

Rendering style and viewer's perception of historic virtual architecture

Wei Tang^{1,*}, Nicoletta Adamo¹, Nicholas J. Villani², Hazar N. Dib³

¹Computer Graphics Technology, Purdue University

²Psychological Sciences, Purdue University

³Construction Management Technology, Purdue University

Abstract

The paper presents a study that investigated the effect of rendering style on users' perception of 3D historic architectural environments. Three architectural styles were considered (Traditional Chinese, Gothic and Classic Greek) and three rendering approaches (photorealistic, non-photorealistic – watercolor, and non-photorealistic – technical illustration) were used to render two landmark buildings for each architectural style. One hundred and fifty subjects were asked to rate the rendering results according to different aspects of perception. Findings show that photorealistic rendering was rated highest for visual appeal, suitability, and accuracy of representation of the architectural style, design elements and architectural details; recognition of the architectural style was highest for the non-photorealistic watercolor renderings.

Keywords: Virtual architecture, PR rendering, NPR rendering.

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*Corresponding author. Email: Nadamovi@purdue.edu

1. Introduction

Choosing an effective and appealing rendering style for virtual architecture is an important step in creating successful 3D environments for virtual tours and virtual and augmented reality worlds.

The visual quality of virtual architecture depends in part on the underlying rendering algorithm that takes digital representations of surface geometry, color, and lights as input and computes the rendered images. Whereas Photorealistic Rendering (PR) methods aim to produce images that are visually indistinguishable from reality, Non-Photorealistic Rendering (NPR) algorithms can generate images that resemble a variety of artistic styles, e.g., painting, technical illustration, watercolor, and more. Although, intuitively, one might think that PR images are the most effective at depicting architectural environments, as they are supposed to produce the same visual response as the physical scenes, this is not

necessarily true. In many areas, an NPR approach can be more beneficial than photorealism, because it can emphasize and clarify the information to be conveyed. For instance, it may be difficult to clearly depict all architectural details because of occlusion problems and lack of contour lines that can help clarify the design features. NPR methods, such as watercolor and technical illustration, could be used to clarify and emphasize the information contained in an image. For example, it is common for architects to render buildings in a way that is inconsistent with any physically-realizable lighting model, but that is specifically intended to bring out surface shape and detail. Fernando and Kilgard [10] suggest that objects in NPR shading can be easily discernible, hence NPR approaches have become popular in many areas including game design [20], architecture [12] and medical visualization. Durand [8] argues that the border between photorealism and non-photorealism can be fuzzy and a virtual world should be more convincing

than realistic; the virtual objects should be expressive, believable and visually pleasing.

In summary, a good understanding of the effect that rendering style has on users' perception of 3D worlds is important, as it could help media artists and technologists make more effective rendering decisions. However, few studies have been conducted in this area [19] [26] [29] and additional research is needed. The study reported in the paper aims to fill this gap by investigating whether rendering style influences how viewers perceive historic virtual architecture.

The paper is organized as follows. In section 2 we report related studies on perception of PR and NPR images, and in section 3 we define and discuss virtual architecture. In section 4 we describe the user study, including the rendering styles, architectural types, subjects, stimuli, evaluation instrument, and procedure. Findings from the experiment are reported in section 5 and a discussion of results is presented in section 6. Conclusion and future work are included in section 7.

2. Related Work

It is not clear yet what are the cognitive, affective and motivational advantages of representing the world through photorealistic versus stylized imagery and the research studies that compared PR and NPR visuals have yielded conflicting results.

From a cognitive point of view, those researchers who believe in the cognitive benefits of PR images argue that learning and training applications can benefit through having a greater fidelity with the represented world (e.g. [6]). One suggestion is that the transfer of training to the real world could be more direct, and therefore with lower number of errors. Due to the high resemblance of the depicted objects with the real ones, PR images may facilitate their recognition and they might especially be helpful for learning, if the learning objective requires interacting with concrete objects in real-world settings [2]. Van Gendt and Verhagen [37] explored the effect of level of realism of the visuals on students' performance on a visual test on the anatomy of a rat. The results showed that PR images proved superior for recognizing anatomical features, whereas NPR images (e.g. line drawings) yielded better results for understanding the relationship between anatomical structures. Researchers who support the cognitive advantages of stylized representations have argued that simplified, relatively abstract representations are useful for extracting the essence of a situation [13]. PR images entail more irrelevant details and therefore might distract learners and take their attention away from the fundamental aspects [9]. By using NPR renderings, key elements, which might be difficult to filter in reality, can be easily perceived by the viewers. For instance, the results of an experiment conducted by Halper et al. [16] show that NPR renderings, specifically cartoon drawings, promote figure-ground-segmentation, e.g. the ability to identify individual

