# VIRTUAL REPAIR & MEASUREMENT WORKSPACE

# EROSION SIMULATION SYSTEM V1.0

**USER MANUAL**

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PRESIOUS
http://presious.eu

This work was supported by EC FP7 STREP Project PRESIOUS, grant no. 600533.

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# 1. Introduction

## 1.1. The VRMW Erosion Simulation System

The Virtual Repair and Measurement System (VRMW) is a multi-purpose platform for virtual operations on digitized cultural heritage objects. The base system (Virtual Reassembly System) is concentrated on object reassembly tasks and measurements in a fully three-dimensional environment and supports collection management facilities and manual manipulation functionality. The Erosion Simulator is a module integrated in the basic system and supplied as a unified application in this special version of VRMW (VRMW-ES).

The Erosion Simulator, which is the back-end of the VRMW degradation prediction functionality, simulates the erosion process on the surface of an input mesh of a stone object over time. The current version of the Erosion Simulator operates in three modes:

- Mode 0: assumes 3D surface mesh data and applies a simple offsetting model, for simulating a pre-calculated recession or deposition process occurring on a stone surface.
- Mode 1: assumes 3D surface-only mesh data for homogeneous stones; if there are textured mineral data, they are ignored.
- Mode 2: assumes 3D surface mesh data textured with mineral map QEMSCAN data for non-homogeneous stones.
- Mode 3: assumes 3D surface mesh data textured with mineral map data generated with the Stone Builder for non-homogeneous stones.

## 1.2. How to Use this Manual

For information about the general VRMW operation, installation and common GUI tasks, please refer to the documentation of the basic system: VIRTUAL REASEMBLY SYSTEM USER MANUAL.

The current manual explains the interface parts and procedures involved in the erosion simulation, only.

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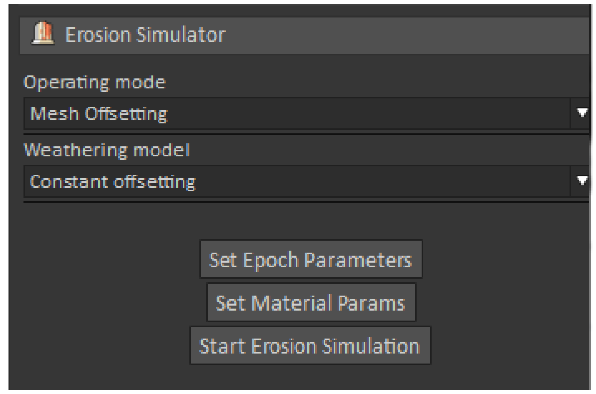
# 2. Erosion Simulation Procedure

## 2.1. Running the Simulator




The erosion simulator is available through the erosion module on the Modules panel. Ideally, any available object type can trigger the erosion simulation. The user is able to select the appropriate *Operating mode* and corresponding *Weathering model* – each associated with different environmental and material parameters. The erosion simulator process is initiated by clicking the **Start Erosion Simulation** button.

## 2.2. Operating Modes

The Erosion Engine of the current version of the software application operates in four Operating modes:

- **Mesh Offsetting**: assumes 2D surface mesh data and applies a simple offsetting model, for simulating a pre-calculated recession or deposition process occurring on a stone surface.
- **Mesh Data Only**: assumes 2D surface mesh data and homogeneous stones; applies a chemical model, the same on every vertex, for simulating the chemical degradation processes that occur on a stone surface.
- **Mesh & QEMSCAN Mineral Data**: assumes 2D surface mesh data textured with mineral map QEM-SCAN data for non-homogeneous stones; applies a chemical model, different on every vertex according to its chemical attributes, simulating the chemical degradation processes that occur on a stone surface.
- **Mesh & Stone – Builder Mineral Data**: assumes 3D surface mesh data textured with mineral map data generated with the Stone Builder for non-homogeneous stones.

## 2.3. Mesh Offsetting Modes

To apply the simple offsetting mode, you have to select **Mesh Offsetting**.

