INTERACTIVE THREE-DIMENSIONAL RECONSTRUCTION AND WEATHERING SIMULATIONS ON BUILDINGS

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ABSTRACT

Architectural sites suffers from weathering effects such as liquid sedimentation, lampblack or pollution deposit, moss growing or longterm erosion. Displaying their impact on present buildings could help deciders to plan relevant actions for preserving the architectural heritage. In this paper we present a user-friendly solution for on-line acquiring a semi-physical model from one or few images of a building, immediately followed by real-time simulations. The goal is certainly not to give an accurate prediction of what will happen, but rather to show a plausible state of the site under various possible degradations arising from natural effects. The solution relies on the coupling of two 3-D modelling programs: one dedicated to interactive reconstructions and a second to discreet manipulation for natural phenomena simulations based on a combination of different surface cellular automata. Several experiments were held to estimate the effectiveness of this approach and to identify future works in order to cope with present limitations. A first series applies a lampblack deposit simulation on a large-size 3-D model to demonstrate the solution feasibility and to provide indications about achievable performance. The second series focuses on the solution sensitiveness to both geometrical and semi-physical models granularity through the application of a stone erosion effect on a smaller but less regular-shaped building model. The third series demonstrates the discreet model ability to simulate multiple effects with the example of a vegetation growth simulation. Guidelines for future works are given in the conclusion of this paper.

1. INTRODUCTION

Every architectural sites suffers from weathering effects such as liquid sedimentation, lampblack or pollution deposit, moss growing or long-term erosion. Displaying their impact at short or long term on present buildings could help deciders to plan relevant actions for preserving the architectural heritage. It relies on the availability of a conform 3-D model to the reality and a simulation tool to make it evolve under different weathering effects. Abundant literature can be found about city models enrichment for urban planning purpose. For instance, both the visual realism and the user feeling of immersion may be greatly improved by providing pedestrians or vehicles animations (Devillers et al., 2002), credible day or artificial lightings (Houpert, 2002; Bur et al., 2003), vegetation and spatialized sounds (Loscos et al., 2003), etc. But applying simultaneous deformations to simulate weathering effects remains a challenging issue.

In this paper we present a user-friendly solution for on-line acquiring a semi-physical model from one or few images of a building, immediately followed by real-time simulations. The goal is certainly not to give an accurate prediction of what will happen, but rather to show a plausible state of the site under various possible degradations arising from natural effects. The solution relies on the coupling of two 3-D modelling programs: one dedicated to interactive reconstructions and a second to discreet manipulation for natural phenomena simulations. Presently geometry modifications are displayed using a simple point sprite technique, and better visual realism could be reached with the help of a more sophisticated rendering tool.

The reconstruction stage is based on a top-down approach (Even, 2001) where solid primitives are assembled together and superimposed to the image in order to achieve geometrical consistency. This approach flexibility is particularly well suited to the production of task-oriented models which take the simulation requirements into account. Some space partition may be done to gather objects featuring the same material and thus affect them some appropriate behaviour; for instance humidity propagates differently inside stone than inside wood. Furthermore the model granularity may easily be adjusted to provide a satisfying level of detail: actually it is important that relief details such as cornices be explicitly defined in three-dimension, and not only rendered using texture mapping.

Computer Graphics (CG) literature about surface imperfections rendering covers a wide range of impressive effects such as corrosion, weathered stone, impacts, scratches and more recently lichen growth (Dorsey and Hanrahan, 1996; Dorsey et al., 1999; Paquette et al., 2001; Merillou et al., 2001; Wong et al., 1997; Desbenoit et al., 2004). Unfortunately, those approaches are not specialized for architectural issues, moreover, most of those simulations were designed on a single purpose with a specific and restricted model. That is why we propose to use a flexible 3-D cellular automaton approach allowing multiple effects to occur on the same building structure. It relies on a generalization of an idea put forward few years ago (Gobron and Chiba, 1999). The technical and formal aspects of this new model are currently in review process within the CG domain. For the present work, simulations of multiple effects that occur over building surfaces due to weathering are set up using several surface cellular automata.

