Real Time optronic simulation using automatic 3D generated terrain, and validation process

André Joly [b], Alain Le Goff[a], Jean Latger[b], Thierry Cathala[b], Mathieu Larive[b]
a- DGA/DET/CELAR, BP 7419, 35 174 Bruz cedex, France
b- Oktal Synthetic Environment, 2 impasse Boudeville, 31 100 Toulouse, France

ABSTRACT

The SE-Workbench technology is used to perform multi-sensors simulations on complex 3D synthetic environment. The SE-Workbench enables the user to create virtual and realistic multi spectral 3D scenes, and generate the physical signal received by a sensor, typically infrared (IR), radar (EM) and acoustic (AC) sensors. To evaluate the efficiency of visible and infrared sensors, simulation tools that give a good representation of physical phenomena, are used. This article describes the elements used to prepare data (3D database, materials, atmosphere, …) for the simulation, and the set of tools (SE-FAST-IR), used in the SE-Workbench-IR for the Real Time simulation in the infrared spectrum. The SE-AGETIM tool turns geographical source data (including GIS facilities) into meshed geometry enhanced with the sensor physical extensions, fitted to the ray tracing rendering of the SE-Workbench and to the Real Time rendering capabilities of the SE-Workbench in infrared. The SE-FAST-IR package allows the compilation and visualization of 3D databases for infrared simulations. It enables one to visualize complex and large synthetic scenes for a wide set of real and pseudo-real time applications. The SE-FAST-IR software automatically computes radiance textures, Open GL light source and fog-law parameters for predefined thermal and atmospheric conditions specified by the user. It is based on the physical model used by the ray-tracing tool of the SE-Workbench, which enables the development of a coherent and powerful validation method.

Keywords:
simulation, ray tracing, infrared, electromagnetism, acoustics, GIS, terrain modeling, real time simulation, sensor effect, API, low light level, Open-GL, shaders

Content:

1. Introduction

The SE-Workbench technology is used to perform multi-sensors simulations on complex 3D synthetic environment. The SE-Workbench enables the user to create virtual and realistic multi spectral 3D scenes, and to generate the physical signal received by a sensor, typically infrared (IR), radar (EM) and acoustic (AC) sensors. To evaluate the efficiency of visible and infrared sensors, simulation tools that give a good representation of physical phenomena like the SE-Workbench-IR, are used. The SE-Workbench-IR is dedicated to passive optronic simulation; It is named CHORALE in the frame of the French DGA/CELAR activities.

This article first describes the software SE-AGETIM, used to prepare the synthetic environment (3D terrain modeling), to compute the thermal state of the 3D scene (thermal computation), and the real time rendering software (SE-FAST-IR) of the SE-Workbench-IR solution. Finally, an introduction to the validation principles of the SE-FAST-IR software is presented.

The SE-AGETIM tool turns geographical source data (including GIS facilities) into meshed geometry enhanced with the sensor physical extensions, fitted to the ray tracing rendering of the SE-Workbench and to the real time rendering capabilities of the SE-Workbench in infrared. The basic idea is to enhance directly the 2D source level with the physical data, rather than enhancing the 3D meshed level, which is more efficient (rapid database generation) and more reliable (can be generated many times, only changing some parameters). The last evolutions implemented in the SE-AGETIM software are presented.

The SE-FAST-IR package allows the compilation and visualization of 3D databases for infrared simulations. It enables one to visualize complex and large synthetic scenes for a wide set of real and pseudo-real time applications. The SE-FAST-IR software automatically computes radiance textures, Open GL light source and fog-law parameters for predefined thermal and atmospheric conditions, specified by the user. The last technology break through implemented in the SE-FAST-IR software are presented.

The SE-FAST-IR software is based on the physical model used by the ray-tracing tool of the SE-Workbench-IR. This enables the development of a coherent and powerful validation method made of several steps, including internal and external validation level. An introduction to this validation process in presented in this article.

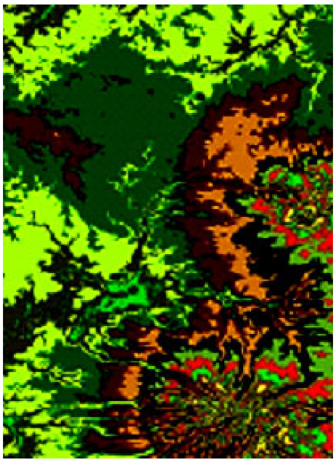
2. SE-Workbench: 3D terrain modeling

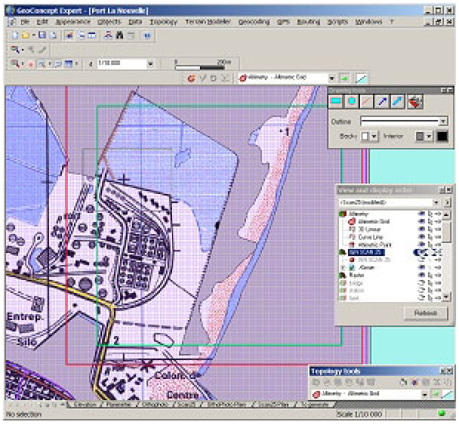
2.1 What is SE-AGETIM

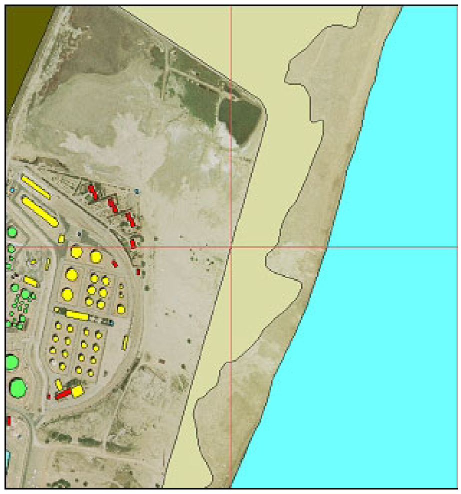
The SE-AGETIM (*Synthetic Environment MultiSensor 3D Terrain Generation Tool*) software is part of the SE-Workbench dedicated to terrain modeling. The SE-AGETIM inputs are source data made of altimetry, planimetry and pictures (satellite, airborne, ground). The SE-AGETIM tool includes the French GÉOCONCEPT Geographic Information System API.

The planimetry is made of the outlines of fields, lakes, forests, buildings and others, of the axis of roads, rivers and others, of the anchor points of objects. This set of punctuals, linears and areals can be represented as 3D geometries. The altimetry can be regular grids, with various resolutions, or set of points (irregular grids) or height curves. Those data are handled in the GIS and fully managed by SE-AGETIM.
The input data can also be real from the terrain or fictive data needed for simulation on a set of generic data. They can be topographic, air photos, geo-referenced or not, planimetric and altimetric data, digitalised or created manually using plans or photos.