objects in relation to other objects within the same image. In addition, NPR images may facilitate symbolic interpretations of represented objects [14]. Scheiter et al. [31] conducted an experiment in which students learned about cell mitosis watching either PR or NPR dynamic visualizations; findings showed the superiority of the NPR visualizations. A study by Dib et al. [7] compared the effectiveness of interactive realistic versus schematic visualizations for learning surveying practices. The realistic visualizations included PR images of terrains and instruments, whereas the schematic visualizations included NPR images (e.g. cartoon drawings). Results showed that students who were exposed to the NPR visualizations and students who were exposed to the PR visualizations performed equally well on a practice test focusing on chaining tasks. Hence, the researchers concluded that when the learning objective is to acquire procedural knowledge of low- complexity surveying practices, the degree of realism of the images does not have an effect on students' performance.

Pan et al. [31] developed an expressive rendering method for visualizing large-scale 3D city scenes. Their approach integrated various rendering styles in a seamless way and produced images that were a combination of photorealistic and non-photorealistic renderings. The goal was to highlight the information that was interesting to the users and de-emphasize the information that was less relevant. A pilot study with 20 subjects revealed that the composite rendering approach increased users' ability to identify specific buildings within a 3D campus model as compared to photorealistic rendering.

Schuman et al. [35] conducted an empirical study with 150 architects and architectural students to investigate the effects of different types of non-photorealistic rendered images in CAD. They produced three types of images, e.g. CAD plots, shaded renderings and computer generated sketches and compared their usability with respect to communicative goals. Findings from the experiment showed that the computer generated sketches were the preferred rendering style for communicating early ideas of new designs, they were also the preferred rendering method for the communication of affective and motivational aspects and for stimulating viewers to discuss and participate in the design process. CAD plots were the preferred rendering approach for cognitive aspects.

Rousseau and Drettakis [33] state that while photorealistic rendering has been the preferred method of representation in virtual archaeology, other non-photorealistic rendering styles can be as or more effective. They argue that the choice of the rendering approach should depend on the purpose of the virtual representation and on the target users. For instance, NPR methods can be very useful when VR worlds are intended for use as research instruments by archaeologists to assist them in the process of interpretation of a site. In this case photorealism may be less important while NPR techniques that resemble traditional methods of depiction may be preferable

Isenberg et al. [18] conducted an observational study that investigated differences in viewer's perception of hand-drawn pen-and-ink illustrations of 3 types of objects (e.g. an archeological model, a botanical model and a medical model) versus NPR renditions of the same 3D objects. The results showed that although participants were able to perceive the differences between the two types of illustration, they gave high evaluations to the computer-generated ones. More specifically, while subjects perceived the hand drawn images as having more 'character' and 'life', they found the NPR rendered images very attractive, informative and useful in the context of educational scientific visualization.

In summary, there is no consensus on which type of imagery (PR or NPR) is more effective for learning. The results achieved by the studies conducted so far suggest that NPR images, especially schematic representations such as line drawings tend to benefit more abstract reasoning based on a symbolic interpretation of the depicted object, while PR images tend to enhance more analogical problem solving skills. The studies also indicate that there is a strong interaction between the rendering style and the learning objectives, as well as the rendering style and the target user characteristics.

