Evaluation of Non-Photorealistic 3D Urban Models for Mobile Device Navigation

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Abstract. This research presents a user evaluation study examining the effect different rendering styles of 3D virtual city models, as intended for navigational purposes, could potentially have on users with emphasis on non-photorealistically rendered (NPR) stylizations. The purpose of this experiment is to establish whether, particularly for the application area mentioned above, non-photorealistic, expressive rendering could provide alternative, more effective visual styles than the photorealistic representations of urban areas usually opted for by developers today. 50 participants were exposed to a predominably questionnaire-based study assessing various parameters by observation of the models on a UMPC (Ultra Mobile PC). The results of this research could potentially have significant implications on how future pedestrian navigational software should be visualised in the future.

Keywords: non-photorealistic rendering, mobile navigation, urban modeling, user studies

1 Introduction

Despite of the fact that traditional computer graphics research to this day still focuses on the production and assessment of photorealism, a relatively new field, the one of non-photorealism (NPR), has produced results that focus on viewer engagement by the use of stylization, abstraction and expressiveness. This new field has been slowly gaining ground not only in research but also in commercial applications since the rich visual styles it can emulate are in many occasions more suitable for certain information visualization communication purposes. Examples include psychological applications ([1], [2], [3], [4], [5]), architectural applications [6], perception of space studies [7], texture-based depiction ([8], [9], [10]), medical applications [11], learning applications [12] and also weather / natural phenomenon visualization software [13].

In the field of mobile navigation and particularly in regards to 3D urban modeling, research has already been conducted offering conclusive evidence that, especially for remote visualization of large city models, NPR can have many potential benefits. A recent approach [14] used a feature-line NPR method for building facades, demonstrating that urban data content using this type of shading over a photorealistic

one can be transmitted much faster over a limited-bandwidth network. Similar work [15] has also yielded positive results for NPR methods and mobile device rendering.

While the technical advantages of using NPR shading for 3D city models have been explored, there has not, to this day, been a cognitive study offering results and evidence to support the argument that indeed artistic rendering is not only less resource-heavy but also, because of its nature, more appropriate in conveying information to the average user of mobile 3D navigational software. Furthermore, the technical studies listed above only evaluated / visualized one NPR style on a mobile device rather than attempting to cover more of the many visual styles the area has to offer.

2 METHODOLOGY

Since the main objective of the project is to contrast photorealistic rendering and non-photorealistic rendering types in context with mobile urban navigation, it was evident that this research should consist of a mainly exploratory study regarding the users' preference. Then, it was decided that the main task of the study would be the viewing/observing of images depicting 3D urban environment (rendered in pre-selected rendering types) on a mobile device. The data would be collected through questionnaires after viewing the images but a face-to-face meeting with each of the participants was considered essential since the same means (a specific mobile device) should be used to view the rendered images. In other words, questionnaires would not be distributed by email or post since the images should be viewed on the same mobile device by all participants.

It is worth noting that 50 sample users participated in total. More specifically, 31 male and 19 female subjects took place in the experiment. The subjects involved were undergraduate students, postgraduate students and professionals and subject age was of a great range (18 to over 43). Moreover, it should be mentioned that all subjects had normal or corrected-to-normal vision. The sampling was randomly performed although the subjects were selected from various places in London and the greater area so that a further diversity of the population participated could be achieved.

The device used in the experiment was an Ultra Mobile PC (UMPC) and more specifically an ASUS R2Hv (with a 7-inch screen display). This device was chosen because the platform technology of such an ultra-mobile, ultra-portable PC with a small screen display is expected to be the norm over the next few years for pedestrian 3D navigation.

In order to contrast the normal shading rendering style with the non-photorealistic rendering styles, it was decided to use six rendering styles overall, representative of NPR styles in general. Thus, 3D rendered images have been created for each of these styles of an average central London urban area using the Virtual City Maker application [16]. The styles were the following; a) normal shading b) toon-shaded c) pen-and-ink with noise d) pen-and-ink e) line rendering and f) volume illustration. Figure 1 demonstrates a variety of the rendering styles used.