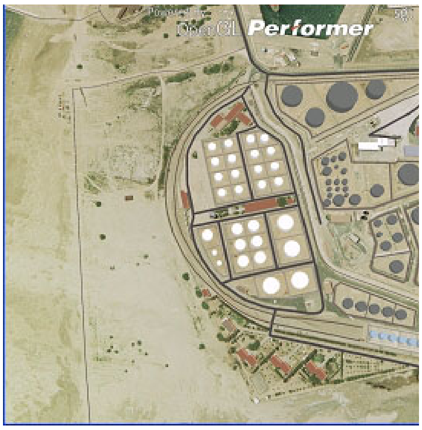
Example of altimetry, planimetry, photography data for a given area:

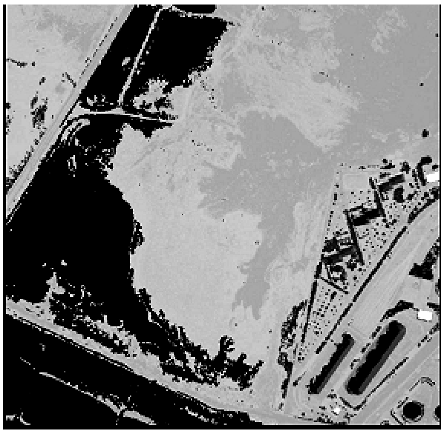






and then the generated 3D scene visualized in visible, infrared (band II) and radar (SAR at 35GHz):





2.2 SE-AGETIM-V2: a new concept

SE-AGETIM represents several man-years of research and development. It benefits since more than 5 years from French and UE public research and development projects funding. It has been recently completely reshaped into SE-AGETIM V2 for two main reasons:

- First, in order to tackle to generation of very large terrains (hundreds km x hundreds km). To illustrate the first reason, let us precise that this new version of the SE-Workbench terrain generation tool, has been used to create a full re-generable 3D synthetic environment for French MoD, corresponding to one half of the France country surface, in the frame of a helicopter application, both with "man in the loop" application (for embedded sensors assessment) and for vulnerability and counter measures studies.
- Secondly, to fit to new rendering approaches (procedural generation of terrains). According to the second reason, the first targeted application is the SE-RAY-IR and SE-RAY-EM ray tracing kernel for IR and EM, in order to take advantage of procedural generation processes directly implemented in the rendering pass of the ray tracing. For instance, it consists in generating automatically micro vegetation like grass or more generally clutter information typically for EM application. The second targeted application is similar, but in the frame of new generation rendering 3D real time engines (like video games middleware), typically SE-FAST-IR V3, the new version of SE-Workbench infrared rendering, based on OpenGL pixel shaders.

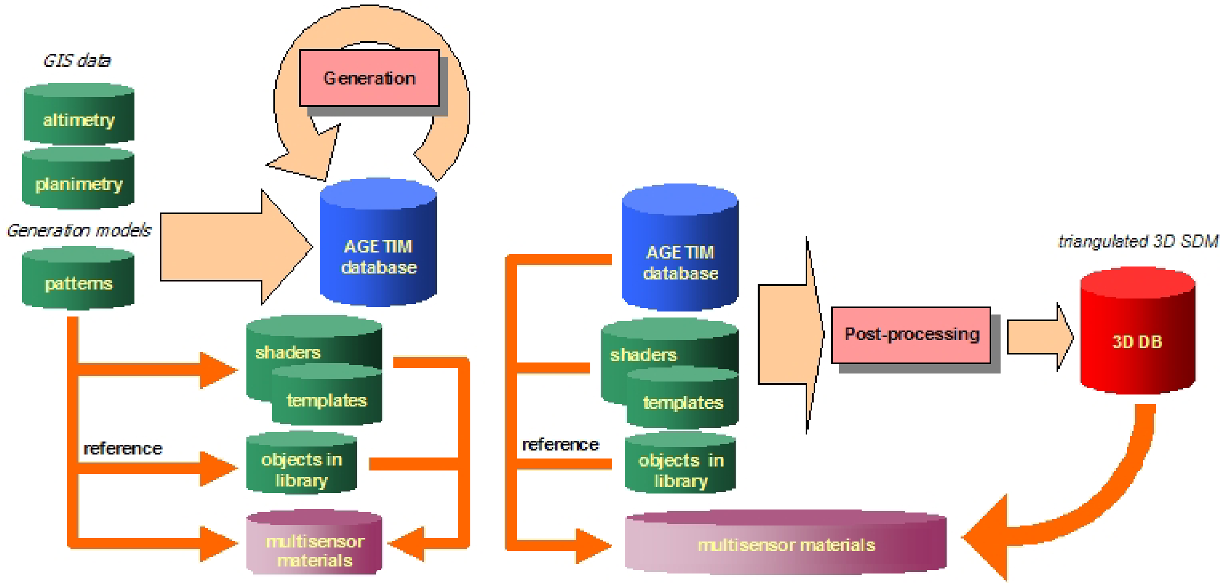
Both developments being made, always paying attention to the fundamental requirement for physical representation i.e. the ability to introduce in the same run all the IR, EM and AC attributes to the automatically generated synthetic environment.

The main conceptual difference between the previous release of SE-AGETIM and the V2 new reshaped product is that previous version simply produced a set of triangles with associated materials, whereas new V2 product generates an organized *database* that combines both source level and meshed data. With this new V2 product, every required attribute from the source level might be used at any step of the generation process. The user application might also access directly the SE-AGETIM database, or require a post processing operation, performed by a *useskill*, which translates the database into an application understandable structure. For instance for standard viewers, a useskill will convert the database into a set of triangles with associated materials, as in previous modeller version.

Basically, the architecture of the V2 requires two distinct steps:

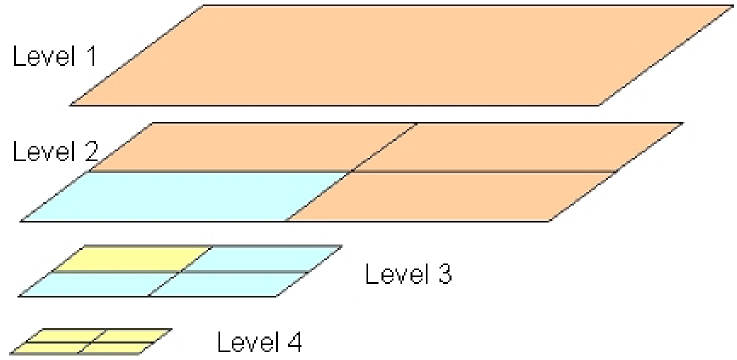
- The source data generation that is collected into the SE-AGETIM database, which evolves during the whole process,
- The post processing using specific useskills that turn the database into common application standard files, for instance the "STATICLOD" useskill that generates static level of details from the generated database, and exports 3D triangles set with their associated materials.