Several researchers have also examined the affective and motivational effects that PR and NPR images have on people. For instance, Halper et al. [16] conducted a series of experiments that investigated the social psychology of NPR images, e.g. the effect of NPR images on social perception and social judgment, and the environmental psychology of NPR images, e.g. how NPR affects interaction and participation in environments. Results of their studies show that the rendering style had a significant effect on people's judgment. They presented subjects with images of geometrically identical characters that differed only in line thickness. The participants perceived the characters rendered with thick lines as strong, and the ones rendered with thin, sketchy lines as weak. In another experiment, they investigated how line style affects people perception of safety and danger. Subjects perceived the normal lines (straight and curved) as safe (whether shown on the house or the tree), and the jagged lines on the door as dangerous. Harper et al. [16] also demonstrated that increased levels of detail in an image can affect both navigation and exploration behaviors. In their experiment, participants who were asked to choose a path to explore or reach a location were more likely to select the path with a higher level of visual detail. The researchers hypothesized that subjects perceived the higher level of detail as more intriguing for exploration. Adamo et al. [1] conducted a study that investigated how rendering style (PR versus NPR) affects user interaction with signing avatars. The researchers presented the subjects with 8 animation clips, 4 featuring a stylized signing avatar and 4 featuring a realistic one; each avatar signed the same 4 sentences in American Sign Language (ASL). Findings showed that rendering style did not have an impact on subjects' perceived legibility of ASL signs and sign recognition, but it did have an effect

on participants' interest in the character. The NPR stylized signing avatar was perceived more engaging and motivating than the realistic one. A study by Cissel et al. [5] investigated the effect of character rendering style on viewer's perception of facial expressions. Findings from the study revealed that for recognition, participants were more likely to recognize the facial expressions of a stylized (cartoon) character than those expressed by a realistic character, although the difference was not significant. Cartoon characters were on average rated higher for sincerity and intensity, while realistic characters were on average rated higher for typicality.

A group of researchers has investigated the effect that differently rendered images have on people's emotional responses. Mandryk et al. [24] selected 18 images from the International Affective Picture System (IAPS) and rendered each image using different NPR styles. They presented a group of subjects with the original photos and the NPR renderings and measured the participants' emotional response to each image using the self-assessment manikin. Findings show that NPR images tended to dampen the emotion in terms of arousal and activation; in other words, when presented with NPR images, participants' reported experiences of valence and arousal close to neutral, showing a decrease in the strength of the emotion compared to the original images (photos), but never a complete absence. In contrast, Park et al. [32] reported a study that showed that the visual style (e.g., realistic, stylized, iconic) of an animated character portraying different emotions did not have an effect on the subjects' empathy and sympathy responses. NPR renderings of the character elicited the same empathy and sympathy responses from the audience as the PR renderings.

Even in regard to the affective effects of PR versus NPR images, research studies have yielded contrasting results. However, some studies have provided evidence for a number of benefits of stylistic depictions created with NPR rendering, and thus motivate further research and development, as well as the implementation of NPR rendering approaches in a variety of applications.

3. Virtual Architecture

The combination of architectural design and virtual world design has led to a rapidly expanding area: virtual architecture. "*Click, click through cyberspace; this is the new architectural promenade*" [27]. This remark suggests the inherent architectural nature of cyberspace. Gu and Maher [15] define Virtual Architecture as an "*interactive, networked spatial environment designed using the metaphor of physical architecture, from which it inherits many visual and spatial characteristics*". The main purpose of Virtual Architecture is to provide an electronic location for people to learn, socialize, work, play in the same way physical architecture does.

When creating historic virtual architecture for applications such as virtual tours, games, or virtual learning environments, it is important to select a rendering style that clearly conveys the design features and details of the selected architecture such that the user feels immersed in an authentic and believable historic environment. The findings from the study reported in the paper can help virtual architects make informed rendering decisions that are likely to result in visually appealing, believable, and engaging virtual environments.

4. Description of the study

The study reported in the paper aimed to answer the main research question of whether rendering style has a significant effect on how people perceive virtual historic architectural environments. More specifically, the study tested five hypotheses:

H0 (1): Rendering style does not have a significant effect on perceived visual appeal of historic virtual architecture

Ha (1): Rendering style has a significant effect on perceived visual appeal of historic virtual architecture

H0 (2): Rendering style does not have a significant effect on perceived suitability of the images for representing historic virtual architecture

Ha (2): Rendering style has a significant effect on perceived suitability of the images for representing historic virtual architecture

H0 (3): Rendering style does not have a significant effect on perceived clarity of representation of the main design elements of historic virtual architecture

Ha (3): Rendering style has a significant effect on perceived clarity of representation of the main design elements of historic virtual architecture

H0 (4): Rendering style does not have a significant effect on the perceived clarity of representation of the details of historic virtual architecture.