In this mode of operation, three different **Weathering models** can be selected:

- **Constant offsetting**: applies the same user-defined offsetting on every vertex.
- **Random offsetting**: applies random offsetting values that come from a normal distribution of a user-defined mean value and a cut-off value (3*standard deviation).
- **Smoothing/Roughening**: applies a smoothing or roughening by offsetting the vertices according to their computed mean curvature and a user-defined rate.

The software implements a mesh offsetting model, according to variations of the Diffusion equation:

$$\frac{\partial \vec{p}}{\partial t} = \mu \nabla^2 \vec{p} = \delta \, \vec{n}$$

which leads to a simple update rule for computing the movements $\delta_i$ of the mesh vertices:

`iterate`

$$\vec{p}'_i = \vec{p}_i + (\delta_i \, \vec{n}_i) \, dt$$

`until # of epochs` (of *dt* duration each)

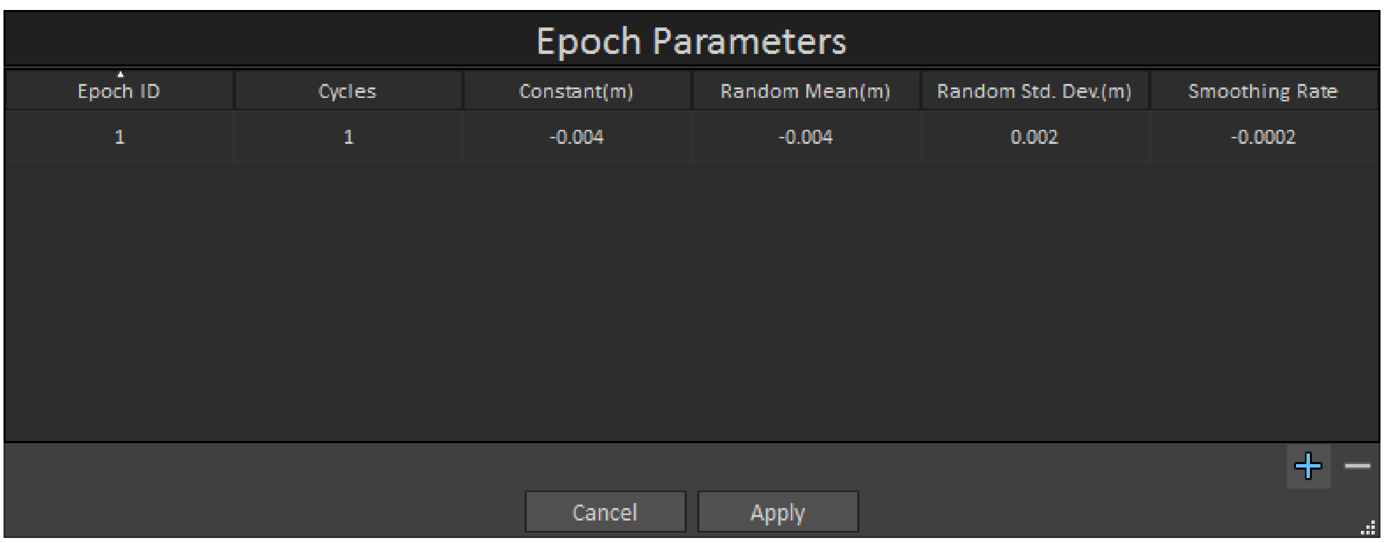
**Offsetting processes** are modeled according to this model, which leads to the computation of the mesh offset $\delta$ for the following cases:

- **Constant offsetting** with $\delta$ user-defined (default: -0.004).
- **Random offsetting** with $\delta$ values that come from a normal distribution with user-defined *mean value* and *standard deviation* (default: -0.004 *mean*, 0.002 *standard deviation*).
- **Smoothing/Roughening** with offsetting values $\delta$ that come from equation $\delta = \mu \|\nabla^2 \vec{p}\|$, where $\mu$ is a user-defined rate (default: -0.0002).