The next section introduces briefly the modelling tools. The interactive reconstruction tool principle was already presented at a former CIPA symposium and we rather focus on dedicated task-oriented aspects. More details are given about the cellular automaton principle which lies at the heart of the discreet simulation tool. Section 3 presents held experiments. The first series is intended to check the solution feasibility on a large data set. At this purpose a lampblack deposit simulation on a large-size building was selected. We adapted a formerly rebuilt model of Zurich City Hall from the CIPA reference data set (Streilein et al., 2000) to take into account this simulation requirements. The second series focuses on the solution sensitiveness to both geometrical and semi-physical models granularity. A stone erosion effect simulation was applied to a smaller but less regular-shaped building which was modelled with different levels of details. The third series demonstrates the discreet model ability to simulate multiple effects with the example of a vegetation growth simulation. It requires at first the stone erosion simulation of the provided model surfaces, then the calculation of a water-map. Finally both lichen and moss growth generations are simulated. A set of future works concludes this paper.

2. MODELLING TOOLS

2.1 Task-Oriented 3-D Reconstruction From Images

In order to set up consistent simulations, some relevant geometry with the appropriate surface level of details and featuring distinct materials must be provided to the discreet manipulation program. Such task is performed using a new interactive 3-D modelling platform still under development within the research group MoTrICE at St Dié. This platform is based on a top-down approach (Even, 2001) where appropriate solid primitives are selected, assembled together and directly displayed on the camera images. Geometric parameters are manually fitted so that the model matches the relevant image features. This approach provides a more natural way to build the 3-D model than a classical bottom-up one, where homologous features are first extracted then processed to recover some surface model. It features a user-friendly interface, that relies on efficient assistances based on geometric reasoning (Even, 2004a) and semi-automatic image processing (Even and Malavaud, 2000).

Because the human operator fully controls the way the model is built, it proves very flexible to cope with partly occluded elements and illumination problems and to exploit the available knowledge on the reconstructed site (Leroux et al., 2002). Moreover, different experimental works for robotics applications (Even et al., 1999) showed that this approach is well suited to provide taskoriented 3-D models, that closely fulfil task level constraints such as space partition, hierarchical organization, or semantic contents (Even, 2004b).

2.2 Cellular Automaton (CA)

2.2.1 Cell, CA, and SCA: Even if the most natural phenomena seem to exhibit complex behaviours, they are always the result of a large number of simple entities with limited capabilities. From this assumption, we propose the study of a geometric model based on dynamic and interactive discreet entities called cells. Their limited but non null capabilities can be simulated using the discrete nature of cellular automata (CA): a set of very simple rules that produce a wide range of complex behaviours.

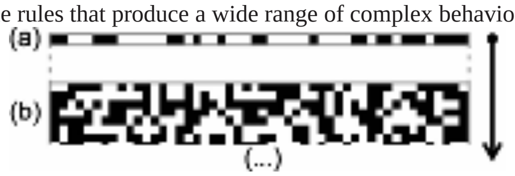

Figure 1. Example of 1-D boolean CA.

Concrete examples are best to illustrate CA behaviour: Figure 1 presents probably the most simple graphical CA application, a single dimensional boolean CA. From a set of initial states (a) and a list of boolean rules (based on the comparison of the current and neighbourhood cell states), a non trivial succession of states (b) are produced. Figure 2 shows the famous two dimensional *life game* (Thalmann, 1986) with respective change state in lockstep from left to right. Notice how similar initial states are; both systems are convergent, nevertheless, after five steps, case (a) shows a non null cellular stability whereas in (b) all potential is false.

Figure 2. Example of 2-D boolean CA: the *Life-game* applied to two similar initial states

The work presented in this paper is based on an advanced CA model specialized into any type of surface (*i.e.* shape and structure) called surface cellular automata (SCA). Figure 3 presents some original SCA onto a building. Rendered picture (a) shows the input polygons; (b) is a simulation of watercolor painting spots; (c) proposes a solution of 3-D surface Voronoi diagram; and (d) a generation of maze-like texture.