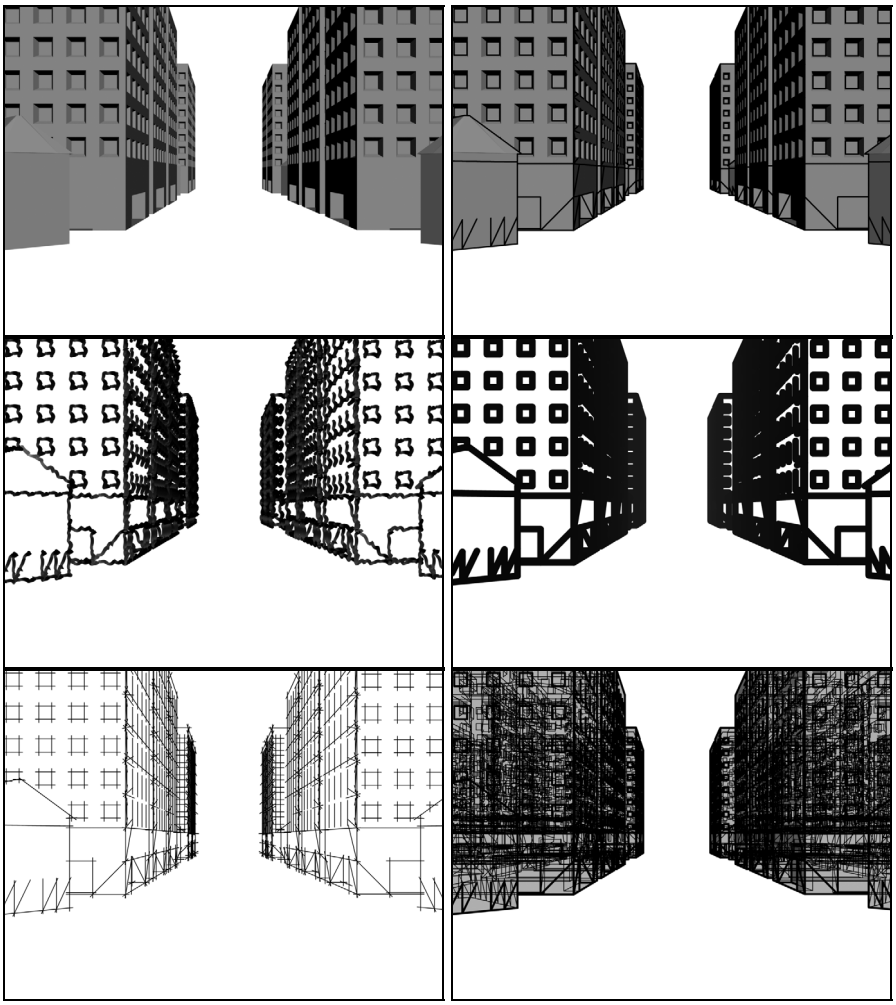

Fig. 1. The six rendering styles used in the experiment

A questionnaire was used for the collection of data. This included demographics such as general details of each participant (age, gender, occupation etc) and some questions regarding their previous experience regarding non-photorealistic rendering, navigation applications and mobile devices. The rest of the questionnaire was divided in six sections; one for each rendering type (normal shading, toon-shaded, pen-ink with noise, pen-ink, line rendering, volume illustration). Each section included seven (ordinal scale) questions, exactly the same ones for each rendering type as well as a special part at the end dedicated to any comments that could be left by the respondents (open question). All the questions were related to the efficiency of the rendering type in context with mobile 3D urban navigation. More specifically, the subjects were asked for each rendering type;

a) how they would rate the urban environment they see aesthetically

b) how easy they would be able to perceive distance in the urban environment given
c) how easy they would be able to perceive height in the urban environment given
d) how easy it would be to distinguish finer details in buildings such as doorways and windows in the urban environment given
e) how immersive they find the urban environment given
f) how effective in interaction with the user they would find the urban environment given if it was used in a navigation application
g) how appropriate and/or visible they think this rendering style is for small-screen display devices like the one used in the experiment

For each of the ordinal scale questions answers should be given from 1 to 5. 40 to 45 minutes were spent on average per subject. After observing on the UMPC device several different angles of the 3D urban model in each rendering style, the participants were given the chance to answer the questions above for each one before moving to the next style.

3 RESULTS

For each of the seven ordinal scale questions that contribute to the efficiency of a rendering style in context with mobile urban navigation we can simply average (calculate the arithmetic mean of) the results in total, as demonstrated in the following sections.