These two steps are illustrated here after:

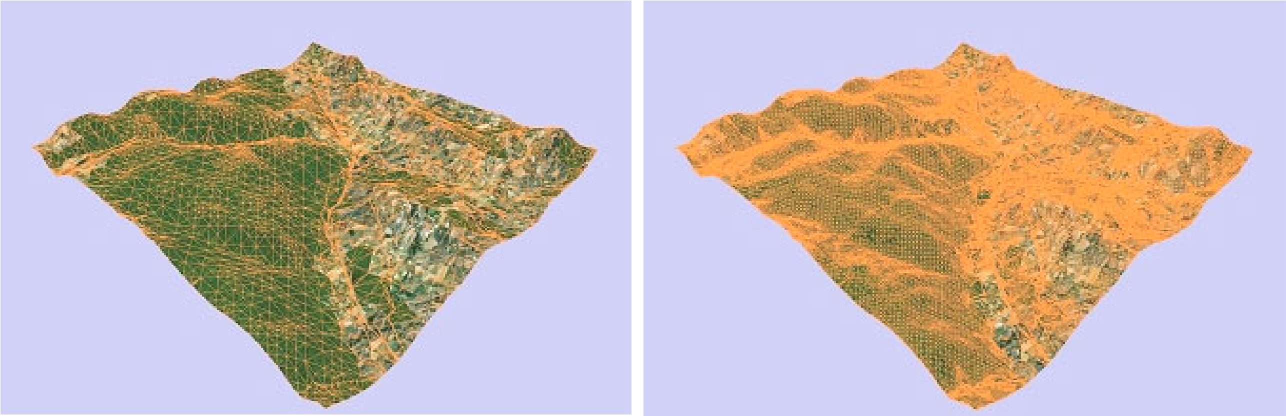


2.3 Continuous LOD for terrain generation

SE-AGETIM previous version was based on an irregular meshing (Delaunay algorithm). SE-AGETIM V2, that aims at generating continuous Level Of Detail of the whole terrain (including altimetry, features and textures) has been enhanced with a quadtree hierarchical decomposition of the terrain as illustrated here:



This enables to simplify the terrain and 3D feature representation for instance function of the observation range, typically being more accurate in the front plan than in the second plan:



There is a lot of other advantages, typically for the feature conforming to the terrain or for texture morphing, as explained in the next paragraphs.

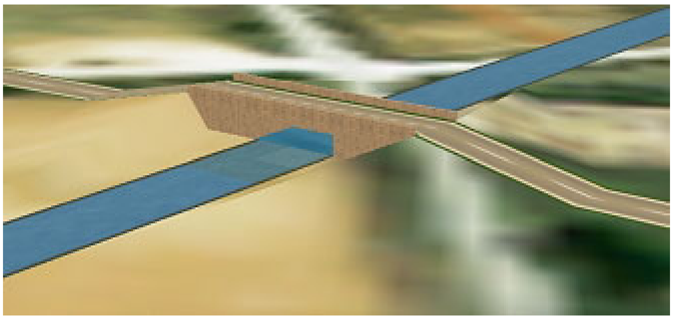
2.4 Patterns for feature generation

SE-AGETIM V2 introduces two new concepts called a *buildskill* and a *pattern*.

- A buildskill is a data specific generator. Each data is handled by one buildskill which is "intelligent" and defines the data behaviour. The buildskill also controls the data coherency.
- A pattern defines a data generation model. It specifies both the material and the geometrical characterisation of the generated data. It gathers some parameters required by a given buildskill to achieve the full generation process. The pattern may also collect additional information that could be used by a useskill.

As for now, there are several distinct patterns that can be derived to define any wanted user pattern. Some of these patterns are dedicated to generically handling punctual, linear and areal features. The other are dedicated to the terrain, and more global generation parameters.

The figure below illustrates the effect of an "integrated punctual" pattern (the bridge) and "intersection pattern" (the road and river crossing). In the picture below, both the road and the terrain shapes are adapted to the bridge introduction over the river.



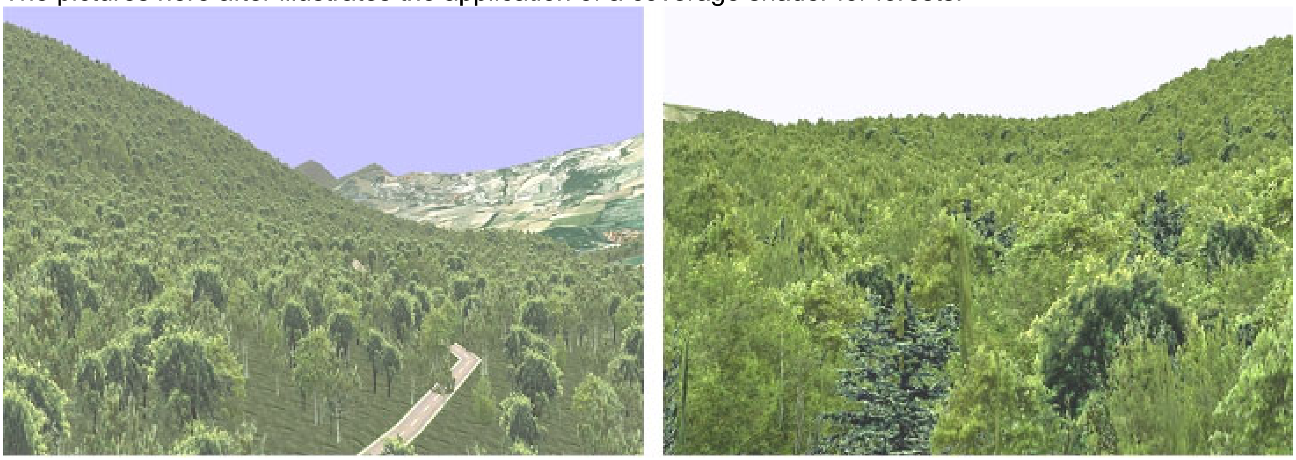
2.5 Shaders for advanced representation

The SE-Workbench user also has access to much more advanced generation models through the use of SE-AGETIM *shaders*. A shader defines an advanced generation parameterisation used by a useskill to perform advanced tasks, such as forest sowing or road profiling. The shader mechanism operates a set of basic shader operations, that are elementary treatments, for different representations, that are level of details.

Many pre defined shaders are available enabling for instance to flatten the inside of an areal feature (a lake, an ocean portion …), extrude a 2D profile along an axis (a road template …), or perform advanced generation of data such as growing houses or forests.

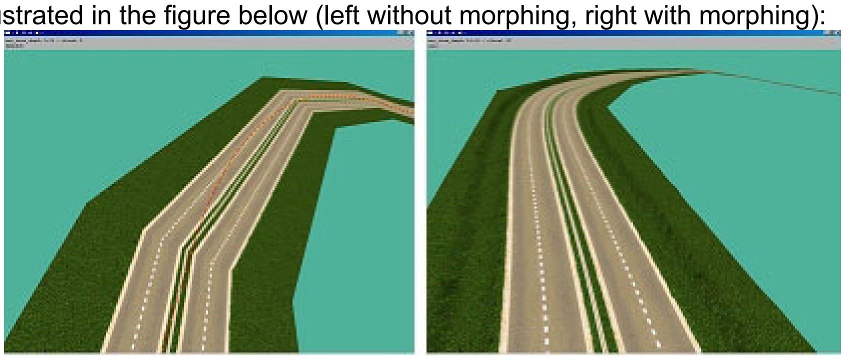
The shader mechanism could be assimilated to a minimal script language that allow the useskills to perform some operations. The associated XML based format allows level specific generation, in order to have different data representation for different level of details.