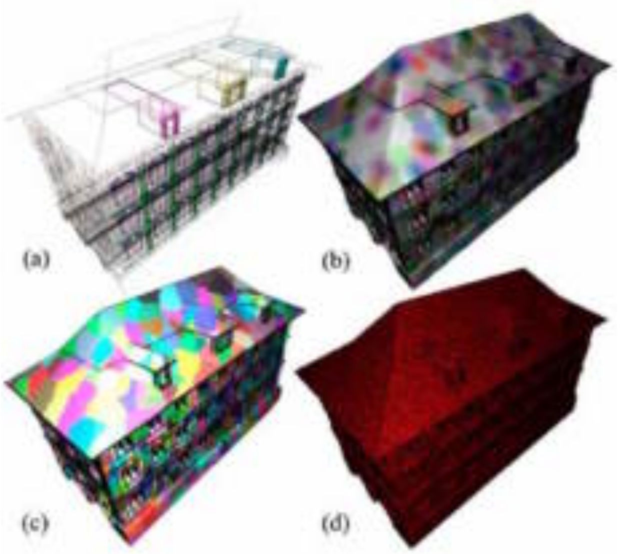

Figure 3. Example of surface cellular automata (SCA) applied to a fairly complex scene. (a) input geometry; (b) watercolor painting; (c) Voronoi diagram; (d) maze-like texture.

2.2.2 Rendering, Memory, and Hardware Expenses: In section 3, simulations of many natural phenomena require complex dynamic structure and hence large amount of memory. It is important to keep in mind our main goal: simulation of weathering in terms of reconstruction and behaviour. To do so, the rendering is kept as simple as possible with two important aspects. First, we must maintain the highest CPU power directed to the simulation of natural phenomena over buildings. Therefore, light properties such as specular, radiosity effects shadows, are not even considered. Second, data from each cell in the CA is directly transmitted to OpenGL (Shreiner et al., 2003) as a dot using a simple *Phong* rendering.

Memory cost is relative to the experiment that has to be shown. Nevertheless, our experiment shows that weathering simulations (over 3-D surface only) begin to produce interesting emerging behaviour if the cell number is larger that 10^5. Considering that each cell requires around 20 bytes –including current behaviour, coordinate, orientation, color, dynamic neighbourhood linking, and previous states– we think that a minimum of 2 Go of RAM is necessary.

Results presented in this paper were generated using MSVC++ on Windows 2000, with a single *AMD Athlon 2600* CPU with 2 Go of RAM and a *GeForce 6800-GT* graphical card.

3. WEATHERING SIMULATIONS

3.1 Surface Natural Phenomena Over Buildings

The schema figure 4(a) presents three groups of effects that can alter building surfaces.

- The first set (*Surface appearance*) modifies the appearance (*e.g.* colors) and corresponds to the following natural phenomena: lampblack, small amount of sedimentation, lichen propagation effects –see subsection 3.4 and figure 4(e)*s*.
- The second category locally changes building surface geometry: *e.g.* erosion, scratches, peeling, or impacts –see subsection 3.3 and figure 4 (b), (c)*s*, and (d)*s*.
- The last group of effects consists of generating new active cells to simulate the action of environment, for instance, vegetation that has non negligible volume such as moss –see subsection 3.4 and figure 4(e)*s*.

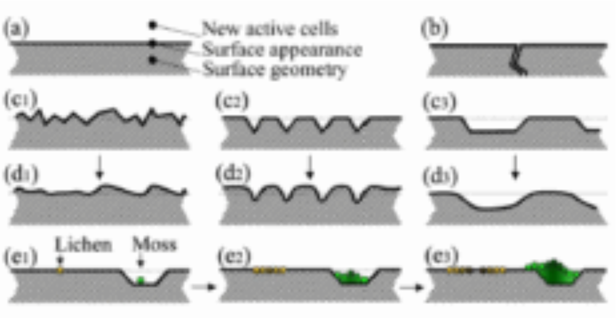

Figure 4. Main categories of natural phenomena that modify building aspect. (a) three types of effects: directly onto the surface, inside the solid, and outside (surrounding interaction); (b) fractured surface; (c) defining local geometry, respectively random, regular local impacts, peeling-like CA; (d) smoothing local geometry; (e) vegetation interaction and behaviour, for instance, lichen and moss.

