

# Software coupling between RadThermIR and SE-WORKBENCH

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## 1. INTRODUCTION

The SE-WORKBENCH workshop, also called CHORALE (“simulated Optronics Acoustic Radar battlefield”) by the French MoD/DGA, is used to perform multi-sensors simulations on complex 3D synthetic environment. RadThermIR is a full-featured thermal analysis software for advanced Computer-aided engineering applications. RadThermIR employs a state-of-the-art radiation module and a user friendly GUI for simulating multimode heat transfer (radiation, conduction, and convection) and one-dimensional fluid flow. RadThermIR is efficient in the accurate computation of a small scene like a target with an engine whilst SE-WORKBENCH is efficient in the computation of large scene. This article describes the recent coupling of the SE-WORKBENCH with RadThermIR. It has been developed in order to inherit the advantages of the two software. There is a base coupling and an advanced coupling. The base coupling consists in the bi-directional conversion of the data generated by SE-WORKBENCH and by RadThermIR. The advanced coupling consists in an API called SE-TK-RADTHERMIR that provides a set of functions in order to use the thermal results computed by RadThermIR in the simulation of infrared images by the SE-WORKBENCH tools.

## 2. SE-WORKBENCH-IR TOOL

### 2.1 Overall presentation of the SE-WORKBENCH

The SE-WORKBENCH is a multi-sensor battlefield modelling workbench mainly used by French DGA, German BWB, South Korea MoD, Singapore DSTA and Swedish FOI in order to achieve the synthesis of 3D scene observed by a sensor, this in two steps:

- The physical characterization of the 3D scene behavior
- The Computation of the physical signal received by a sensor.

The SE-WORKBENCH is entirely based on software products developed by OKTAL-SE. It performs the multi-spectral unification of optronics, electromagnetism and more recently GNSS, using a common kernel & physical extensions affectation both aimed at a unique 3D scene and a common technology. The SE-WORKBENCH is a winning initiative for sharing R&D efforts and federating a user group community that intends to exchange experience and knowledge.

The first development was in 1994 and has been strongly boosted by the French SCALP missile program and the qualification of the IR tracking system. At the beginning, the SE-WORKBENCH was focused on the IR domain. In 2001, an electromagnetic version of the workshop was initiated, with the help of ONERA French research center, mainly focused on millimeter waves and wide scenes, typically for SAR applications. A new GNSS version for satellite application has started in 2009.

The control of the SE-WORKBENCH validity domain is based on both a theoretical validation approach (development of physical models, general modelling and simulation knowledge, elementary tests and validity assessment) and a validation process based on comparisons with experiments (SCALP/EG missile [FR], AASM missile [FR]).

### 2.2 The SE-WORKBENCH-IR architecture

The SE-WORKBENCH-IR is made of different components, as described hereafter, corresponding to the successive steps of a IR sensor simulation that are the modelling, the scenario edition, the rendering without the sensor effects and finally the sensor transfer function simulation. Furthermore, the user can do software integration in order to control the generated scenario execution from a remote or custom application. This can be achieved with the help of the SE-TOOLKIT consisting of a set of dedicated libraries and application programming interfaces (API) to help the complex application design and integration.

