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Weathering of Urban Scenes: challenges and possible solutions

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Abstract

In this paper, we propose to discuss on one of the main challenges in realistic rendering of urban scenes: changes in appearance over time within a urban context. After studying the previous work on weathering techniques, we have found that there is a lack of estimation for some important environmental parameters (such as sun radiation) that have a wrong impact on weathering phenomena simulation and, thus, on the appearance of virtual objects. We also think that such a problem needs to be addressed on large urban models. Here, we discuss some possible solutions we have studied in our research. These solutions are focused on screen-space techniques, in order to efficiently compute those factors and use them to interactively generate weathering effects.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Physically based modeling I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Motivation

Being able to capture and synthesize realistic material behaviors over time and on different environments is an important research topic in Computer Graphics. When striving for realism, high quality material modeling is not enough because real materials also have a temporal dimension. Over time, aging and weathering effects significantly alter their appearances, from color and texturing changes to light/matter specific responses, either by natural processes or due to human factors. It is very important to notice that these processes affect every single task of the traditional image synthesis pipeline, from geometry to rendering. Therefore, handling these temporal changes in appearance is a key factor to achieve realistic rendering of virtual models.

Nowadays, the main strategy in the video-game or animation movie industries for realistic scene modeling relies on the manual work of a group of artists, who adjust and modify textures and/or geometry of virtual models. Thanks to it, several types of high quality imperfections are modeled, but following only aesthetic criteria and often disconnected from real life effects. In other studies, the developed techniques are based on texture-transfer of these effects from existing images to virtual objects, or in the simulation of the physical underlying phenomenon, which also consumes large amounts of resources.

Accurately modeling aging and weathering processes, in order to be able to compute realistic images at a low computational cost is still an open problem, which we propose to study here.

2. Main goals

Our goal is to synthesize images of large weathered urban environments at interactive rates. In Figure 1, we show some examples of what we would like to simulate. In the literature, this problem has mainly been addressed by an effect-centered approach, i.e., for each considered weathering effect, try to figure out where it would appear and simulate it locally. The main problem of this approach is that, in order to achieve a multi-effect final image, we must perform different weathering algorithms on the same geometry several times. Moreover, most current techniques are not suitable for large models, as cities. In that way, it is not feasible to produce this kind of images at interactive frame-rates with current techniques.

To achieve our objective, we need to consider the city as

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Figure 1: Examples of weathering effects in a urban environments.

a whole and to study the relations between weathering effects and the internal and environmental factors which cause them. This opens a series of important problems: determination of the factors that influence weathering, their detection or the detection of their causes, and their combination. After determining the influence factors, we have to take care on how they influence different weathering effects at the same time. Thus, we need to develop automatic (or semi-automatic) methods to compute these factors independently. Besides that, there are factors that can be described as the combination of other ones. For this reason, we need to study these processes and carefully model these interrelations. Once this is done, we will be able to design an algorithm to simulate several weathering effects in function of its causes.

Low computational cost is another key aspect that current techniques do not achieve. In this paper we focus on developing new methods to simulate weathering effects with a very reduced computational and memory cost, still able to handle large scale models at interactive rates. Therefore, instead of using expensive physical simulations, it is necessary to rather focus on approximations of physical laws to obtain believable results.

3. Background

To the best of our knowledge, realistic rendering of urban scenes has not dealt with global weathering effects. Relevant work has been done to produce impressive real time images of virtual urban environments [SKK*14], and even whole cities. Local weathering effects [DRS08, MG08] may be applied to different predetermined parts of a whole urban environment to confer it a weathered aspect. Grosbellet and colleagues [GPG*16] considered environmental parameters to study season influence in large urban environments. But, as far as we know, no technique has been proposed to deal with the aging process of a urban environment as a whole.

In the context of our work, among the many aging techniques that have been proposed, we may pay attention to those that are based on a kind of preprocess to, afterwards, deal with different weathering effects (so called *generic techniques*). In particular, the techniques that are closer to our interest are those that handle the phenomena using particles coming from weathering sources. Among these techniques, one can stand out the work of Wong et al. [WNH97]. In this work they used a 3D texture that handled weathering processes. This texture is controlled by a tendency distribution generated using weathering sources, similar to illumination sources, taking into account the occlusion and curvature of the surface. Another important technique is the work of Chen et al. [CXW*05]. Their technique, inspired by photon mapping, computes a weathering map throwing weathering particles from weathering sources to, afterwards, apply the effects by modifying the properties of the materials and the geometry of the model.