1.1 Aesthetics

In Figure 2 it is noticed that the normal shading rendering style is aesthetically equal to the toon-shaded rendering style. That is to say, the majority of the population that participated in the experiment preferred aesthetically both of the aforementioned rendering styles. It is very interesting to see an average value on both rendering styles which is exactly the same. Furthermore, it is also noticeable that line rendering scores second as far as aesthetics is concerned. Volume illustration scores third aesthetically while from the two pen-and-ink styles the one without the noise scores higher leaving pen-and-ink with noise last. Interestingly, we notice that normal shading and toon-shaded rendering styles score equally aesthetically but much above the average of levels (ranging from 1 to 5 or “very poor” to “excellent”) while line rendering comes second with some distinguishable difference from the first ones (but again above the average). The other styles score below the average, a fact that shows that they are not preferred aesthetically by the participants.

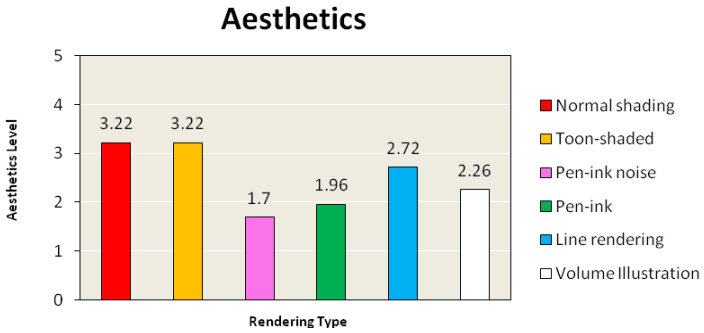

Fig. 2. User aesthetical preference

1.2 Distance

In Figure 3, we notice that the toon-shaded rendering type is almost equal to the normal shading rendering type as far as distance perception is concerned. That is to say, the majority of the population that participated in the experiment suggested that they were able to perceive distance easier in both of the aforementioned rendering types than the other types with a slight preference of the normal shading over the toon-shaded. Again, it should be mentioned here that the average value in those types is almost the same. Line rendering scores third as far as distance is concerned. Volume illustration scores fourth while from the pen-and-ink styles the one without the noise scores higher leaving the style of pen-and-ink with noise last. Finally, the results indicate that the normal shading and toon-shaded rendering styles score almost equally and much above the average of levels (ranging from 1 to 5 or "very hard" to "very easy") while line rendering comes third with some distinguishable difference from the first ones (although slightly below the average). The other styles score below the average, a fact that shows that they are not preferred by the participants as satisfactory rendering styles as far as distance recognition is concerned.

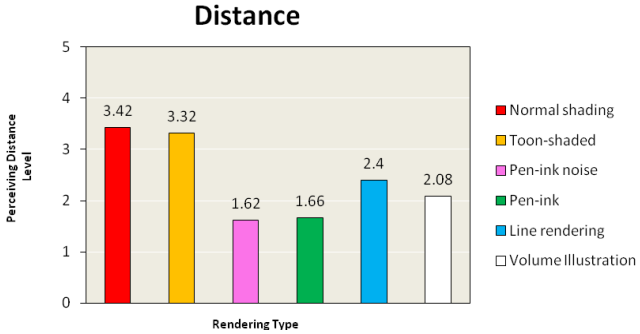

Fig. 3. Ability to perceive distance in rendering styles

1.3 Perceiving Height

In Figure 4, we notice that the toon-shaded rendering style is almost equal to the normal shading rendering style as far as height perception is concerned. That is to say, the majority of the population that participated in the experiment suggested that they were able to perceive height easier in both of the aforementioned rendering types than the other types with a slight advantage of the normal shading over the toon-shaded. Again, it should be mentioned here that the average value in those types is almost the same. Line rendering scores third as far as height is concerned. Volume illustration scores fourth while from pen-and-ink styles the one without the noise again scores higher leaving the style of pen-and-ink with noise last. The data indicate that the normal shading and toon-shaded rendering types score almost equally and much above the average of levels (ranging from 1 to 5 or "very hard" to "very easy") while line rendering comes third with some distinguishable difference from the first ones (but above the average). All the other styles score below the average, a fact that shows that they are not preferred by the participants as satisfactory rendering styles as far as height is concerned.