3.2 Lampblack-like simulation

The simulation tool effectiveness was evaluated using a 3-D geometrical model of Zurich City Hall. This large building model was formerly rebuilt from the CIPA reference data set (Streilein et al., 2000) in order to validate the 3-D interactive modelling top-down approach (Even, 2001).

Some adaptations to the present work requirements were performed. Firstly non-convex parts such as walls or basement were decomposed into several convex solid primitives. As the interactive modeller was actually designed for robotics purpose and does not supply any specialized primitives for architectural environments, windows and arches of the former model were simple plates jutting out the walls. This modification was necessary to provide the simulation tool with a fully consistent 3-D model. Secondly, the different parts were groups by façades, then by functions: walls, quarry stones and cornices, window frames and friezes, roofs. The adapted model is composed of 2591 solid primitives arranged into 1651 assemblings.

Figure 5 illustrates key steps to generate a lampblack-like simulation. Rendered images (a) and (c) show the original pictures with the mapped reconstructed 3-D geometry; (b) and (e) present the corresponding derived cellular views; (d) illustrates a set of assembling geometry; and finally (f) proposes the result of the lampblack-like CA model –the main idea being to locally darker cells that have high derivative neighbourhood (*i.e.* where pollution smokes tend to deposit carbon particles).

Software statistics for figure 5 and the corresponding lampblack simulation are: about 1 million cells and about 5 minutes of computations.

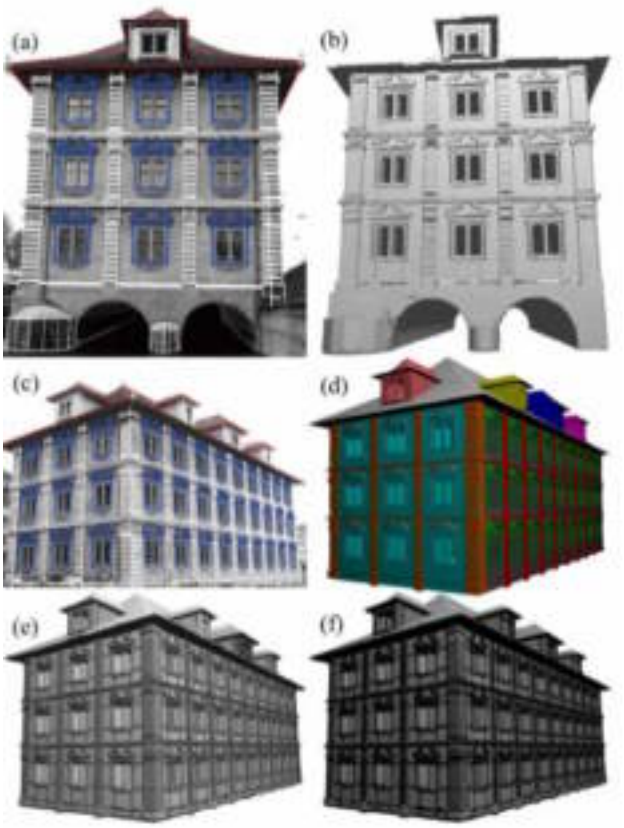

Figure 5. Zurich City Hall: From image-based 3-D reconstruction to a simulation of lampblack.

3.3 Stone surface effects

Remaining evaluations were led on the Donon temple, a smaller but less regular-shaped building. This sandstone block structure is a Neo-Greek style imitation erected in 1861 during the romantic period at the top of the Donon mountain at Vosges chain. Several images were taken with a Canon EOS 300D digital camera at fixed zoom position and focus at infinity.

Figure 6. Front (a) and back (b) views of Donon temple.

A simple camera model featuring a focal distance value and the principal point position was identified using a very rough but fast method based on the detection of two vanishing points corresponding to orthogonal directions (Guillou et al., 2000). This coarse calibration was quite enough to ensure acceptable model registrations on the images.

A coarse model was realized using only 16 solid primitives and

4 assemblings. Rough surrounding volumes were used to approximate the roof. A more detailed model where each stones of the roof was rebuilt individually using simple polyhedrons was also acquired. It features 101 primitives and 22 assemblings.

Figure 7. Coarse (a) and detailed (b) models of Donon temple.