Note: each parameter value refers to the user-selected unit of measurement for each specific object.

**Epoch ID:** define the different epochs through which the object is exposed to weathering. Epochs also determine the number of the intermediate result files that the program will create as an output at certain weathering time frames.

**Epoch Cycles:** the number of cycles of the offsetting process for each epoch; an integer value between 1 and 1,000,000.



## 2.4. Chemical Erosion Process

To apply a chemical erosion process, the user has to select one of the following 3 operation modes:

The **Mesh Data Only** mode or the **Mesh & QEMSCAN Mineral Data** or the **Mesh & Stone – Builder Mineral Data** mode.

**Chemical processes** are modeled by the unreacted-core model, which leads to the computation of the mesh offset $\delta$ for the following **"Weathering models"**, which can be selected by the user:

- **Dry deposition of crust due to $SO_2$:**

$$\left(\frac{1}{2D_e}\right)\delta^2 + \left(\frac{1}{h_d} + \frac{1}{k_s}\right)\delta = C_{SO_2}\frac{M_B}{\rho_B}t$$

- **Dry deposition of crust due to $SO_2$+$NO_2$:**

$$\left(\frac{1}{2D_{en}}\right)\delta^2 + \left(\frac{1}{k_{sn}}\right)\delta = 2\,a_m\left(C_{SO_2}\right)^{\alpha_1}\left(C_{NO_2}\right)^{\alpha_2}\frac{M_B}{\rho_B}t$$

- **Recession by acid rain due to $SO_2$+$NO_2$+$CO_2$:**

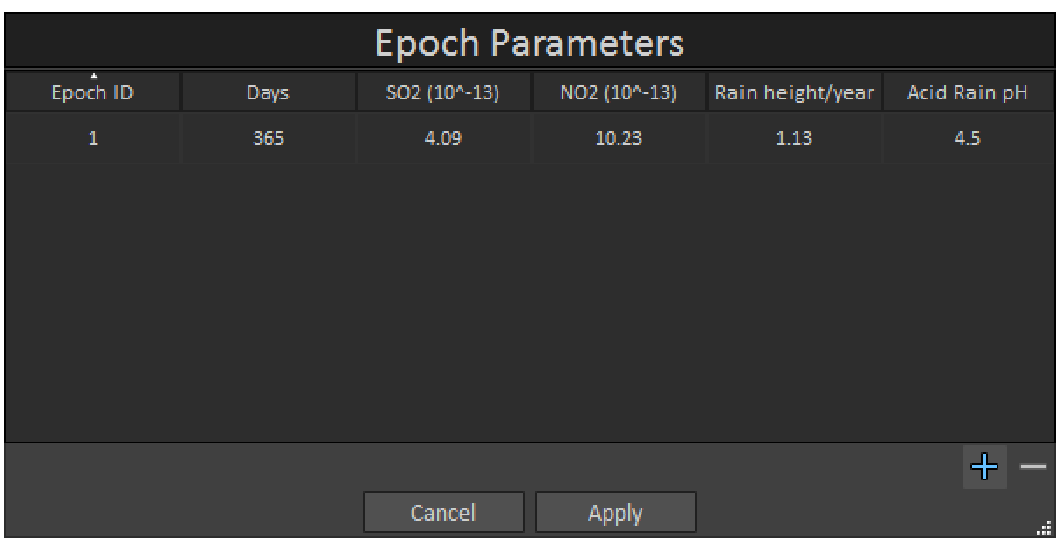
$$\delta = \left(3.65 + 27.38\;10^{(3.0-R_{pH})}\right)R_V\;t + 2\,k_r\left(C_{SO_2}\right)^{\alpha_1}\left(C_{NO_2}\right)^{\alpha_2}\frac{M_B}{\rho_B}t$$

In the case of homogeneous stones (i.e. **Mesh Data Only** mode) $\delta_i$ is considered the same over all vertices $\mathbf{p}_i$ of the stone mesh, while in the case of non-homogeneous stones (i.e. **Mesh & QEMSCAN Mineral Data** and **Mesh & Stone – Builder Mineral Data** modes) $\delta_i$ is related to the mineral assigned to each vertex $\mathbf{p}_i$ of the stone mesh.