Ha (4): Rendering style has a significant effect on the perceived clarity of representation of the details of historic virtual architecture.

H0 (5): Rendering style does not have a significant effect on the viewer's recognition of the architectural style of historic virtual architecture

Ha (5): Rendering style has a significant effect on the viewer's recognition of the architectural style of historic virtual architecture

4.1. The rendering styles selected for the study

Three rendering styles were selected for the study: Photorealistic Rendering (PR), Non-Photorealistic Rendering-watercolor (NPR-W), and Non-Photorealistic Rendering- technical illustration (NPR-TI).

The goal of PR is to create images that are indistinguishable from photographs of the physical objects. Ferwerda [11] states that a photorealistic rendering should produce the same visual response as the real scenes. The photorealistic renderings used in the study were created in Maya software using Mental Ray and a physical sun and sky lighting model. Different levels of raytracing and final gathering were used to achieve a realistic scene with correct specular, reflectivity and shadows.

The Society of Architectural Illustration (SAI) [17] defines architectural illustration as a series of techniques that architects and developers use to visually represent their designs. In this research, two of the most popular forms of architectural rendering were chosen: technical illustration and watercolor. Technical illustration is a type of NPR in which an image is rendered by a computer to have a look that simulates a traditional pen and ink drawing. It is characterized by the use of areas selectively colored with a fill, a highlight, shading, and/or a shadow colors, and by contour lines that further define the shape of the objects. The contrast and thickness of the contour lines can be adjusted to improve clarity of communication.

To create the technical illustration renderings, we used Maya vector renderer and the Maya toon shader. Different levels of shadows and highlights (specular) were calculated in the scenes to maintain the same level of details as the other two rendering styles, and the lighting model was the same as the one used for the photorealistic renderings. The resulting images have a stylized hand drawn look, with constant size outlines and uniformly colored areas (figure 1, right).

Watercolor is characterized by the use of semi-transparent pigments, which are applied using a variety of brushes and techniques. The artist creates the scene by applying thin washes of watered paint to various regions of the paper, and *"colors can be mixed by applying a semi-transparent wash over washes that have already dried, allowing parts of the deeper wash to show through. Using watercolor techniques, it is possible to convey the shape and texture of an object that might not be visible in reality.through the careful selection of a limited set of colors the artist can create a painting that may not be true to reality, but is rich with information"* [23].

To produce the watercolor renderings used in the study, image-processing techniques were applied to the Maya PR renderings. One of the authors wrote a script in Matlab, which blurred and differentiated the colors of the Maya renderings, while performing edged detection to preserve the outlines and silhouettes of the architectural elements (figure 1, left).

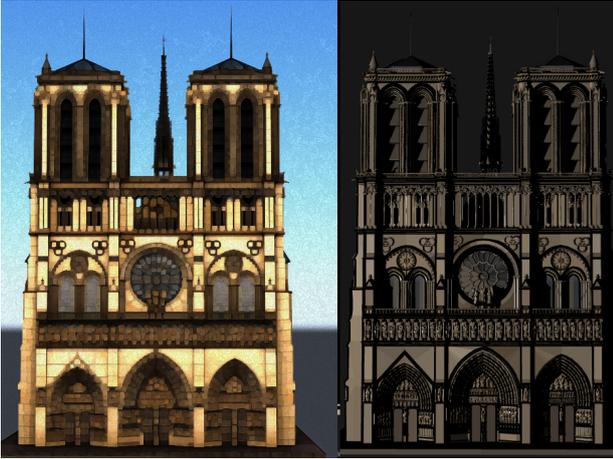


Figure 1. The two NPR styles used in the study: watercolor (left) and technical illustration (right)

4.2. The architectural styles included in the study

This study focused on three styles of historic architecture — (classical) Greek architecture, Gothic architecture, and (traditional) Chinese architecture. These architectural styles were selected for two reasons: (1) they are considered major styles, which have had a significant influence on later architectures, and (2) they are very distinct from each other. Two of the most representative buildings for each style were chosen for the study.

4.2.1 (Classical) Greek Architecture

Cartwright [25] claims that Greek architecture was the finest and most distinctive style of architecture in the world when it was popular (roughly 2000 years ago). Its design emphasized simplicity, proportion and perspective. These features make Greek architectures look exceptionally harmonic and unique.