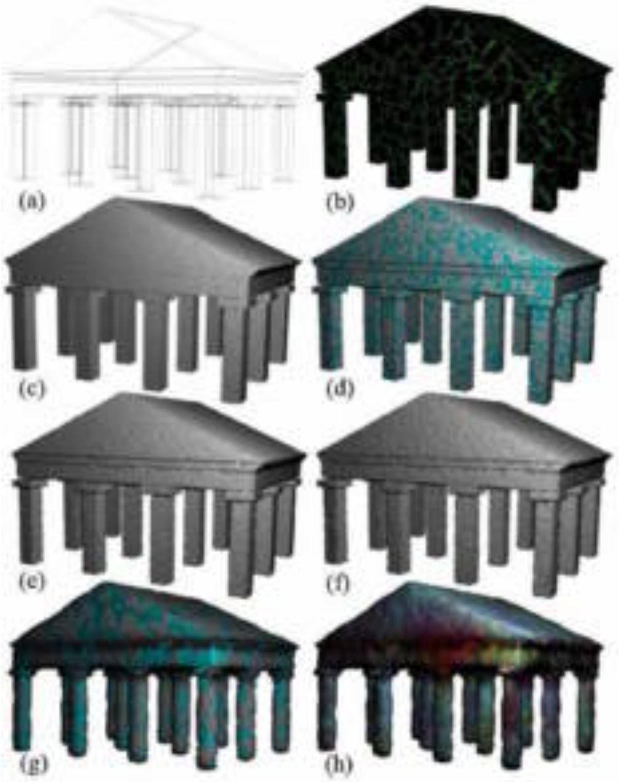

Figure 8. Other examples of CA applied to a simplified geometric version of the *Donon Temple*. (a) input geometry; (b) fracture potential; (c) generating 3-D cracks from potential; (d) local peeling simulation using digression-diffusion; (e) massive local random impact simulation; (f) local erosion after impacts; (g) large peeling and massive erosion; (f) similar to (g) plus a parallel mazelike simulation.

Many weathering effects can alter stone surface and sometimes even strongly and deeply change its geometric nature. As schematized in figure 4 (b), (c), and (d) we have simulated the following weathering effects using CA:

- Cracks and fractures, see figures 8(b) and (c). Further information on SCA specialized in the fractures propagation can be found in (Gobron and Chiba, 2001a);
- Peeling, see dark yellow lichen in colored version of figures 9(d) and (f), and greenish lichen in figure 10. An advanced SCA peeling model is detailled in (Gobron and Chiba, 2001b);

