional and digital representations of a building. After the explosive spreading of handheld devices such as smart phones and tablets, we now have the augmented reality technology, that has quickly become widely available at low cost and offers many of the functions ideal for our purpose.

This technology targets some type of physical artifact and augments it in a screen by superimposing their view with relevant digital information. Various precedents of its applications has been already built (Fig. 10) for different occasions including systems that augment city buildings with business rating display (Nokia, 2012); fossil skeleton exhibit with skinned illustration of the dinosaur (Royal Ontario Museum, 2013); museum gallery with virtual art pieces (Veenhof and Skwarek, 2010); sculptures with annotations and illustrations (British Museum and Samsung, 2013); art exhibits with annotations (meSch, 2014; Metaio, 2014); Coliseum with its missing portion digitally reconstructed (ARMedia, 2013); and a book on Paris with digital 3D models of its buildings (Dassault Systems and Flammarion, 2012).



Fig. 10 – Recent relevant precedents of Augmented reality applications. From topleft clockwise, City Lens (Nokia, 2012), Ultimate Dinosaurs (Royal Ontario Museum, 2013), WeAR in MoMA (Veenhof and Skwarek, 2010), Paris 3D (Dassault Systems and Flammarion, 2012), Augmenting Rome Coliseum (ARMedia, 2013) and The Loup (meSch, 2014).

Like many of these examples, we set our goal as deploying augmented reality technology for exhibitions, while our situation is unique in that we have a multitude of architectural representations such as a variety of drawings and 3D models for a single building. In other words, we have a good number of heterogeneous visual forms to exhibit about a single subject and thus controlling their combinations becomes crucial, while most of our precedents use one or a small number of visual forms or text as augmentation.

Ramalytique: Our System and Installation for Palladio's Villa Poiana

We designed our prototype system, Ramalytique (Nagakura and Sung, 2013), with primarily two considerations for improving the visitor's experience in architectural exhibitions: spatial context and contingent combination. As its example use, we installed representations of Palladio's Villa Poiana, selected from archival and scholarly documents and other digital materials produced through our digital heritage project in the lab and on the field.



Fig. 11 – Ramalytique: augmented reality prototype for architectural exhibitions shown with contents for Palladio's villa Poiana. This photograph shows the Artoolkit binary markers used in our earlier development. (Copyright: Nagakura and Sung)

Spatial Context

The artifact augmented in our installation is a scale model of the villa. It is schematically based on Palladio's documentation of the building in The Four Books on Architecture, and includes only the northern half of its bilaterally symmetrical form as shown in Figure 11. A visitor looks at this model through the camera of a handheld device such as smart phone or tablet, and it appears on the device screen superimposed with other visual representations that share the same scale and coordinate system with the model. For instance (Fig. 12), the longitudinal section depicted by Bertotti Scamozzi (1796) appears in parallel to the view of the physical model's cut plane nearby. This way, the aligned drawing immediately establishes a spatial reference to the model and is understood in a proper context. Likewise, Palladio's main floor plan is placed extending out from the physical model at the floor's level. This allows observation of corresponding walls and columns in two and three dimensions simultaneously. In addition, Palladio's plan and a recent surveyed version (Burns and Beltramini, 2008) can be switched for reference. Also, a photogrammetric model our group captured on the site showing the southern half attaches to and completes the physical white model, providing a comparison between the textured built reality and its counterpart described in Palladio's book. In the end, each representation regains a proper spatial context established by the sum of all the others, instead of losing it by appearing separately on an exhibition wall. Our augmentation target was a 3D printed model, but it can instead be a sheet of plan, an excavated piece of heritage building such as column base, or any physical exhibit a curator intends to showcase. The augmenting image may appear transparent as seen for the section or opaque as done for the plan. Shadow, color, and lighting of the synthetic model can be crafted. Finally, animated synthetic figures can be added on and around the physical model, and provide the sense of circulation and habitation (Fig. 13).















Fig. 12 – Ramalytique: Villa Poiana's section (Bertotti Scamozzi, 1796), plan (Palladio's and the recent conditions are switchable), or photogrammetric model aligned to its scale model. The Topleft illustration shows Palladio's portrait, our image marker prepared to work with Vufolia's augmented reality. (Copyright: Nagakura and Sung)

Contingent Combination

The representations used in the example include the plan, elevation, section, photogrammetric model, geometric study models of the base floor and roof tectonics, site model, and animated digital figures. And the user interface of the handheld device provides switches for toggling visibility of the visual representations one at a time, or by programmed groups.