The first example of Greek architecture chosen for this study is the Parthenon. The Parthenon is a temple designed to venerate the goddess Athena. Boardman [3] suggests that one of its unique characteristics is the successful combination of various features from other types of architecture, such as the Ionic column. The dimension of the temple's platform (69.51 feet by 30.86 feet, which is a 9-to-4 ratio) embodies the perfectness of the design of the Greek temples [30].

The Erechtheion is the other landmark of Greek architecture chosen for this research. The Erechtheion, built circa 420 B.C., was once described as “the most exceptional Ionic building on the Acropolis” [32]. It was chosen because its structure is very unusual among the temples of the Acropolis. There are two lateral porches attached to the opposite sides of the west ends of the cella (the temple's inner chamber). The smallest porch, which is also known as the renowned porch of the maidens,

projects to the south, facing the Parthenon. The north porch is a very large open-air porch, which counterbalances the south porch [36].

4.2.2 Gothic Architecture

Gothic architecture thrived through the high and late medieval periods. Its most famous features include the pointed arch, ribbed vault, and flying buttress [4]. These features were considered more as “motifs for a new aesthetic purpose” than as purely efficient structural features [21].

The Palace of Westminster and the Notre Dame de Paris Cathedral were chosen as representative buildings of Gothic architecture for this study. As two of the grandest and most beautiful pieces of architecture in the world, they represent the apex of this style for two of its most common applications: the church and palace. Notre Dame de Paris Cathedral embodied “the earliest example of the gigantism that was to become characteristic of Gothic architecture,” which includes “the flying buttresses of the nave of Notre-Dame”. The Houses of Parliament (also known as the Palace of Westminster), a masterpiece of gothic revival built in the influence of the contemporary Romantic Movement in England, is one of the aesthetically most successful large-scale public buildings in the Gothic style, with its decorative designs derived from old Gothic architecture [20] [28].

4.2.3 (traditional) Chinese Architecture

The traditional architecture of China is as old as Chinese civilization, having developed in China for over 4000 years [22]. Distinctive features of Chinese architecture include the use of wood as the main material, and components such as columns, beams, and purlins, which are connected by tenons and mortises. Another unique design element is the Dougong, a system of brackets inserted between the top of a column and a crossbeam. Traditional Chinese architectures are praised for their elegant profile and varied structure, for example, the overhanging eaves, upward roof corners, and different shapes of roofs.

In this study, we chose the Hall of Supreme Harmony and the Temple of Heaven as two different instances to render. As previously mentioned, one of the most unique elements of Chinese architecture is the roof and there are various styles of roof in traditional Chinese architecture. For example, the Hall of Supreme Harmony features a Fudian roof, which is only found on important buildings. The distinguishable features of this roof are its five ridges, which include “a main ridge and four sloping ridges, which generate a roof with slight curvature” [38]. The Hall of Supreme Harmony holds 9 Jiaoshou on each ridge in order to demonstrate the temple's importance to ancient Chinese society.

The Temple of Heaven, features a completely different roof called a Cuan Jian roof, also known as a conical roof [34]. Such roof has a cone-like shape and lacks the ridges of the Fudian roof. The main building in the Temple of Heaven was built with a triple conical roof. Such a shape

symbolized that heaven was round or circular, an ancient concept in traditional Chinese philosophy [34].

4.3 Subjects

One hundred and fifty subjects (18 years or older) participated in this study. 101 were undergraduate students, 14 were faculty members, and 35 were graduate students. All subjects were familiar with the architectural styles included in the study.

4.4. Stimuli

Eighteen sets of images were used as stimuli for the study (2 buildings x 3 architectural styles x 3 rendering styles). Each image set (block) contained 3 rendered shots of each landmark building taken from different camera angles (see figure 2). Hence the study included a total of $18 \times 6 = 54$ rendered images. Since the number of images was too large for a single participant to view, each subject was asked to view and rate 6 sets of rendered shots (18 images) which were randomly assigned and presented in random order. Each participant viewed 2 sets of images and took the online survey; this process was repeated three times for each subject.