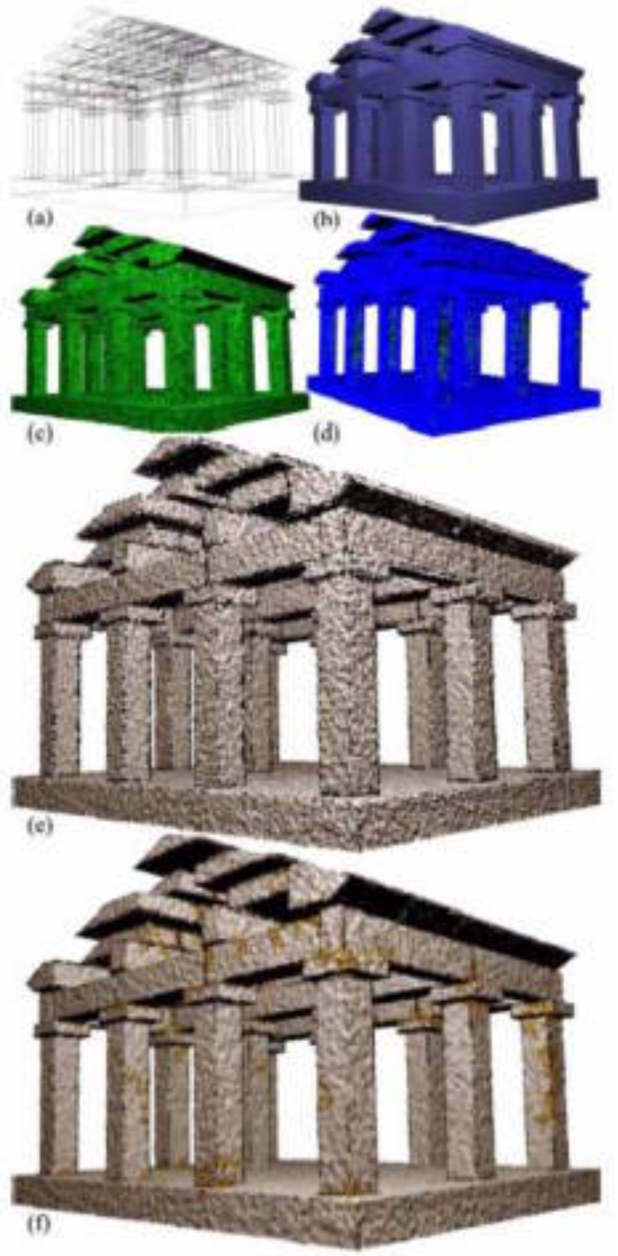

Figure 9. Multi effects over a realistic geometric version of the *Donon Temple* backside face. (a) input geometry; (b) cellular encapsulating boxes view; (c) potential map for massive impact; (d) water-map after average convergence of the CA water-flow simulation; (e) cells view after massive impacts; (f) final view after erosion and lichen simulations.

- Massive local random impacts, see figure 9(e);
- Erosion and surface smoothing, refer to figures 8(f) to (h), 9(f), and 10.

Software statistics for figure 8 and the corresponding cracks, erosion, and peeling simulations are: about 300 thousand cells and computations were made in real-time (few seconds for each effect to converge).

Software statistics for figure 9 and the corresponding water-map, massive local impacts, and erosion simulations are: about 600 thousand cells and computations were made in less than 20 minutes. This relatively long computational time was due to the water-flow CA simulation –see figure 9(d).

3.4 Vegetation

As previously seen, surrounding events interact with building appearance. In nature, water-flows produce pigment sedimentation and stone erosion. In a similar way, humidity indirectly contributes to weathering effect: it allows vegetation to grow.

To simulate humidity and water accumulation on natural geometric area we have designed a water-flow CA. Notice that this CA is not real-time as it must take into account a large number of parameters related to the solid vs. liquid relationship –among which viscosity, absorption, evaporation, gradient, etc.

We have identified two geometric categories of vegetation:

- Surface propagation, which can be simulated by directly changing building cell's parameters;
- Volume generation, which implies new interactive cells (*i.e.* new solid) to be defined.

The following subsections detail a representative example for each of these two categories.

3.4.1 2-D vegetation: *e.g.* lichen: Lichen is a very common natural phenomenon that propagates on the surface of any kind of stone. Many types, colors and behaviour of lichen exist. We only proposed two of them: a dark yellow one (see figure 9(f)) and a greenish lichen (see figure 10). To simulate their respective behaviour, we assumed that it mainly follows humidity percentage –non-saturated region of the water-map (see figure 9(d)).

Figure 10. Simulation of green lichen with stone erosion over the front face of the Donon Temple

3.4.2 3-D vegetation: *e.g.* Moss: Moss can also be found almost everywhere, however it requires much more water and sun light exposure than lichen, and therefore is strongly influenced by the water-map. Furthermore, even if buildings are very large object compared to vegetation, the volume of moss cannot be neglected –see figure 4(e). Realistic moss behaviour and visual aspect require huge amount of cells (see figure 11), and structure interactive connections (see rendered picture 11(f)).

Software statistics for figure 11 and the corresponding cracks and moss simulations are: about 665 thousand of initial cells plus 150 thousand moss cells and computations were made in less than 5 minutes. Notice that due to the special 3-D growth behaviour of moss, internal connections increased memory cost by 50%.