The user can set the following parameters:

**Epoch ID:** define the different epochs through which the object is exposed to weathering. Epochs also determine the number of the intermediate result files that the program will create as an output at certain weathering time frames.

**Epoch Days:** the number of days for each epoch; an integer value between 1 and 1,000,000.



The user can also set the environmental parameters for the erosion process.

The **Default Values of the Environmental Parameters** for each epoch are the following:

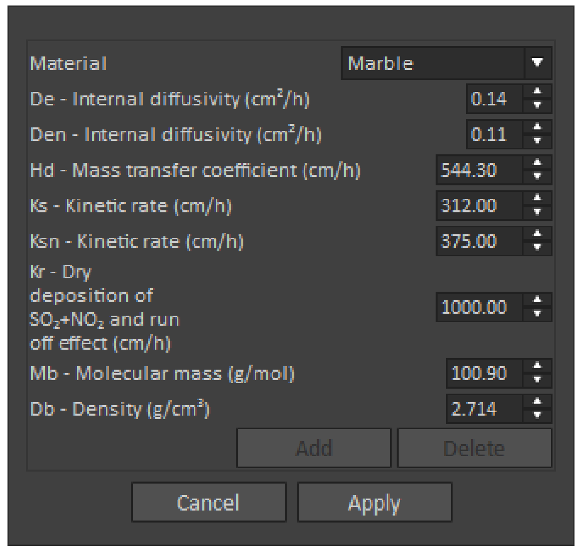
$C_{SO2}$ = 4.09 $10^{-13}$: concentration of $SO_2$ ($mol/cm^3$)

$C_{NO2}$ = 10.23 $10^{-13}$: concentration of $NO_2$ ($mol/cm^3$)

$R_v$ = 1.13: rain height per year (m/year)

$R_{pH}$ = 4.50: acid rain pH

The user can finally define the parameters for the stone material. The **Default Values of Material Parameters** for *Marble* are the following:




$D_e$ = 0.14: internal diffusivity ($cm^2/h$)

$D_{en}$ = 0.11: internal diffusivity ($cm^2/h$)

$H_d$ = 544.3: mass transfer coefficient (cm/h)

$K_s$ = 312.0: kinetic rate (cm/h)