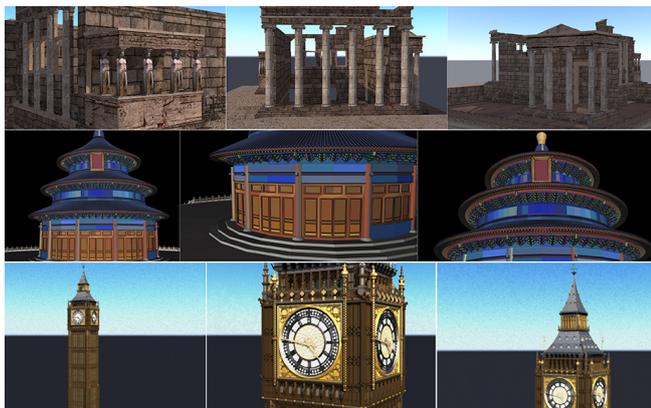


Figure 2. Three image sets (blocks) (9 rendered shots) used in the study. Erechtheion temple rendered using PR (top); the Temple of Heaven rendered using NPR- TI (middle); the clock tower of the palace of Westminster (Big Ben) rendered using NPR-W (bottom)

4.5. Evaluation instrument

The evaluation instrument used to collect participants' data was an online survey developed in Qualtrics software. The survey included the sets of images, one demographics question (position, e.g. faculty, student, other), one fill-in the blank question (subjects were asked to enter the architectural style of the building or leave the

answer blank if they could not recognize the style), and four rating questions. The rating questions used a 10-point Likert scale (1 = strongly disagree and 10 = strongly agree).

4.6. Procedure

Subjects were sent an email containing a brief summary of the research and its objectives, an invitation to participate in the study, and the http address of the web survey. Participants completed the on-line survey using their own computers and the survey closed when the number of participants reached 150. In total, each participant was asked to view three sets of images (18 rendered shots in total) and answer a set of questions for each image.

5. Findings

The study used a Balanced Incomplete Block Design. Each stimulus was one block and a questionnaire was used to rate two blocks. The results from the survey were analyzed using 3 statistical methods:

(1) ANOVA to determine whether there was a block effect, e.g., whether the order of presentation of the blocks affected the rating results. As the p-values of all blocks are larger than 0.05, there was no block effect.

(2) Pair-wised t-tests to identify the significant differences between the rendering styles.

a. For the first variable (perceived visual appeal) photorealistic rendering style was rated significantly higher than watercolor and technical illustration across all architectural styles with p-values of 0.0215 and 0.0015, respectively. Since the p-values are smaller than alpha level of 0.05, we reject H_0 (1). Although NPR-W was rated slightly higher than NPR-TI, there was no significant difference in ratings (p-value=1).

b. For the second variable (images are well suited for representing historic architecture) PR style was not rated significantly higher than NPR-W (p-value = 0.2239) but was rated significantly higher than NPR-TI (p-value = 0.0014) across all architectural styles. Hence, we reject H_0 (2). Although NPR-W was rated slightly higher than NPR-TI, there was no significant difference in ratings (p-value=0.2181).

c. For the third variable (overall the images convey the intended architectural design of the building /environment clearly) PR style was rated significantly higher than NPR-NPR-TI across all architectural styles with p-values of 0.0235 and 0.001, respectively. Hence, we reject H_0 (3). Although NPR-W was rated slightly higher than NPR-TI, there was no significant difference in ratings (p-value = 0.9416).

d. For the fourth variable (architectural details are clearly perceivable): PR was rated significantly higher than NPR-W and NPR-TI across all architectural styles with p-values of 0.0133 and 0.0006, respectively. Hence, we reject H_0 (4). Although NPR-W was rated slightly

higher than NPR-TI, there was no significant difference in ratings (p -value=1). Table 1 includes the p -values, standard deviation and median values for all variables.

Table 1. Mean, STD and MD for the 4 perception variables.

| Images are visually appealing | | | |
|--|-------------|---------------|----------------|
| | Mean | Median | Std Dev |
| PR | 8.151 | 8 | 1.996 |
| NPR-W | 7.34 | 8 | 2.268 |
| NPR-TI | 7.095 | 8 | 2.348 |
| Images are well suited for representing historic architecture | | | |
| | Mean | Median | Std Dev |
| PR | 8.266 | 9 | 1.928 |
| NPR-W | 7.84 | 8 | 1.949 |
| NPR-TI | 7.401 | 8 | 2.224 |
| The images convey the main architectural design elements of the building /environment clearly | | | |
| | Mean | Median | Std Dev |
| PR | 8.525 | 9 | 1.648 |
| NPR-W | 7.884 | 8 | 1.903 |
| NPR-TI | 7.657 | 8 | 2.052 |
| The architectural details are clearly perceivable | | | |
| | Mean | Median | Std Dev |
| PR | 8.266 | 9 | 2.0308 |
| NPR-W | 7.456 | 8 | 2.198 |
| NPR-TI | 7.204 | 8 | 2.503 |

(3) The distribution of the correct answers to the multiple choice question, e.g., recognition of architectural style question. The distribution of correct answers is included in table 2.