The pictures here after illustrates the application of a coverage shader for forests:



2.6 Texture morphing

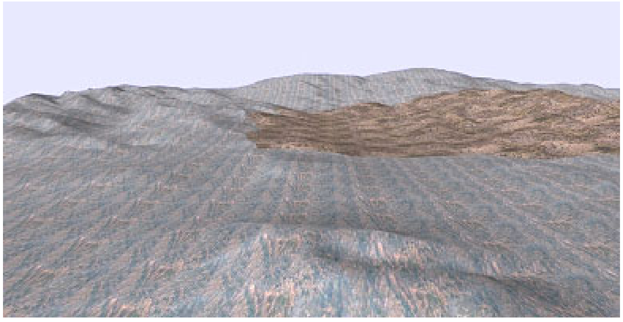
One key advantage of the SE-AGETIM V2 quadtree hierarchical generation of terrain and features is the capacity to twist and morph the texture using a close combination of meshing and texture mapping deformation, as illustrated in the figure below (left without morphing, right with morphing):

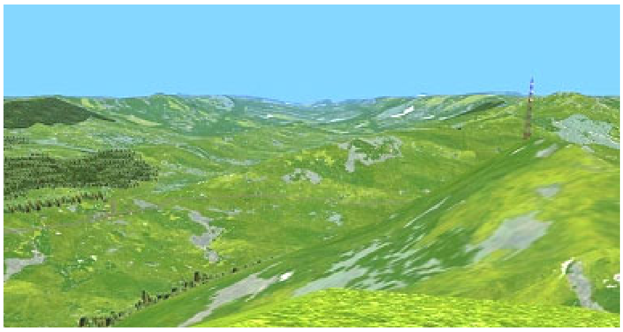


2.7 Multi texturing

Another key new feature of SE-AGETIM V2 product is the multi texturing capability. Classically, only one texture is affected to a polygon. In the case of "geo-typical" synthetic environment – close to reality but not the ground truth – it is not affordable to have the geo-specific texture, in the best resolution, for all the synthetic environment. As a consequence, generic physically classified texture, extracted from a pre generated library of classified materials, may be used. The classical drawback of this approach is the self-repetition effect that is prejudicial to realism.

The multi-texturing enables to combine several textures for a common surface or polygon. This multi-texturing capability is fundamental to fight the previous problem as illustrated here after, first a terrain without any multi texturing (self repetition effect, left image) and a same multi texture for the whole terrain (variability effect, right image):

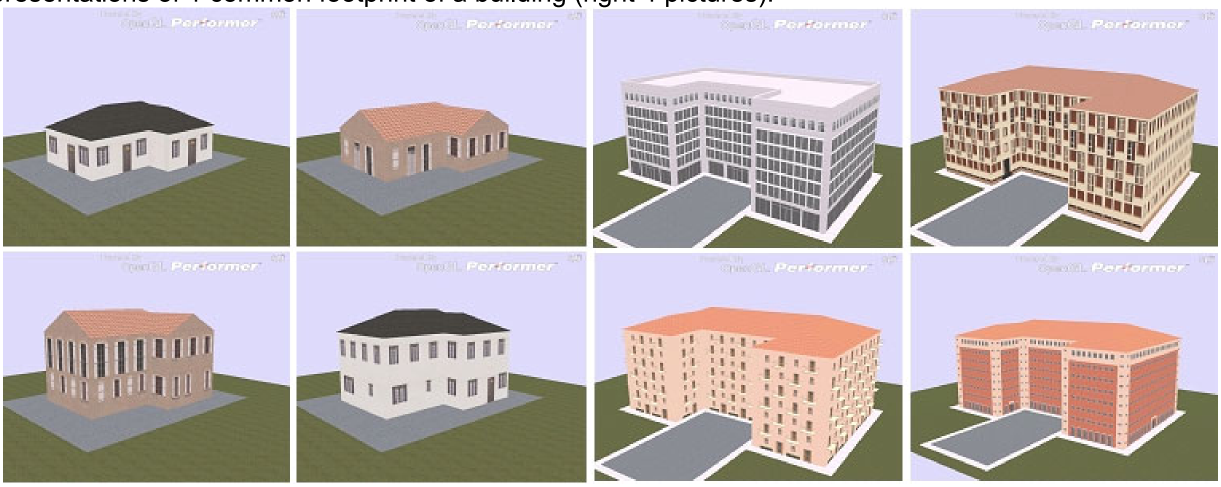




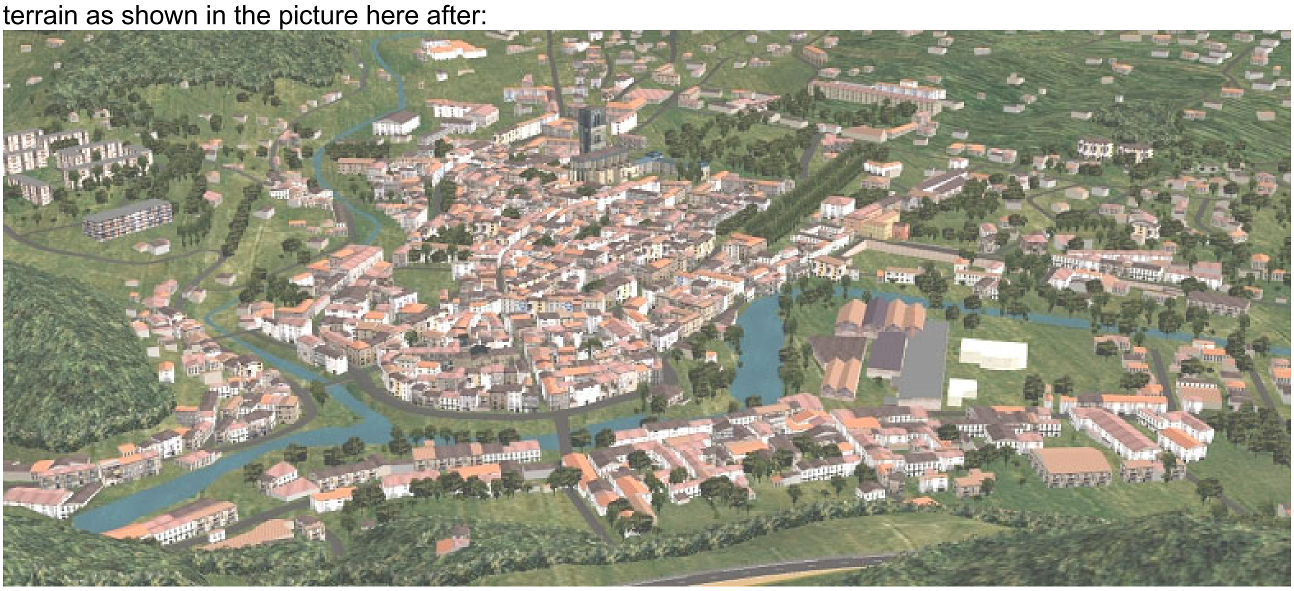
2.8 3D buildings automatic generation

SE-AGETIM V2 includes dedicated algorithms to automatically generate 3D buildings, directly extruded from their footprints. The footprints are typically acquired using urban feature vector files or paper maps, or using airborne picture, possibly geo-referenced via the GIS included in SE-AGETIM V2.