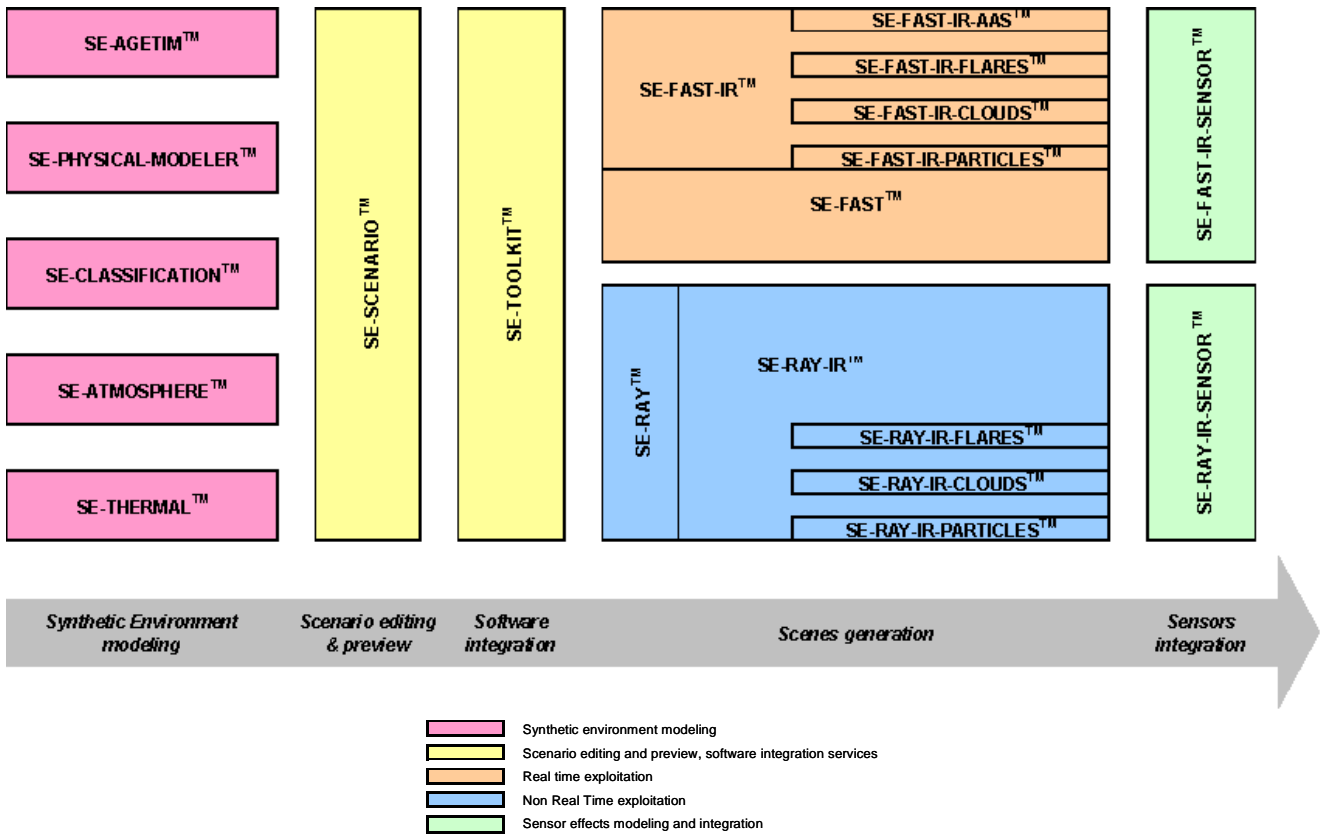


Figure 1: The SE-WORKBENCH-IR components.

### 2.3 Non real time rendering based on SE-RAY-IR

SE-RAY is the ray tracing kernel developed by OKTAL-SE which enables to compute high realism images in several spectral domains. SE-RAY-IR is dedicated to the rendering of synthetic environments in the IR domain and is based on SE-RAY ray tracing kernel. The great originality of SE-RAY comes from its model based on physics. SE-RAY uses elementary pyramids, defined by four adjacent rays (one basic pixel), which allows one to compute elementary surfaces and solid angles.

Besides SE-RAY-IR takes into account the wavelength sampling. Actually SE-RAY-IR works wavelength by wavelength. Time consumption is very optimized using SE-RAY. Actually performances are nearly independent on scene complexity. To do this SE-RAY uses a spatial subdivision method that enables to get a perfect knowledge of the scene topology before computing the first image. The scene space is decomposed in a hierarchy of volume elements (voxels) and then turned into a recursive space of voxels that improves efficiently the intersection computations. The solution to improve image quality mainly consists in over sampling by tracing more rays. The method adopted for SE-RAY-IR is the adaptative one. The most important antialiasing criteria are the following: number of different polygons in the pixel, number of different materials, normal vector variation within the pixel. Based on generalization of texture definition to any physical data, SE-RAY-IR can simulate the variation of specular reflectivity with the observation angles.