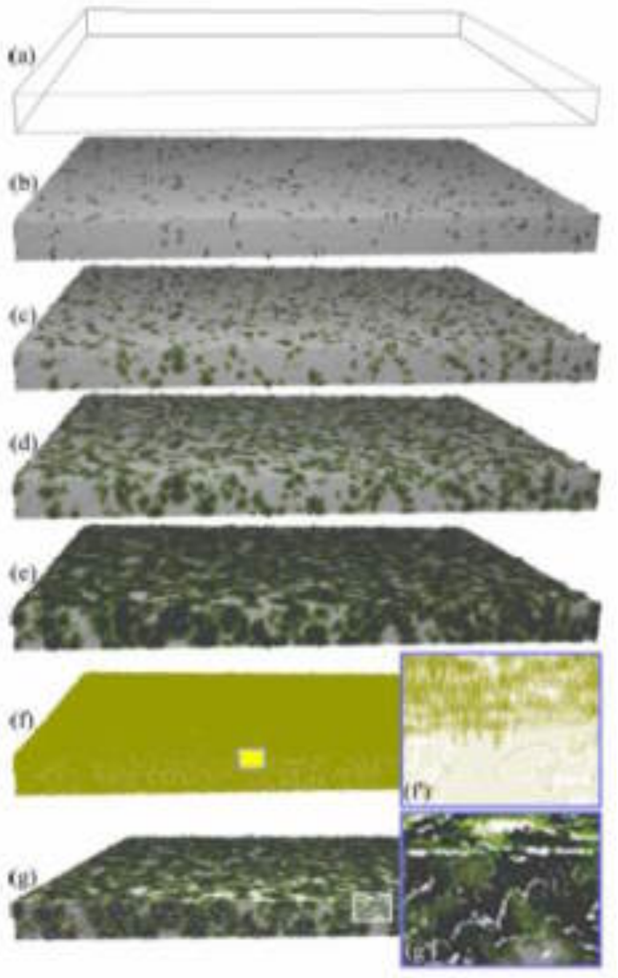

Figure 11. Advanced simulation of growing moss on a fractured surface. Based on one of the simplest 3-D object (a), the moss growth is shown from (b) to (e); (f) presents how complex the structure of moss is; (g) demonstrates that moss propagates in priority where water is: into cracks and small holes.

4. CONCLUSION

In this work two 3-D modelling programs have been coupled to provide a user-friendly solution for on-line acquiring a semiphysical model of a building from one or few images and immediately performing real-time simulations of weathering effects.

In order to allow multiple effects to simultaneously occur on the same structure, the building 3-D representation relies on a network of dynamic and interactive cells spread all along the building surface. The cells have limited but non null capabilities defined by a set of local rules. Their interactions produce a wide range of emergent complex behaviours. For instance natural phenomena may be simulated from a relevant selection of individual rules.

The geometric data is recovered using an interactive 3-D reconstruction program. Its user-friendly man-machine interface ensures a high flexibility which allows to apply the relevant level of detail and semantics to each object. Task-oriented models that are well adapted to the task requirements are thus easily built. For that specific experimental work, surface details are explicitly defined in three-dimension and not simply rendered using texture mapping. Moreover the model is structured into distinct parts, that are further used to assign appropriate rules to the respective cells to run plausible simulations.

The simulations are based on a cellular automata technique that was extended to take into account any type of surface and then enable a concurrent execution of different effects. Dedicated cellular automata to different weathering effects such as stone erosion, lichen or moss growing or lampblack deposit were designed and evaluated. We observed that almost any kind of simulation could be obtained in real-time using very large dynamic surface cellular automaton.

Achieved results are quite promising and let hope for quite challenging demands in various application domains. In a first stage, we are currently working on an optimized version of the simulation step where heavy cellular automaton computations are shifted on a Graphical Processing Unit using vertex and pixel shaders (Lefebvre et al., 2004).

Then both 3-D modelling programs used in the proposed approach may be enhanced in order to facilitate user interventions and thus improve the overall reactiveness. For instance the detection of useless cells may greatly release memory requirements and computation time of the simulation step. Concurrently, user assistances may be set up from the simulation requirements in order to focus the reconstruction on actual needs and thus speed up this step.

Coupling the present solution with a high performance rendering tool may greatly improve the visual realism of the simulation results by taking into account a real global illumination model. A more long-term challenging goal deal with the constitution of a reference set of cellular automata dedicated to weathering simulations on buildings in order to allow end users to effective exploit this interactive modelling and simulation technique.

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