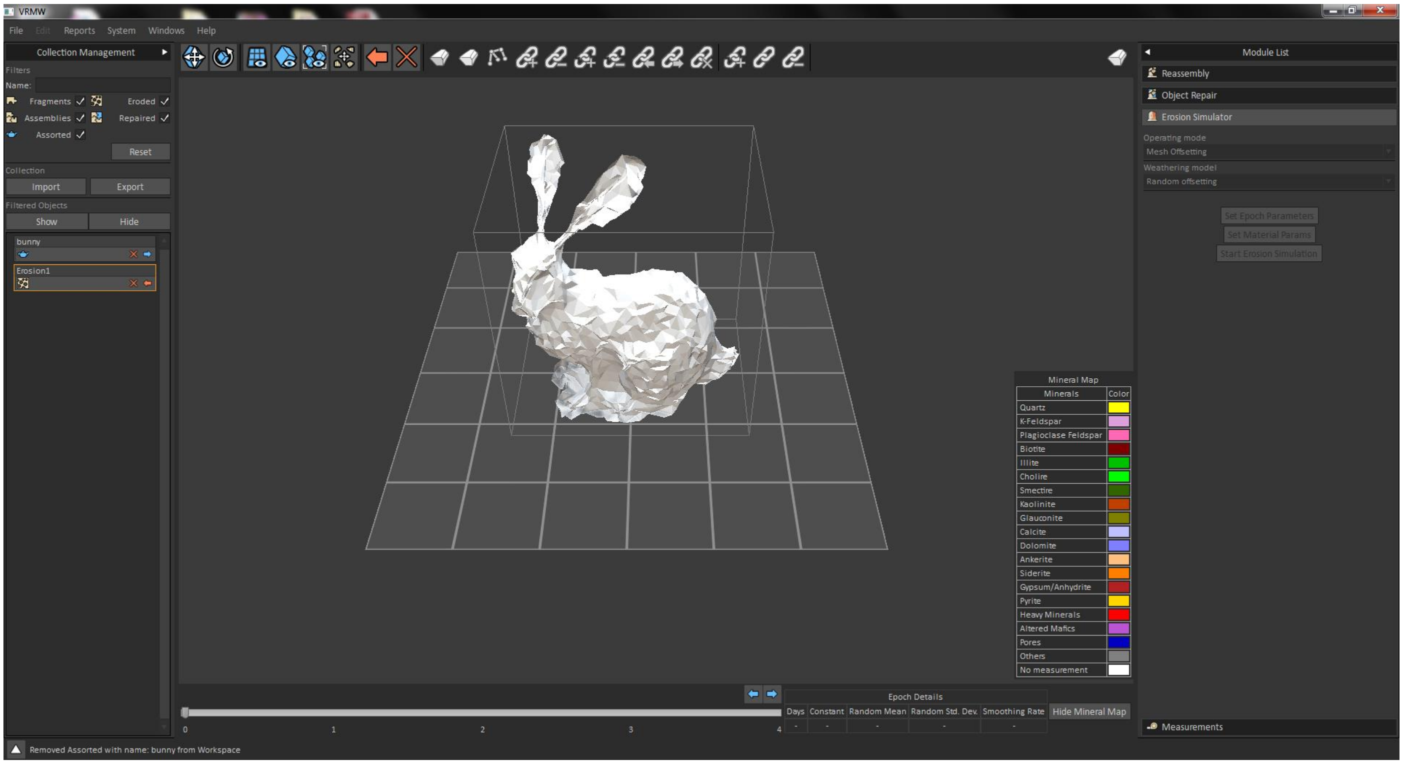
$K_{sn}$ = 375.0: kinetic rate (cm/h)

$K_r$ = 2452.0: dry deposition of $SO_2$+$NO_2$ and run off effect (cm/h)

$M_b$ = 100.9: molecular mass (g/mol)

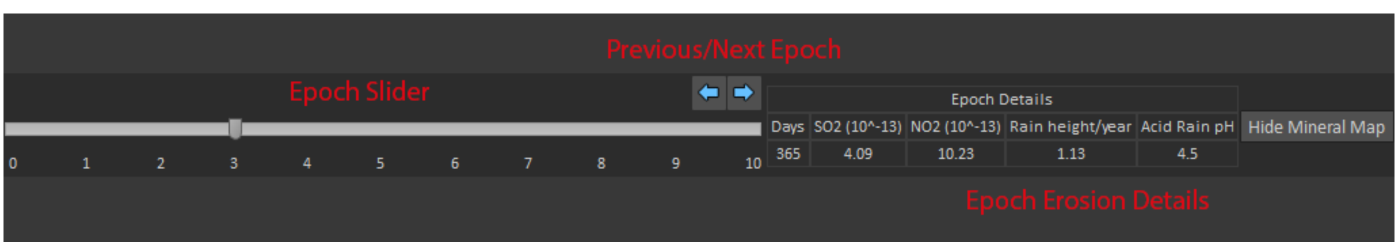
$D_b$ = 2.714: density ($g/cm^3$)

The erosion simulator process is initiated by clicking the **Start Erosion Simulation** button. After the process finishes, the resulting eroded objects are added to the Collection Management panel and displayed on the stage.