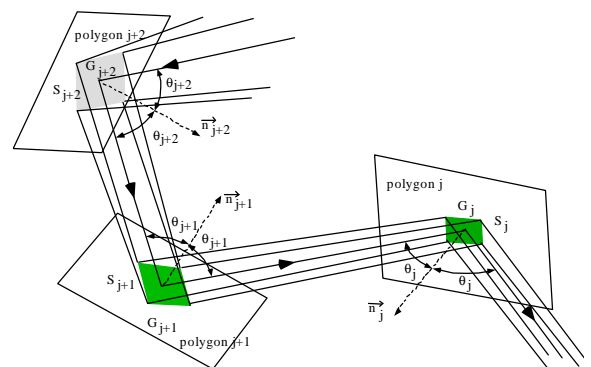


Figure 2: Management of ray tubes in SE-RAY-IR

Concerning the physical IR model, SE-RAY-IR can take the following contributions into account:

- The thermal emission
- Diffuse and specular reflections
- Direct Sun lighting: Direct sun or moon lighting takes into account the atmospheric attenuation and diffusion between the astral source and any point in the 3D scene. An external data file (typically based on LOWTRAN or MODTRAN) contains attenuation and diffusion values for discrete values of the wavelength and of the altitude.
- Diffuse Sun lighting and sky/ground illumination: Sky and ground are considered as a global entity providing energy in any space direction. When loading the database, the canopy is tessellated in discrete solid angles defined using elevation and azimuth angles.
- Self emission of the atmosphere: An external data file (typically based on MODTRAN or MATISSE) contains atmospheric radiance data for discrete values of wavelength, altitude, elevation, azimuth and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric radiance is determined using linear interpolation.
- Atmospheric attenuation: An external data file (typically based on MODTRAN or MATISSE) contains atmospheric attenuation for discrete values of wavelength, altitude, elevation and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric attenuation is determined using linear interpolation
- Sky, horizon and cloud cover: Sky and horizon are pure analytic models.

Beyond this classical forward ray-tracing, SE-RAY-IR uses SE-RAY-PHOTON-MAP module in order to take advantage of photon maps to pre-compute the scene global illumination, in a first pass, and then to trace rays from the observer to the scene, in a second pass.