Fig. 13 – Ramalytique: a physical scale model composed with digital models of base floor and roof tectonics, which are previously studied by Sass (2000). (Copyright: Nagakura and Sung)

For instance, a visitor may use this interface to see a combination of the scale model with the plan and elevation drawings, and examine the three in alignment (Fig. 11). Beside the scale model, the digital model showing the roof tectonics, previously studied by Sass (2000), can be combined with that of the base floor (Fig. 13), or with the photogrammetric model of the building envelope. The representation of the building site and animated people figures may be studied with the floor plan to understand the view from each room (Fig. 14), or combined with the photogrammetric model to get the sense of how the building looks in real life. Selecting and assembling a proper combination of a building's visual representations provides a visitor with a chance to appreciate those exhibits in each of many meaningful ways of examination, unlike when they visit a fixed set of isolated exhibits. And the user interface contingently delivers each combination to take place

on-demand within the limited resource of a small handheld screen. This way, a handful of exhibits ordinary presented fixed in a museum room can be condensed instead in a small mobile display, with multiple patterns of their carefully aligned combinations delivering a variety of curated interpretations for the visitors.



Fig. 14 – Ramalytique: Villa Poiana's scale model composed with its synthetic site and floor plan as well as animated figures (Copyright: Nagakura and Sung)

Technical Implementation: Hardware and Software

Our augmented reality application uses marker-based technology for detecting positions of the camera relative to the scale model. We tested two major public domain coding libraries and built prototypes. The first one used ARToolkit library (Kato, 1999) and the application was built on Visual Studio and OpenGL platform for implementation on Microsoft Surface tablet. The second one used Vuforia library (Qualcomm) and the application was built on Unity3D platform for implementation on Android and iOS mobile devices. Vufolia-based system can take advantage of a camera with higher resolution and seems to provide better tracking stability, especially for multi-marker deployment. It also allows use of tonal images for markers (Fig. 12), instead of black and white patterns in squared frame (Fig. 11) used by ARToolKit. Vufolia tracks only partially revealed markers to a good extent, letting a user get much closer to the scale model without losing tracking of nearby markers. And because the Unity3D environment is for building games, it avails many convenient

tools for editing visual contents for augmentation, managing those assets, and designing a desired user interface. For instance, you can add animated people showing on the floor of the building without requiring additional coding. However, the distribution of its application may involve some technicality for using app stores and license cost.

Another technical detail is worth noting here for those replicating our method. For proper occlusion to happen between a physical and a synthetic model, the image of the synthetic may need digitally masked by the image of the physical (Fig. 15). For instance, adding a synthetic figure standing in front of a physical wall just needs superimposing the whole figure over the image of the wall in the camera. But to place the figure partially behind the wall, the figure's part behind the wall needs trimmed before the image of the figure is pasted over that of the wall. In computer graphics visualization, an easy way to achieve this partial image of the figure appropriately is three dimensional masking, a process of preparing the digital model of the same wall, rendering the figure with it, and removing the rendered wall from the rendition.



Fig. 15 – Digially masking a synthetic figure occluded by a physical wall in a video. A: synthetic figure, B: masking by digital model of the wall, C: visible part of figure extracted, D: correct overlay, E: wrong overlay. (Copyright: Nagakura and Sung)

Retrospect and Prospect

Our investigation proposed a type of augmented reality application, and discussed how and why it is particularly suitable for presenting heritage architecture to ordinary visitors in exhibition settings. The following summarizes our main points.

1. Multitude of representations

A building itself usually is too big to fit in exhibition space, but instead many forms of its representations are available. They include precious original drawings and models produced by its architect and scholars as well as other derivative materials such as photos, videos, and satellite imaging of the site. Computer graphics technology recently has added additional types of visual representations such as geometric and photogrammetric models. An augmented reality application can offer an economical way of delivering this multitude of contents on a handheld device and combining them with physical exhibits.

2. Augmentation

Understanding spatial relationships between the drawings and models individually placed on the floor and walls is not a trivial mental task. This situation is improved by aligning those exhibits together into proper positions much like how architects often present paired drawings in publications. An augmented reality application can arrange exhibits as to be viewed in specific spatial relationships with each other and contextualize a variety of representations including three dimensional artifacts and digital contents. A scale model placed as reference is effective for letting a visitor adjust the viewing angle interactively and intuitively.