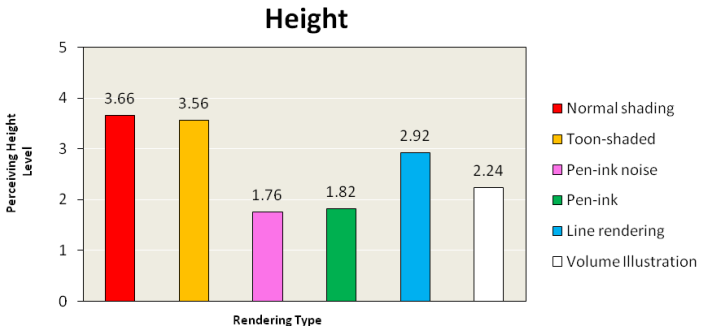

Fig. 4. Ability to perceive height in rendering styles

1.4 Distinguishing Details

Interestingly in Figure 5, we notice that the toon-shaded rendering type scores higher than the normal shading rendering type as far as the details that can be distinguished is concerned. That is to say, the majority of the population that participated in the experiment suggested that details in buildings (windows, doorways etc.) were clearer to make out in the toon-shaded rendering style than the normal-shading. Line rendering scores third as far as the distinguishable details are concerned. Volume illustration scores fourth while from the two pen-and-ink styles the one without the noise scores slightly higher leaving the style of pen-and-ink with noise last. Finally, the data indicate that normal shading and toon-shaded rendering types score almost equally much above the average of levels (ranging from 1 to 5 or "very hard" to "very easy") while line rendering comes third with some distinguishable difference from the first ones (below the average). The other styles score below the average too, a fact

that shows that they are not preferred by the participants as satisfactory rendering styles as far as making out details is concerned.

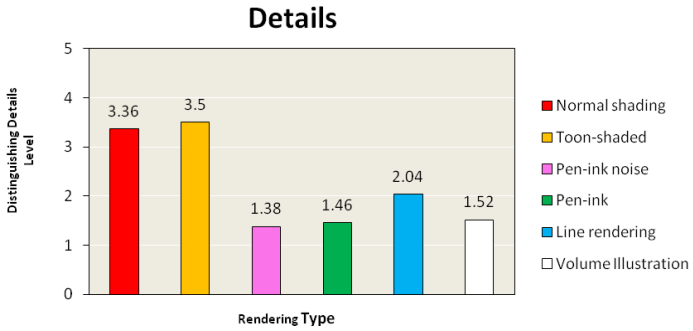

Fig. 5. Ability to distinguish finer details in rendering styles

1.5 Immersiveness

In Figure 6, we notice that the toon-shaded rendering style scores slightly higher than the normal shading rendering style as far as immersiveness is concerned. That is to say, the majority of the population that participated in the experiment suggested that they have found the 3D urban environment given very immersive in both of the aforementioned rendering styles (since the difference between them is really small). Line rendering scores third as far as immersiveness is concerned. Volume illustration scores fourth while from the pen-and-ink styles the one without the noise scores higher leaving the style of pen-and-ink with noise last. Finally, the data indicate that normal shading and toon-shaded rendering types score almost equally much above the average of levels (ranging from 1 to 5 or "not at all" to "very much") while line rendering comes third with some distinguishable difference from the first ones (although slightly below the average). All the other styles also score below the average, a fact that shows that they are not preferred by the participants as satisfactory rendering styles as far as immersiveness is concerned.

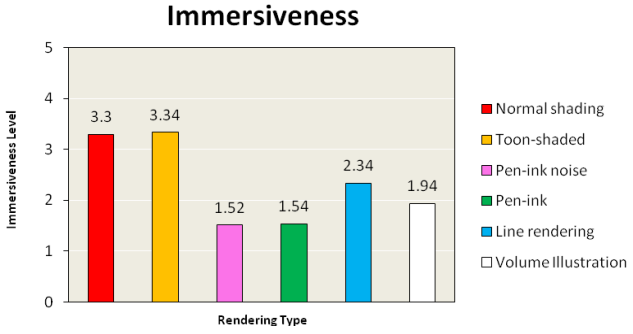

Fig. 6. Immersiveness of rendering styles

1.6 Interaction Effectiveness

In Figure 7, we notice that the normal shading rendering type scores slightly higher than the toon-shaded rendering type as far as the effectiveness in interaction with the user is concerned. That is to say, the majority of the population that participated in the experiment suggested that the user could be able to interact more effectively in the 3D urban environments relating to both of the aforementioned rendering styles (since the difference between them is really small). Line rendering scores third as far as the effectiveness in interaction with the user is concerned. Volume illustration scores fourth while from pen-and-ink styles the one without the noise scores higher leaving the style of pen-and-ink with noise last. Finally, the data indicate that normal shading and toon-shaded rendering types score almost equally and much above the average of levels (ranging from 1 to 5 or "not at all" to "very much") while line rendering comes third with some distinguishable difference from the first ones (although below the average). All the other styles score below the average.