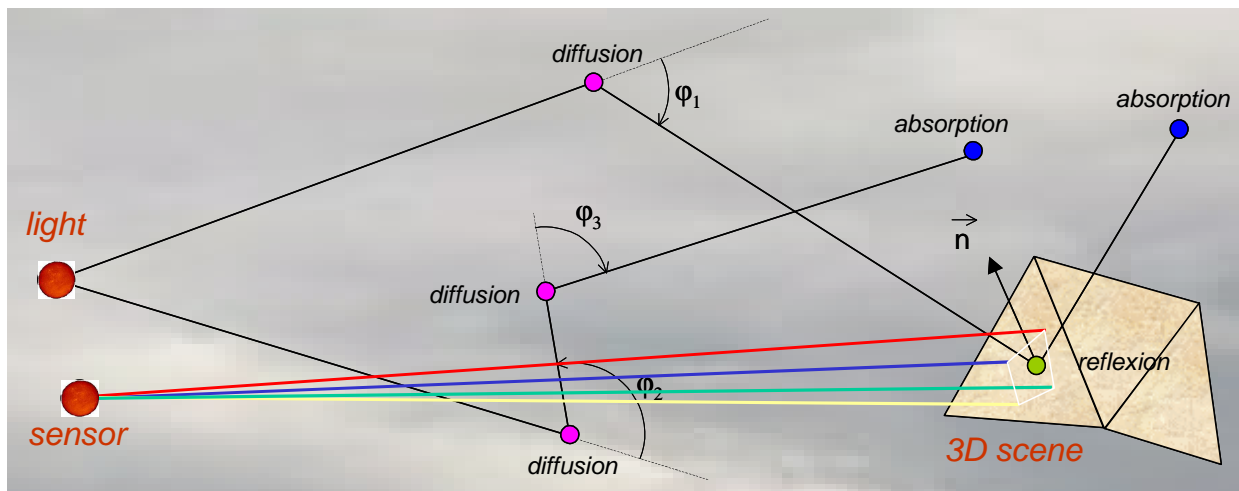


Figure 3: Path 1 & Path 2 of SE-RAY-IR

In the first pass, a ray tracing is made from each source, through the atmosphere. A ray is either absorbed, either diffused or scattered in a direction given by the local phase function and can be also reflected by the scene geometry. After this first pass, lots of “photons” are stored on the scene surfaces as local irradiances. In the second pass, rays are traced from the observer onto the geometry, and the radiance pixel computation takes into account the local interpolated irradiances thanks to the BRDF.

## 2.4 Real time rendering based on SE-FAST-IR package

The SE-FAST-IR package is made of a major product (SE-FAST-IR) and additional modules depending on the considered application.

With the help of some pre-calculation steps, real time images are computed with the SE-FAST-IR solution. It is dedicated to the computation of image sequences for near infrared sensors (light intensifying) and thermal infrared

systems with short, medium or long waves (SWIR, MWIR, LWIR). The products make 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 modelling depending on elevation, 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 C like language that replaces a part of the graphic pipeline of a 3D graphic board. The new core of SE-FAST-IR is based on the open source “Open Scene Graph” layer upon Open GL.

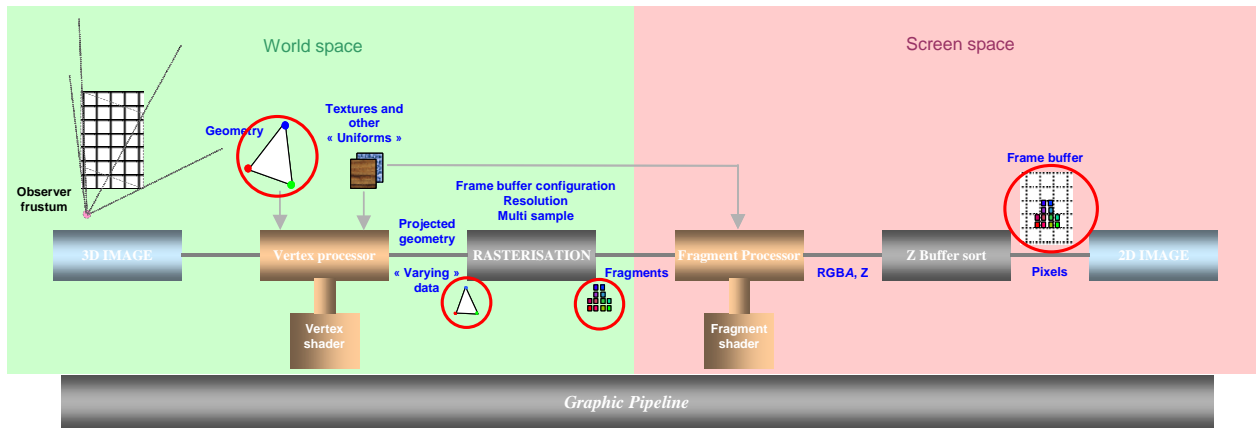


Figure 4: Rasterisation process

When the ray tracing image is constructed pixel by pixel, the rasterized image is constructed by projection of the polygons. A given 3D polygon is projected in the screen 2D space, the varying data that characterize this polygon, being associated to this projection. Then the polygon is split into 2D sets of pixel, called fragments, that are stored and sorted (frame buffer) in function of their depth i.e. the distance to the screen.