The algorithm is based on a “straight skeleton” method with special arrangements to allow several different wall and roof styles to be generated, and taking into account level of details and conforming to the terrain. This is illustrated here after with 4 representations of 1 common footprint of a house (left 4 pictures) and 4 representations of 1 common footprint of a building (right 4 pictures):



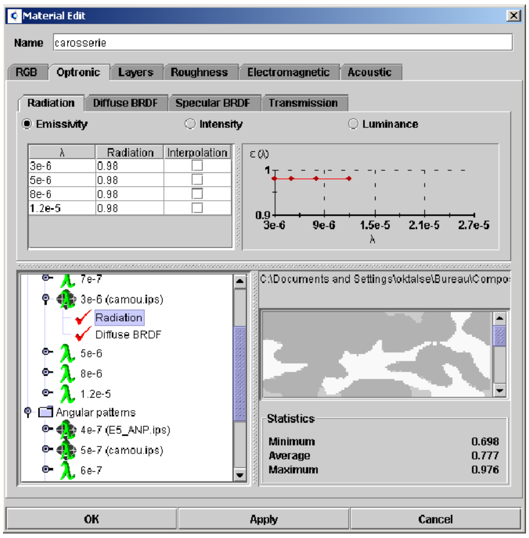
This SE-AGETIM-V2 functionality enables to rapidly generate a whole urban area fully integrated in the terrain as shown in the picture here after:



3. SE-Workbench: thermal modeling

3.1 SE-PHYSICAL-MODELER

The product SE-PHYSICAL-MODELER (*Synthetic Environment Physical Modeler*) enables the 3D synthetic environment developer to easily characterize the elements of the scene in terms of their physical properties. It gets state-of-the-art display capabilities, including interactive 3D visualization window based on Open-Inventor. The visualization windows are updated when modifying mapping or material. All the material used can be shown with a palette editing, with spectral and thermal characteristics graphic display.



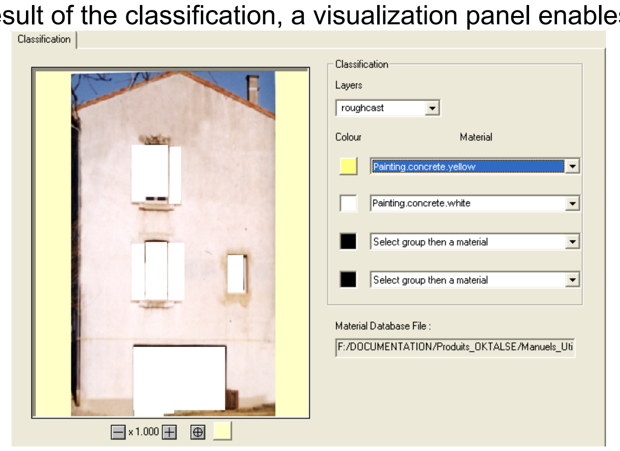
Infrared material physical properties edition

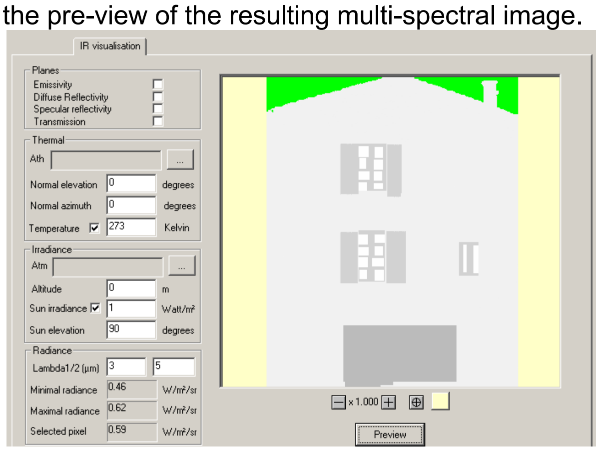
Polygon edition for structure modification, material association, texture assignment

3.2 SE-CLASSIFICATION

The SE-CLASSIFICATION (*Synthetic Environment Classification*) product is used to classify texture of physical materials. The picture to be classified is decomposed in layers. For example, one “roughcast” layer, one “window” layer and one “shutter” layer are created for a wall picture. For each layer, a material modulation is computed. For the “window” layer, brown pixels are associated with the “wood” material, and the others ones with the “glass” material.

The classification panel enables the selection of a color by picking on the picture; the association of a physical material is based on photo-interpretation. To check the spectral behavior of materials in use, and the result of the classification, a visualization panel enables the pre-view of the resulting multi-spectral image.

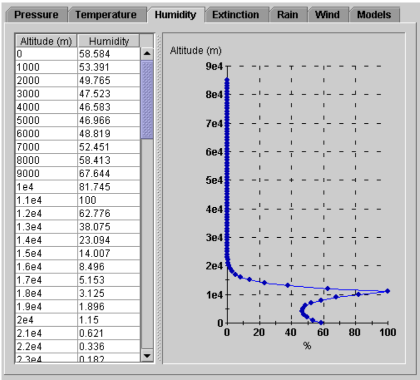


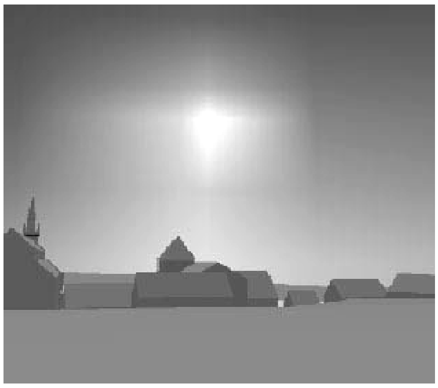


Textures classification panel as function of a material library (left) and pre visualization window (right).

3.3 SE-ATMOSPHERE

The SE-ATMOSPHERE (*Synthetic Environment Atmosphere*) software allows the user to characterize the atmosphere. It can be used to parameterize the LowTRAN and ModTRAN kernels as well as a generic atmospheric model whose physical model has been developed by Oktal-SE in cooperation with CELAR (DGA, France). It can ease the edition of the configuration files with the help of a JAVA based user interface that avoids parameterization errors.





Atmospheric model parameterization visualization (left) and infrared atmospheric effect (right).