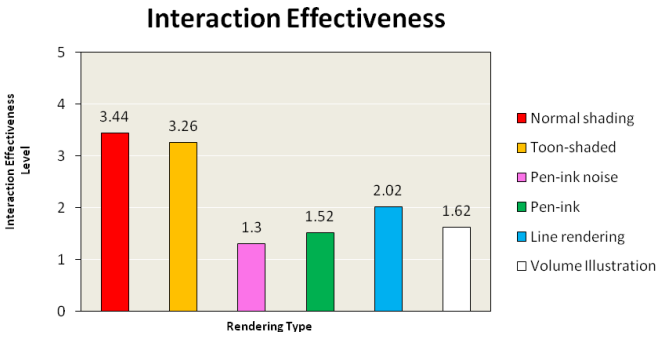

Fig. 7. Effectiveness of rendering styles in interaction with the user

1.7 Suitability for Small Screen

In Figure 8, we notice that the normal shading rendering type scores higher than the toon-shaded rendering type as far as its suitability for small-screen display devices is concerned. That is to say, the majority of the population that participated in the experiment suggested that both of the aforementioned rendering styles (since the difference between them is really small) are very appropriate and visible for usage on a small-screen display device. Line rendering scores third as far as the appropriateness/visibility for small-screen display is concerned. Volume illustration scores fourth while from the pen-and-ink styles the one without the noise scores higher leaving the style of pen-and-ink with noise last. Finally, the data indicate that normal shading and toon-shaded rendering types score almost equally and much above the average of levels (ranging from 1 to 5 or "not at all" to "very much") while line rendering comes third with some distinguishable difference from the first ones (but again below the average). All the other styles also score below the average.

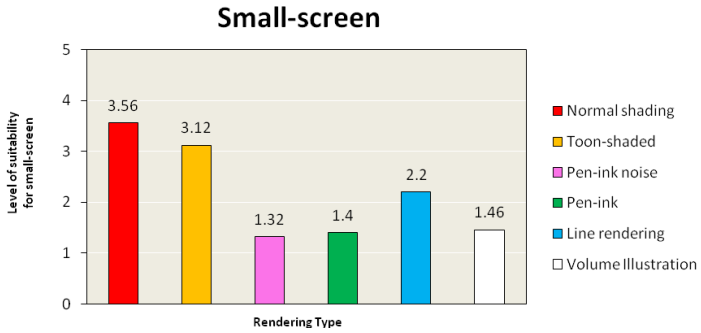

Fig. 8. Suitability of rendering styles for small-screen display device

4 DISCUSSION OF RESULTS AND CONCLUSION

The collected data was also analysed by a number of other ways (not shown in this publication) including averaging male-female population and using the one-way ANOVA model. Overall, results agree on the following: the cartoon-shaded view (one of the NPR rendering styles) is efficiently equal or almost efficiently equal to the photorealistic shading in context with mobile urban navigation (i.e. in all categories examined). Notably, finer details of the 3D environment were more distinguishable to the subjects in the aforementioned NPR rendering style than in any of the others including the photorealistic view, meaning that building outlines, doorways, windows, street signs and other intricacies of the scene are more easily recognised with this visual representation. This style was also ranked as the most immersive according to user preference. These findings support the initial argument that a mobile navigation system with an expressively rendered view (a toon-shaded one in particular) has tangible advantages over the standard photorealistic shading on a cognitive level.

Currently a real-time navigation experiment is underway (as the second part of this study), where users are asked to walk a distance of approximately 100 metres in the same area, for each rendering style, with a mobile device (PDA) in hand, while observing the corresponding 3D model which is translated in real-time according to the subject's positioning and orientation. The mobile device comes equipped with a GPS and digital compass and is running a prototype of the LOCUS application [17]. The same seven areas with the study presented above will be researched again with similar questions post-tasks, after each one of the rendering styles. This way, a complimenting and contrasting study for real-time NPR results will emerge which can offer comparable results with the ones presented in this publication, leading to further discussion on the applicability of NPR to mobile navigation visualisation.

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