3. Combination

With a variety of available representations, various meaningful combinations and alignment methods are possible, and each helps a visitor to make a specific sense. For instance, a scale model of a building may be combined with plan and section drawings for studying spatial layout or with a photogrammetric model for comparison with built reality. The interactive user interface of an augmented reality application can be crafted and used to let a visitor conveniently select or assemble a combination of representations delivered on-demand. Preparing some explicit combinations becomes a curatorial tool for the exhibition designer. During our investigation and development of the prototype, many interesting questions and ideas for possible extensions appeared. We conclude this paper by listing those as inspirations to future projects by anyone, including ourselves, sharing interests in using augmented reality for representing heritage architecture.

- Development of an open-source tool kit with a drag-and-drop content compilation method would serve significantly to help exhibition designers and curators as well as architects and students for presenting their own designs in studios and client meetings.

- An augmented reality system can be combined with server-based media content delivery. A massive amount of contents in the entire museum becomes accessible for an application running on the mobile devices of visitors. A curator selects and compiles relevant contents for an augmented reality-based exhibition, which can be revised without a need of repackaging a self-contained presentation and downloading that file onto each handheld device. The server may log statistics about visitor's viewing of contents, and help curators adjusting the exhibition in real time.

- A plausible way to spatially associate and display still photos and videos in both conventional and panoramic formats needs developed for use in the augmented reality application.

- An augmented reality application can incorporate interactive content manipulation tools for the visitors such as one to cut digital models for sectional viewing and another to write comments on exhibits.

- A new emerging position sensing method uses an object's form as a marker instead of an image. This can

be used to augment a part of architectural heritage on site without placing an explicit image marker on it.

- Social networking sites can be integrated with the Augmented Reality application, and allow augmentation with digital images, 3D models, and comments posted on their public sites by experts and enthusiasts.

We predict a future when a carefully designed augmented reality-based presentation system condenses a whole gallery into a small handheld device and provide a visitor with much richer appreciation and experience than the one in the traditional exhibition. We hope many others explore this route with us.

We thank Dr. Daniel Tsai and Prof. Howard Burns, our brilliant and gracious collaborators. Special thanks go to Prof. Larry Sass (2000) whose tectonic model of Villa Poiana became our valuable reference.

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References

Bertotti Scamozzi, O. (1796) *The Buildings and Designs of Andrea Palladio*. Translated by Emiliabianca Pisani., 1786. New York: Princeton Architectural Press.

Burns, H. and Beltramini, G. (2008) Palladio, Catalog of the exhibition, Venezia: Marsilio.

d'Espouy, H. (1905) *Greek and Roman Architecture in Classic Drawings*. Translated by Henry Hope Reed., 1999. New York: Dover Publications.

Kato, H., Billinghurst, M. (1999) Marker tracking and hmd calibration for a video-based augmented reality conferencing system., In: *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR 99)*. IEEE Publisher.

Mitchell, W. J. (1998) The new image for the museum, born of digital technology. Interviewed by Ryusuke Naka. *AXIS*, vol. 75 September - October 1998, pp.38-43.

Nagakura, T. (1998) Gushikawa Orchid Center. 17th Exhibitgion of Winning Architectural Models and Drawing. SD Review, December 1998, pp.36-38.

Nagakura, T. (1997) DIGITARAM. In: Ken Sakamura and Hiroyuki Suzuki, ed. 1997. *The Virtual Architecture*. Tokyo: Tokyo University Digital Museum.

Nagakura, T. and Oishi, J. (2006) Deskrama. In: *Proceedings of ACM SIGGRAPH 1998, Emerging technologies*. Article No. 6. New York: ACM New York.

Nagakura, T. and Sung, W. (2013) Augmenting Architecture through Ramalytique: A Tablet to See the Lost in Translation. Video clip presentation. [online] Available at: http://cat2.mit.edu/ramalytique [Accessed 10 January 2015].

Palladio, A. (1570) *The Four Books on Architecture*. Translated by Robert Tavernor and Richard Schofield., 1997. Cambridge, Massachusetts: MIT Press

Palladio Museum, (n.d.) Media Library. [online] Available at: http://www.palladiomuseum.org/mediateca [Accessed 10 January 2015].

Qualcomm (n.d.) Vufolia Developer Portal. [online] Available at: https://developer.vuforia.com/ [Accessed 10 January 2015].

Sass, L. (2000) Palladio's villas: an analysis of Palladio's villa design and construction process. PhD Thesis, Massachusetts Institute of Technology.

Shepard, R. N., and Metzler, J. (1971) Mental rotation of three-dimensional objects. Science, 171, pp.701-703.

Shepard, R. N., and Feng, C. (1972) A chronometric study of mental paper folding. Cognitive Psychology, 3, pp.228-243.