The SE-ATMOSPHERE software computes:

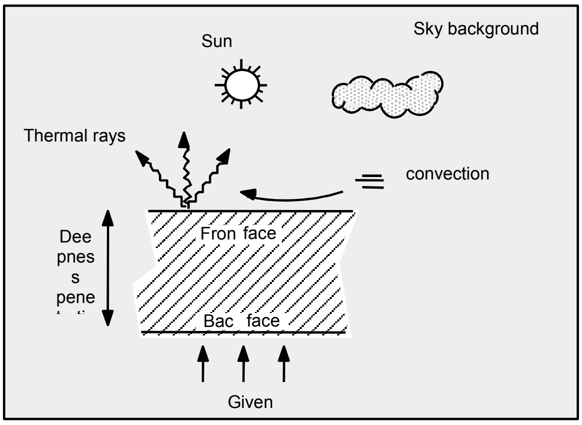
- a table of spectral data of sun/moon irradiance for a list of altitude h_j and a list of wavelength λ_i,
- a table of atmospheric transmission for a list of wavelength, altitudes, and Lines of Sight (LOS),
- a table of sky radiance for a list of wavelength, altitudes, and Lines of Sight (LOS).

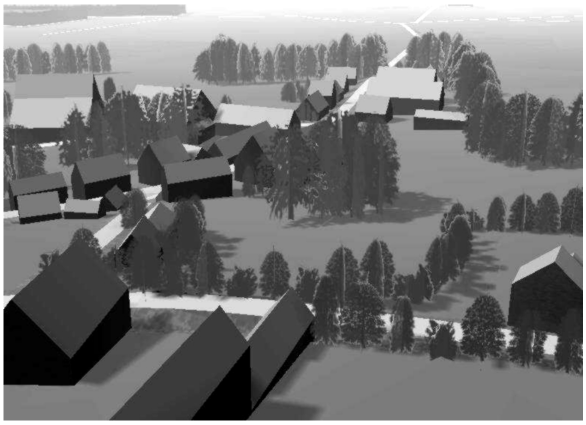
These data are stored in a file and used by:

- the scene generation software (SE-RAY-IR and SE-FAST-IR) for the computation of atmospheric transmission, sun/moon irradiance and sky radiance,
- the thermal software (SE-THERMAL) for the computation of incident fluxes.

3.4 SE-THERMAL

The thermal software SE-THERMAL (*Synthetic Environment Thermal*) enables the pre-calculation of all the possible temperature states of a scene at a given time of the day for a given atmosphere (SE-ATMOSPHERE). It also contains a module that enables the thermal shadow calculation.





Physical effects taken into account (left) and infrared image (right) with thermal shadows.

The SE-THERMAL software takes into account:

- the history of atmospheric conditions,
- a decomposition in layers of the polygons and, for each layer, the thermal attributes (conductivity, specific heat, thickness, convection coefficients, …),

- two kinds of polygons: “terrain polygons” and “wall polygons” (for which an inner temperature or an inner heat flux can be defined by the user),
- the wind and its direction.

4. SE-Workbench: real time infrared rendering

Beside the ray-tracing based software SE-RAY-IR dedicated to infrared high fidelity multi-spectral image computation, the SE-Workbench also includes real time rendering functions. This service is provided by the SE-FAST-IR software, based on OpenGL technology. The SE-FAST-IR software has been improved in order to take into account the recent development of the graphic board techniques.

The SE-FAST-IR software inherits the SE-RAY-IR validated physical models, which allows a maximum level of accuracy and realism. They also use a unified scenario (created by the SE-SCENARIO tool).

4.1 SE-FAST-IR history and evolution

With the help of some pre-calculation steps, real time images are computed with the SE-FAST-IR solution. It is dedicated to low light level and near to far infrared sequences of image calculation. The product makes use of the results of the SE-CLASSIFICATION tool, the SE-PHYSICAL-MODELER modeler and the SE-ATMOSPHERE atmospheric files computation product. The thermal pre-calculations are based on SE-THERMAL code.

The previous version of SE-FAST-IR was based on a pre computation of the whole 3D scene with specific radiance texture adapted to a given waveband for a given spectral response. The real time process only consisted in using Open GL laws basically for non-static parts of the scene (for instance the specular parts, or the moving objects) and for the atmosphere propagation modeling depending on site, azimuth and range.

The new release of SE-FAST-IR brings a technological rupture by using OpenGL pixel shaders enabling direct calculation on 3D graphic cards. A shader is a procedure written in a special purpose high-level language that replaces a part of the graphic pipeline of a 3D graphic board.

4.2 Key advantages of the new implementation

The main advantages of these new improvements are:

- the ability to dynamically change the sensor band and spectral response (very convenient for training simulation application), without reloading any geometry nor texture, which was not possible in the previous release,
- the ability to compute a multi wavelength image (limited by the graphic board memory of texture), which was not possible in the previous release, and which is very convenient to stimulate a spectral model of the technological sensor,
- a better dynamic due to HDR (floating point radiance computation, no more limited to 8 bits),
- an implicit dynamic gain control,
- a better management of dynamic parts of the 3D scene (targets, specular parts, …),
- the management of emissive textures and light points,
- the computation of temperature, emitted radiance and reflected radiance at pixel level due to classification process.

Pre-computation is therefore only used for converting physical materials and textures into standard textures and colours, which can be exported into Open FLT, OpenGL or any kind of scene graph.

4.3 Functions managed by the Shaders

In the rendering part of SE-FAST-IR V3, the shader manages the following functions:

- Associate a temperature table (ttm) with the scene,
- Recompose classified materials (mpc) into pixel information,

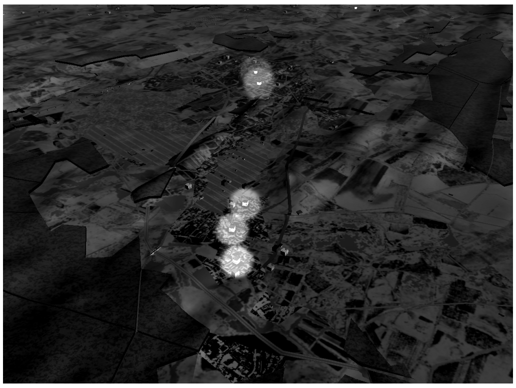
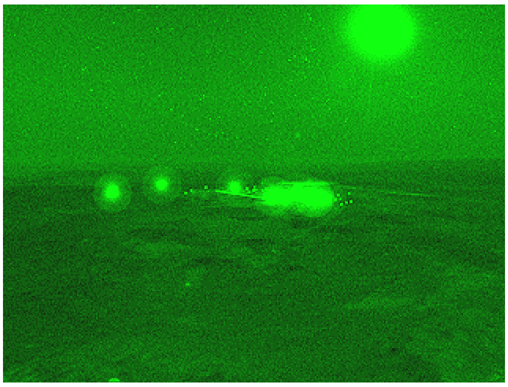
- Recompose associated percentages,
- Recompose emissivities and spectral BRDF per materials,
- Compute black body's law in real time,
- Compute specular and diffuse reflections, depending on materials BRDFs,
- Compute atmospheric component.

With SE-FAST-IR v3, each computation is done for each wavelength, which is also an improvement compared to release v2.

4.4 Application and examples

All illumination computations are done in real time on the graphic board : the Black Body law, the specular and diffuse reflections. For each pixel, a radiance value is calculated. It takes into account the atmospheric conditions (atmospheric transmission and irradiance of the sky). Basic sensor effects can be applied on the resulting radiance image (non stationary noise and contrast inversion). A complementary software, SE-FAST-IR-SENSOR enables to create more sophisticated sensor effects. As these computations are performed using 16, 24 or 32 bits floating values, the final color of the pixel is computed according to the pixel radiance and Automatic Gain Control (AGC) capabilities.