4. Considered parameters/factors

We have observed that most weathering effects share a set of factors that influence their presence, which, however, have almost not been addressed in the literature. On one hand, there are factors related to the building intrinsic properties. The internal factors more determinant in weathering processes are geometry and material properties. On the other hand, there are external factors related to the environment surrounding the buildings. In urban models, these external factors mainly are sun, rain, wind and pollution. Although one can find more external factors, most of them can be considered as a combination of this four. In next subsections, we discuss them in detail.

4.1. Insolation

Solar irradiance is a factor that has traditionally not received enough attention in weathering techniques. Nevertheless, it is a key factor in several weathering processes: it influences in biological growth weathering, it is responsible of the modification of chemical properties of building materials, and it is an accelerant of several chemical processes as corrosion, pollution deposition, salts crystallization, among others. Moreover, it interacts with other factors like rain and water sources drying the surfaces and reducing the humidity factor. For this reasons, we think that its estimation and usage will improve current weathering techniques significantly. For the best of our knowledge, the existing techniques to estimate insolation do not allow complex geometries of buildings and are time consuming when dealing with large cities. That can be the cause of the lack of usage of this factor in current weathering techniques.

In our research we have already addressed this challenge. We have developed a real-time technique to estimate insolation in complex urban scenes. In a first step, we precompute a solar irradiance map using Hosek and Wilkie [HW12]

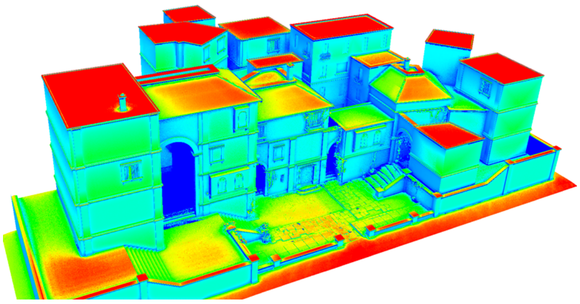

Figure 2: Example of our insolation estimation in real-time.

solar radiation model. Then, we evaluate the sky visibility using a two-scale screen-space approach that handles both global and local visibility. Finally, we use this visibility to estimate insolation, sampling the irradiance map and taking advantage of mipmap prefiltering. We obtain detailed insolation estimation in real-time, as we show in Figure 2.

4.2. Rain

Rain is a factor which has influence on several aspects. It is directly related to surface erosion and biological growth processes, it modifies material deposition in two senses (as surface cleaner and as pollutant carrier) and it interacts with other factors as well. Traditionally, rain has been estimated either using costly particle simulations [CP13, WJGG15] or relying on approximations that evaluate sky visibility in a vertical cone. The latter approach is intuitive and, although it represents an important approximation, the results obtained have enough quality for weathering purposes. In our research, we have also followed this idea using a screen-space implementation that reduces computation time.

4.3. Wind

Wind is also an important factor in weathering processes. As rain, it is directly related to surface erosion, material deposition and the interaction between different factors. Moreover, it is a key factor to compute pollution distribution. In previous work, it has been studied using accessibility or fluid dynamics simulations [VHB10]. Such solutions have important drawbacks. The first can not be used to compute pollution particles distributions because it does not take into account fluid dynamics. The second, although it works well when dealing with erosion simulation, it has high computational costs.

We have addressed this challenge by designing a solution

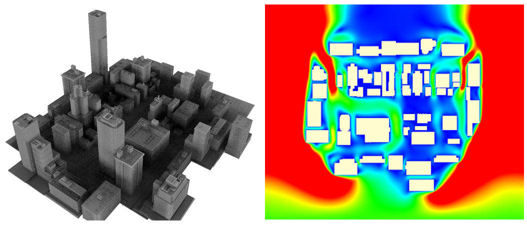

Figure 3: Examples of wind estimation. At left, the screen-space accessibility estimation and, at right, the wind distribution map.

that combines the best of both. On the one hand, we perform a fast computation of the accessibility using a horizontal cone implemented with a fast screen-space approach. On the other hand, we use a 2D voxelization of the scene, and we perform a wind simulation for a set of wind directions using a *Lattice-Boltzmann* method implemented in CUDA. In run-time, we combine both steps with a very low cost. Although it requires some pre-computation, the parallelized implementation allows real-time changes in the wind map. In our solution, we improve the accessibility approach with the wind distribution and we can use this wind map in the estimation of the pollution factor. Figure 3 shows an example of both solutions before combination.