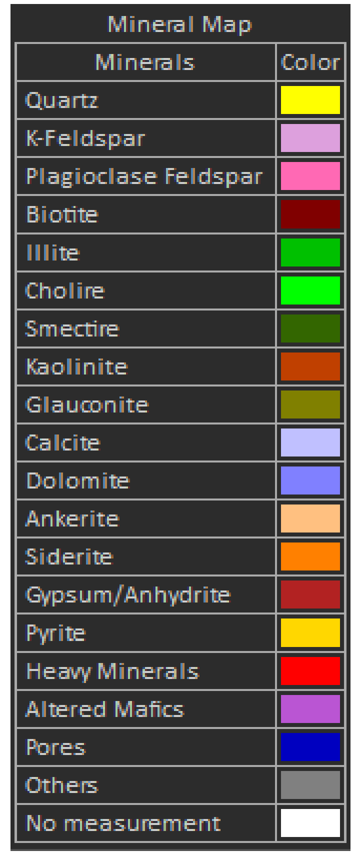

## 2.5. Erosion-Specific Interface Components

**Erosion workspace widget.** A slider control which appears on the bottom of the stage enables the display of each corresponding erosion epoch 3D mesh and the parameter values. Alongside, the mineral map legend illustrates the corresponding vertex colors used when a mineral map is available as texture with the data.




- ***Erosion Slider***: Switches between different epochs (0 displays the original, un-eroded object)
- ***Previous/Next Epoch***: Quick access buttons providing an alternative interaction interface for switching between different epochs.

**Epoch Erosion Details**: Display environmental parameters for the selected epoch. For eroded objects containing a mineral map, the “Hide/Show Mineral Map” can be used to provide a mapping between the object’s texture colors and its associated minerals.

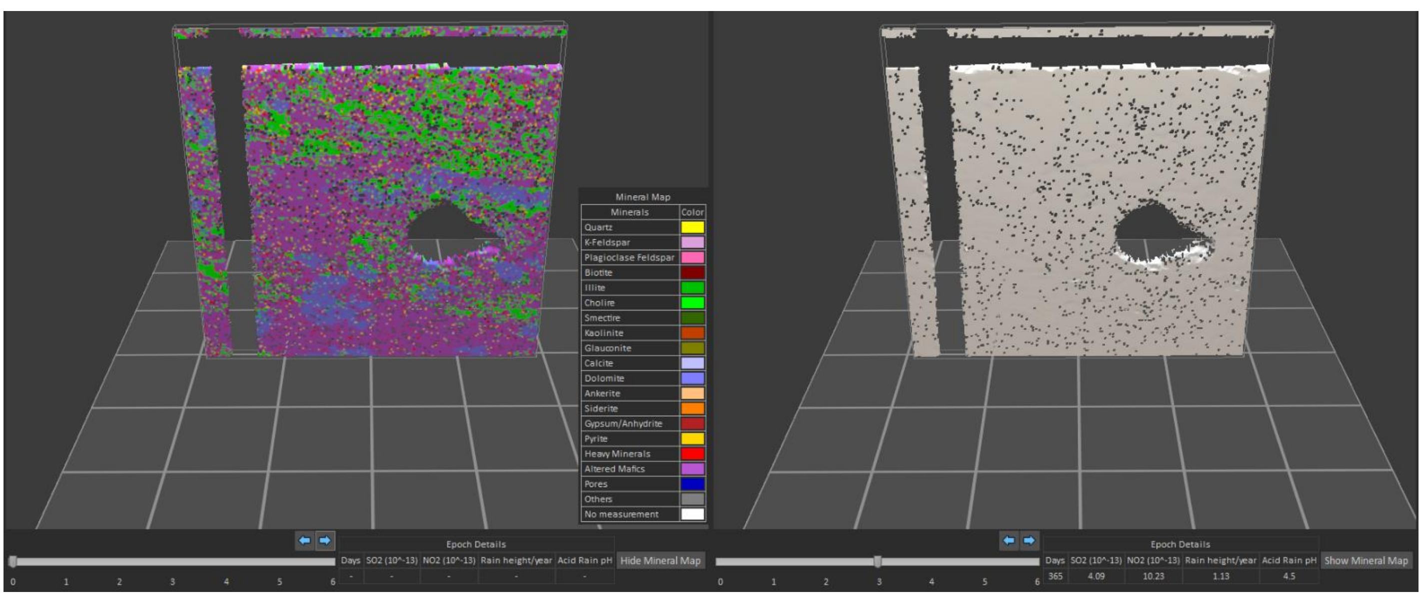


## 3. A Simple Erosion Scenario

The steps of a simple erosion scenario are described below:

- Open VRMW. If the only operation that the user is interested in is the erosion simulation, select "Disable and Continue" if the preprocessing and reassembly servers are not active.
- Import an object directly via the File Menu or as part of a collection using the Import button in the Collection Filter. In the import wizard select the object's units and click OK.
- Once the object is loaded, select the object in the Collection Management.
- Open the Erosion Simulator tab in the Module Panel.
- Define the "Operating mode" and the corresponding "Weathering model".
- Using the "Set Epoch Params" and the "Set Material Params" buttons set the erosion parameters for each corresponding epoch and the object material, accordingly.
- Select "Start Erosion Simulation" button.
- When the simulation finishes, several new obj files will have been written in the location of the original .obj. The number of files corresponds to the number of epochs set for the selected object(s). Also, a new erosion object is created and automatically placed in the workspace and the collection.


- The erosion object is a special (temporal) aggregate object, consisting of multiple instances of the eroding geometry over time. Use the erosion workspace widget to navigate between the different epochs.



# 4. Supporting Tools

## 4.1. Purpose and Functionality

The degradation prediction module developed in the PRESIOUS project is divided into three parts, the Erosion Simulator, whose functionality was described in Chapter 2 and which is also available as a standalone (command line) tool, the Stone Builder and the Differential Geometry Measurer.

The **Stone Builder** is an important producer module for the erosion simulation. It is used to synthetically generate a specific type of stone, either to fill in plausible stone data that fits a given or measured stone sample or to synthesize stone data from scratch for a specific stone type. This functionality is provided as a separate tool.

The second supporting tool, the **Differential Geometry Measurer** (DGM), is an auxiliary and a currently independent sub-module that measures the difference (erosion) between the subsequent scans of the same stone surface. Its primary purpose is to provide the ground-truth measurement from scanned eroded surfaces and support the optimal adjustment of parameters that can be varied within the Erosion Simulator. This module comes as a standalone tool as well.

## 4.2. Installation and Execution

The standalone software components for the degradation prediction along with the sample data are gathered within a single zip-compressed file. This file is named: PRESIOUS-D3.5-Software.zip

The software and data files can be uncompressed into an arbitrary directory of the Windows file-system. The archive contains a directory structure corresponding to the implemented tools - namely the Stone Texture Generator, the Erosion Simulator (command line back end) and the Differential Geometry Measurer.

We chose the directory structure shown below where each tool directory includes an Exe directory for the executables, other binary files and possible configuration files and a Data directory which contains a minimal set of data files and possible data configuration files that are needed to run the application. A typical directory structure as extracted from the installation archive is shown below:

```
/-
  +   TextureGenerator
        +   Exe
        +   Data
        +   Results
  +   ErosionSimulator
        +   Exe
        +   Data
  +   Tools
        +   DifferentialMeasurer
              +   Exe
              +   Data
```

The *TextureGenerator* directory contains the prototypical implementation of a 2D texture synthesis approach for the creation of artificial stone surface data. The *ErosionSimulator* directory contains the prototypical implementation of a stone erosion simulator. As we consider the *Differential Geometry Measurer* as a tool that supports the computation of some parameters for the degradation simulation it is found as sub-directory in the directory named Tools.

## 4.3. User Guide

The details for running the three command line modules are given separately for each executable in the associated Users Guide. There the user can also find details concerning the parameterization and the setup of an erosion scenario that can be run by the Erosion Simulator as a standalone tool, as well as instructions for the other two, supporting tools. For the detailed *up-to-date* user guide of the *Object Degradation Prediction Module* please refer to the PRESIOUS project web site.