The SE-FAST-IR process is made of two steps:
- first step: the 3D database compilation (physical materials and textures are turned into Open GL materials and textures),
- second step: the infrared visualization. Given the compiled 3D database, the table of temperatures defining the material behavior with regard to heating sources, the infrared features of the materials (spectral emissivity, spectral BRDF, spectral transparency), the real time software computes real time black body law, specular and diffuse reflections, the effects of the atmosphere.

Low light level images with halos generated with the sensor library SE-FAST-IR-SENSOR.


Examples of objects in band III, flying helicopter (left) and burning transport vehicle (right).

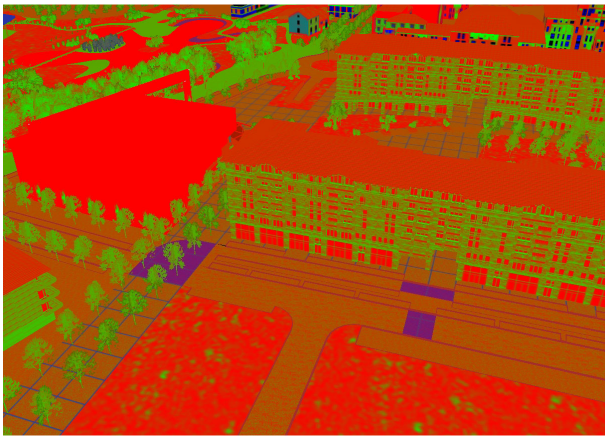
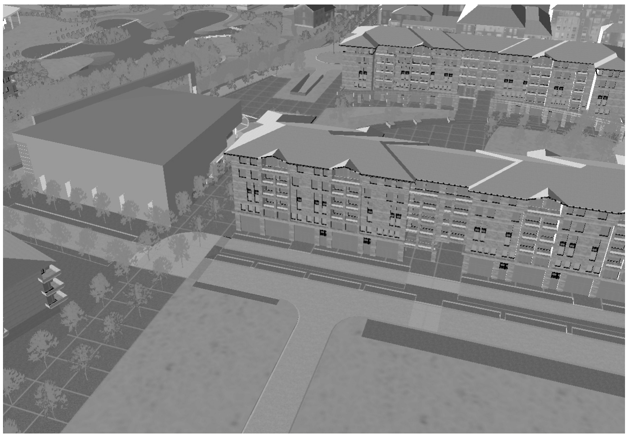


Image in false colors of the material classification

Band I – Fine weather – Daylight – Noise

Band II – Fine weather – Daylight

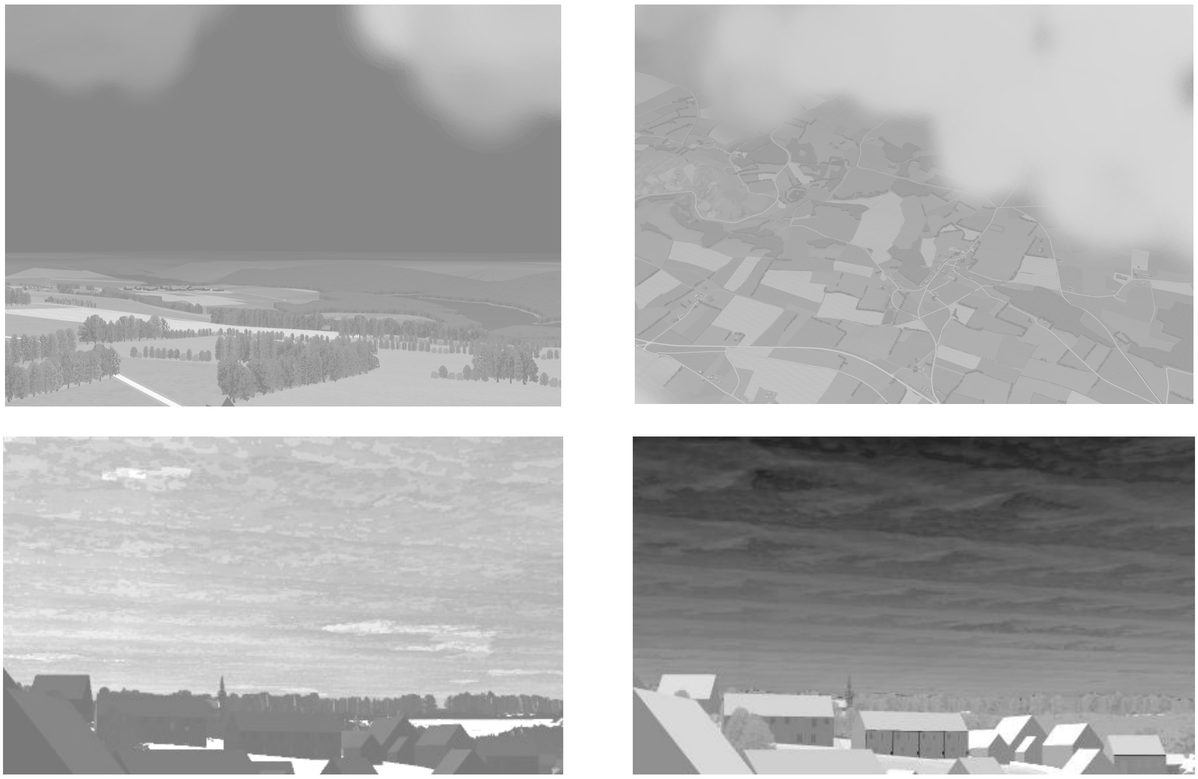


Band III – Fine weather – Daylight

4.5 Additional modules

Additional modules can be used to add more realism or extend the physical accuracy of the generated scenes.

- SE-FAST-AAS: advanced atmospheric transfer function calculation. This module enables to access to atmospheric tables, pre-computed using SE-AMOSPHERE tool, pixel by pixel, in real time, in order to take into account very accurately the atmosphere spectral attenuation and self emission as a function of site, azimuth and range
- SE- FAST-FLARES: optimized flare countermeasure generation tool. This module enables to create special laws of radiance and irradiance of high-level light sources.
- SE- FAST-CLOUDS: optimized cloud generation and calculation tool. This module enables on one hand to create physical cloud layers consistent with SE-AMOSPHERE tool, and on the other hand to create isolated clouds, made of transparent billboards with levels of detail.



Examples of infrared images with volumic clouds (top images) and cloud layers (bottom images).

- SE-COMP-PARTICLES: particle generation tool for special effects. The particles system can be applied to very complex dynamic effects just like fireworks or exhaust plumes. The SE-SCENARIO tool enables to assess the parameterization of the associated dynamic laws in order to achieve the desired effect.