4.4. Pollution

Pollution diseases, that affect all materials, represent a very important phenomenon when dealing with appearance. Discussing here the importance of cultural heritage conservation against pollution could be very interesting – and it is one of our main goals – but we have first to understand and model its underlying effects, as pollution affects both modern buildings and historical monuments. Such influence has wide implications in the simulation of weathering processes: it is a huge source of material deposition and it influences chemical reactions in corrosion processes, resulting in strong change in appearance. Its estimation is not easy as its distribution is related to numerous parameters such as wind, and, in a second term, to rain and sun accessibility. Moreover there are few models which study the pollution deposition on materials. A first attempt has been proposed by Merillou et al. [MMG*10], focusing on ambiant pollution (with out transport of pollutants) on individual buildings. The complexity of a more comprehensive model, along with the fact that studying huge cities is a quite recent goal in Computer Graphics, could be the reason for the lack of physically plausible weathering simulations of this kind.

In our research, we have divided this external factor into two groups. On the one hand, we model pollution caused by chimneys and factories as a constant ambient pollution term, modulated with the rain accessibility estimation. On the other hand, we compute the pollution caused by vehi-

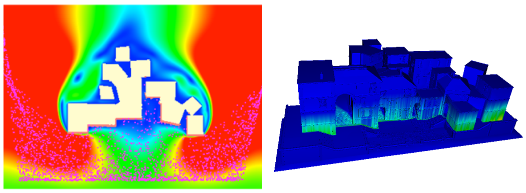

Figure 4: Examples of pollution estimation. At left, the simulation of the pollution particles transport across the scene and, at right, the resulting deposition on the surface.

cle traffic using a specific wind distribution and the modeling of pollution as particles. In a first step, we perform a pre-computation where we generate these pollution particles from sources at the streets, following dynamic laws and a wind distribution map. In our proposed pollution deposition model, each time a pollution particle hits a building, we store this hit in a pollution map and we bounce again the particle, reducing its mass depending on the building material and particle properties, until it completely disappears. Then, in screen-space, we use this pollution map to extrapolate the deposition on the facade attenuating it as a function of the height of the current point in the scene. Figure 4 shows the pollution path simulation and the resulting deposition.

5. Rendering

After computing all the factors that influence the presence of weathering, as listed in the previous section, we need to know how to combine them into models that describe the final appearance of weathering phenomena. Each specific phenomenon is influenced in a particular way, and no general model is currently available for all of them. This opens a significant challenge that needs to be addressed.

Certain models, especially those tailored at specific phenomena, already cover the influence of certain factors. However, we need to find more comprehensive formulas able to handle far more environmental effects. In addition, a general model is also of interest for practical purposes, even if limiting its physical accuracy.

Besides the combination of such factors, rendering the final appearance of each phenomenon has many other implications. Since we want to achieve photorealistic looks, we will need to find new ways of producing more compelling simulations or combining images and data with final simulations. Dealing with large scale city models also means faster approaches for achieving all this.

Within our research, we are currently working on combining all the factors into a single model, focusing on pollution-related effects. We are also investigating the use of fast screen-space solutions for rendering final appearances, which could involve the simulation of rain flows taking advantage of depth information, for instance. This work, however, is still in progress.

6. Conclusions

In this paper, we show how we propose to address some of the main challenges to reproduce weathering effects in large urban scenes in interactive frame rates. As a possible solution, we have pointed out the need of a change in the weathering simulation paradigm handling the city as a whole. Moreover, we have reviewed the main factors that influence weathering, their treatment in the literature, and finally we have proposed several solutions for efficiently evaluating them onto urban scenes. In conclusion, we believe this document opens an interesting discussion about urban weathering challenges and their possible solutions.

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