### 3. GLOBAL ARCHITECTURE

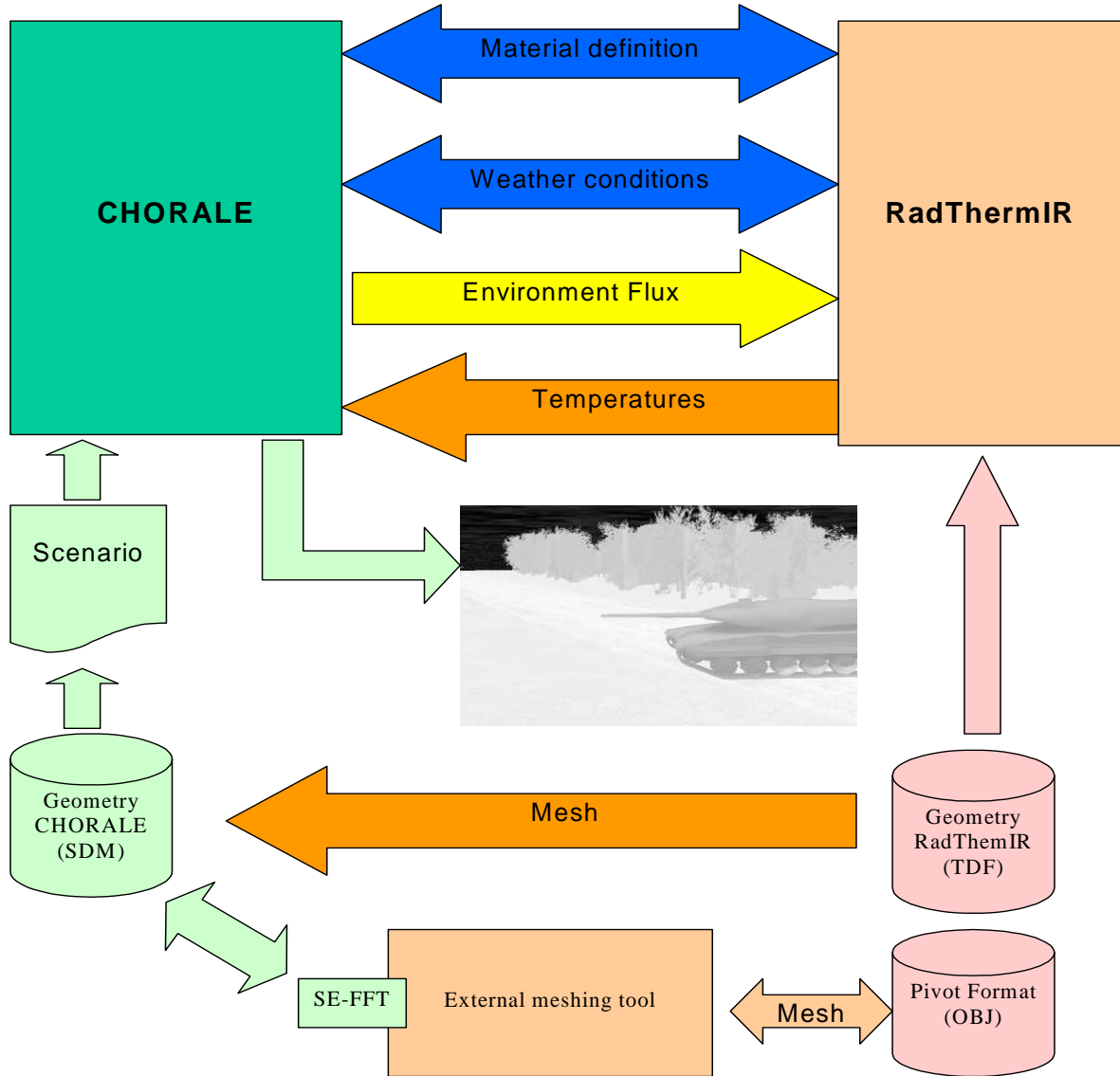


Figure 5: Global architecture

The coupling between RadThermIR and SE-WORKBENCH has for final objective the infrared image generation in SE-WORKBENCH of a scene containing objects (targets) whose temperatures are calculated by RadThermIR and influence the temperature of their environment. This infrared image generation can be made within the framework of an animated scene.