5. SE-FAST-IR validation process

4.6 Validation principles

The validation process used for the SE-FAST-IR software is the same as the one used for any physical software from the SE-Workbench, in infrared, electromagnetic or acoustic. The validation process of the real time infrared rendering tool benefits from the validation of the ray tracing based software SE-RAY-IR. This enables to cross validate the results generated from different sources, using different technologies (ray-tracing and Open-GL).

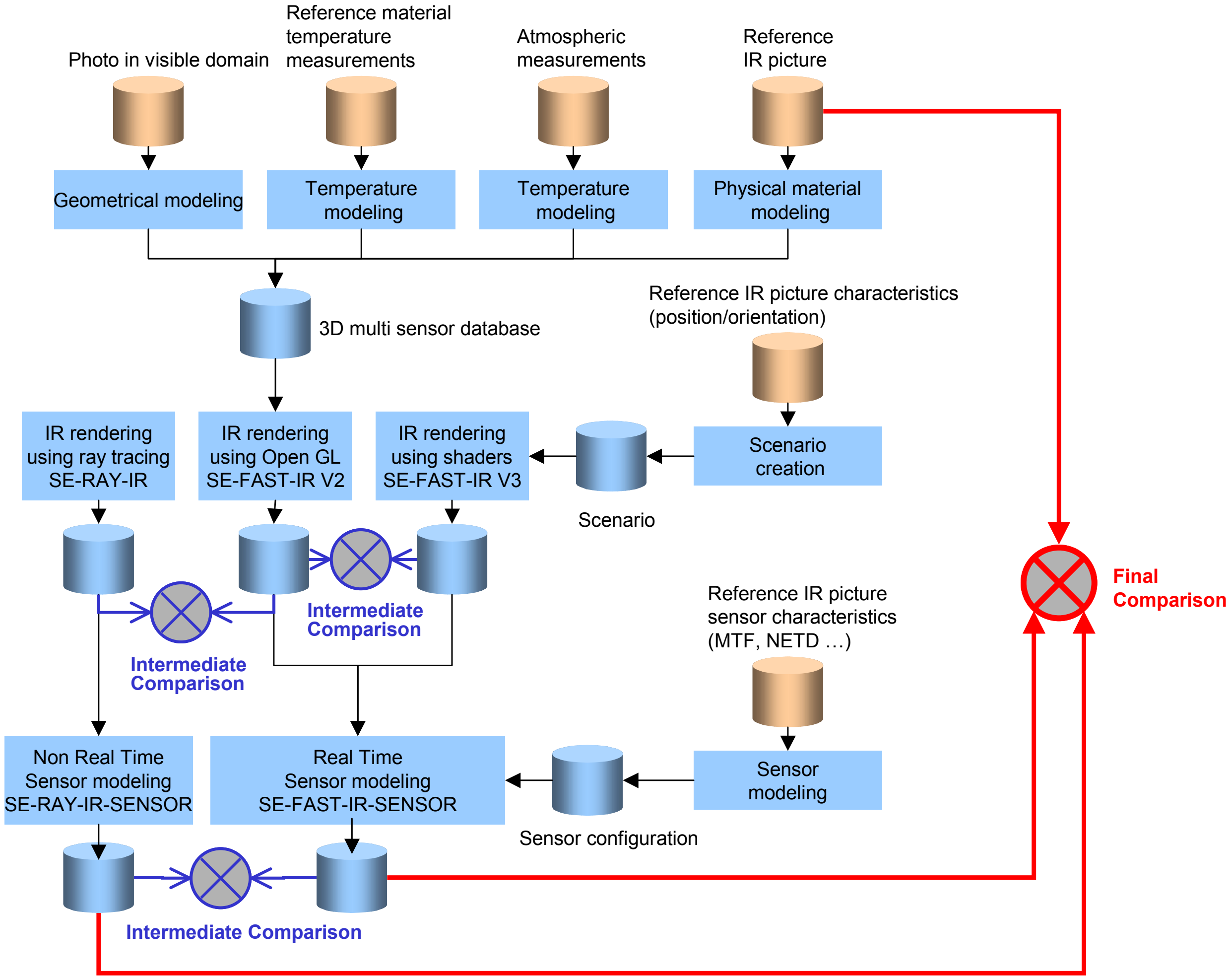
The general principle of the validation can be divided in 5 different steps:

- Unitary tests: fundamental tests of the geometrical optics, the energy conservation law, …
- Unitary physical tests: validation of the BRDF mechanism and heat equation solving,
- Full scale image computation: generation of full scale images of complex 3D scenes, including sensor effects and corresponding corrections,
- Cross comparison SE-RAY-IR vs. SE-FAST-IR: comparison of synthetic images generated with two different technologies,
- Comparison with experiment: comparison of synthetic infrared images with real measured images.

The comparison with experiment can itself be separated in three major steps. The most significant one is made by the software user in the frame of confidential external validation programs. Then, from the literature, public reference cases can be found to perform external validation tests. Those tests are public and can be accessed by any user of the SE-Workbench software. Finally, OKTAL-SE is able to make non confidential internal tests based on public or own measurements.

4.7 Details on the cross validation process

For the validation process, in the frame of the SE-Workbench, a documented comparison between simulated images and measurements is provided. Input data for the validation are made of pictures in the visible domain, infrared images from calibrated cameras and associated atmospheric measurements, a database of physical materials, temperature measurements, a precise physical model of the camera and its sensors.



At each step, the simulated infrared images are compared with the reference infrared images.

The general methodology of validation for the SE-RAY-IR and SE-FAST-IR infrared images is therefore clear from the previous picture. According to these data, 3D scene are created as close as possible to the ground truth. Materials are associated to the polygons and textures of this 3D scene. Finally, scenario are simulated to compute infrared images using:

- the non real time ray tracing tool SE-RAY-IR,
- the real time simulation tools SE-FAST-IR V2 and SE-FAST-IR V3,
- the sensor models SE-RAY-IR-SENSOR and SE-FAST-IR-SENSOR software.

6. Conclusion and future applications

The SE-Workbench suite of software have been already used for important industrial and research and development programs involving thermal imagery. The recent improvement of the solution and recent customer feedback lead OKTAL-SE to further develop the large 3D scene modeling for very demanding real-time applications. The technological development and the maturity of the OKTAL-SE multi-sensor software solution enables to afford realistic and physically accurate optronic simulation (infrared and intensification of light) on very large terrain databases in real-time. This opens a wide range of applications in the training and mission planning area.

Beside this area, the urban combat in the second important application domain of the SE-Workbench suite of software. The SE-AGETIM software is used to model very rapidly a given site. Concerning the target building, additional module of SE-AGETIM enables to create a credible inside environment. The SE-Workbench sensor models have been adapted to run in real time and simulate a credible performance of new generation sensor (Light Intensifiers, Ultra wide band …) applied to building interiors. The general objective is to assess new sensors capabilities, new contexts of use in various environment.

Finally, all that leads to a very important area of application: time sensitive targeting. This area of application makes the like between the ray-tracing based application of the SE-Workbench, used for infrared sensor validation and qualification, and the graphic board based applications of the SE-Workbench used for doctrine development and training, mainly in urban combat situations.

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