Table 2. Distribution of correct answers to the architectural style recognition question

| | PR | NPR-TI | NPR-W |
|----------------|-----------|---------------|--------------|
| Gothic | 92.45% | 88.89% | 95.65% |
| Chinese | 95.00% | 98.00% | 100.00% |
| Greek | 92.50% | 92.86% | 95.35% |

Findings show that rendering style has an effect on the viewer's ability to recognize the architectural style and NPR-W renderings had the highest recognition rate across all architectural styles, followed by PR and NPR-TI. Hence we reject H_0 (5).

6. Discussion

The paper reported a study that investigated whether rendering style has an effect on how viewers perceive historic virtual architecture. Findings show that rendering style affects the viewer's ability to recognize the architectural style, as well as other perception variables. More specifically, results show that participants perceived PR as the most visually appealing method for rendering historic architecture, and the most effective at conveying the architectural style, main design elements, and architectural details. NPR-W had the highest architectural style recognition rate across all architectures.

This result might appear surprising, as one could think that it is easier to recognize the architectural style from a photograph rather than from a watercolor painting. As mentioned in section 4.1, one of the characteristics of watercolors is that they can convey certain shape and texture elements that are not visible in reality. This could explain why the watercolor renderings had the highest architectural style recognition rate. In addition, prior research has shown that NPR images facilitate figure-ground-segregation, e.g. object identification relative to other objects within the same image [16]. The watercolor images might have increased the viewer's ability to identify elements that are typical of a particular architectural style, and therefore the subject's ability to recognize that style.

The findings of the study have important practical implications for both researchers and practitioners in the field of virtual architecture, and in particular interactive virtual tours. First, results of the study advance knowledge in this area in that they provide additional evidence in support of the effectiveness of NPR rendering for virtual architecture applications, such as VR tours aimed at teaching different architectural styles. Second, the findings from the experiment reported in the paper can help media artists make more informed decisions on which rendering style to use. In general, photorealistic models and renderings are more time consuming to produce and much more computationally expensive, especially for real time interaction, than NPR renderings. For certain applications such as interactive educational virtual tours of archeological sites, NPR images of lower detail 3D models can be as effective as PR renderings with the advantage of being much less costly.

7. Conclusion and future work

In conclusion, we can say that we learned a lot from this study but we still have much to learn in terms of what

makes a good virtual architecture rendering. The study revealed that participants found the PR renderings more appealing and more effective for conveying the architectural design, while they perceived the NPR-W images most helpful for recognizing the architectural style. In order to state with confidence that these results will generalize to other architectural styles and other groups of subjects, additional research is needed to overcome the limitations of our study.

The study was limited to three architectural types and three rendering approaches. As one of the objectives of our research is to develop a set of general rendering guidelines for virtual world developers, future studies focusing on other types of architecture, other rendering methods, and spanning a variety of applications will need to be conducted.

Although all the images used in the study were rendered using the same lighting scheme and color palette, they showed some differences in contrast, average intensity, and hue. These differences could have been potential confounding factors, and hence they could have affected the results. In future studies, more care should be taken in balancing the stimuli images for contrast overall color intensity, and background color.

The study did not reveal significant differences in 4 out of the 5 perception variables between NPR-W and NPR-TI. This could be due to the fact that the study was not fully balanced and not all of the viewers were exposed to all three rendering styles. In the future, a complete balanced study could be repeated to test the differences between TI and W. In addition, in future research it would be interesting to explore the effect that various levels of stylization within the same NPR style have on perception of virtual architecture.

Finally, another interesting future research direction would be to investigate whether subjects' characteristics such as gender, age, cultural background, and level of expertise in architecture would affect the results and in what way.

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