## 4. DATA COHERENCE

To bring to a successful conclusion this objective it is at first necessary to put in coherence the input data of SE-WORKBENCH and those of RadThermIR. These data are:

- Materials
- Weather conditions
- Target geometry
- Environment geometry

The couplings of materials and weather conditions, even if they sometimes require arbitrations, do not raise real problem. The coupling of the geometries raises a real problem so much the geometry of RadThermIR and SE-WORKBENCH are different.

### 4.1 Materials coherence

The model of materials held by RadThermIR, although different from that of SE-WORKBENCH in its structure, has almost the same information and a nearly bijective correspondence can be established.

However it is not possible to realize an automatic conversion from a class of materials. They are materials proposed by RadThermIR as "part" of type " background ". These materials are configurable by RadThermIR as a combination of user parameters more qualitative than physical (as the age or the wear of a cover) without giving access to the corresponding physical properties.

To allow the user to use in RadThermIR this class of material, well adapted to the definition of the materials of environment, it is not desirable to impose the SE-WORKBENCH version of these " background " materials to the user. In coupled mode, RadThermIR loads a " TDF " version of the SE-WORKBENCH multi-domain library which the user can modify to redefine if needed the materials of environment.

### 4.2 Weather coherence

The weather conditions used by RadThermIR result from files in the XWA format (eXtented WeAther). The SE-WORKBENCH weather conditions are based on a history (TCT) of atmospheric files (ATM). The SE-WORKBENCH model is richer than the RadThermIR one, but in terms of thermal exploitation the information used in both cases is compatible. A TCT file can be converted to produce a XWA file. A XWA file can be converted with more difficulty in TCT, but on the other hand a XWA file can be easily exploited for a thermal calculation. Consequently, SE-ATMOSPHERE knows how to produce XWA files, SE-THERMAL knows directly how to exploit XWA files.

The weather conditions exploited within the framework of the coupling SE-WORKBENCH / RadThermIR will exploit indifferently TCT or XWA files.

### 4.3 Geometry coherence

First of all RadThermIR strongly forces the nature of meshes because of the bijective relation existing between thermal node and polygon of the input meshing. The precision of meshing and the quality of the thermal result are thus directly connected. Consequently a RadThermIR geometry is generally strongly meshed to allow a good thermal calculation quality. It also has for consequence the limitation in complexity as much as in area of the environment scene managed by RadThermIR. Furthermore, it is necessary to ensure a certain number of points, as the strict connectivity of the meshing.

In SE-WORKBENCH, the relatively extensive use of textures of classification as well as masks of transparency in the modelling of the environments makes complex the automatic conversion of the scenes or pieces of scene.

An external meshing tool compatible of input formats of RadThermIR (OBJ for example) such as 3DSMAX must be used. If in addition this tool is compatible of the SE-WORKBENCH tools via SE-FFT, it allows to import SE-WORKBENCH geometries or to export it either.

If the import of SE-WORKBENCH geometry towards RadThermIR is strongly forced for the reasons previously evoked here, the direct export of RadThermIR geometries towards SE-WORKBENCH does not raise problem and is thus held

by SE-FFT. Nevertheless, this mode of use is not either necessary for a correct depiction of the temperatures (mechanism of the thermal definitions (DTH)).

The SE-WORKBENCH meshes can be totally different from that of RadThermIR and contain specific information (classified textures, transparencies, bump mapping, vertex normal vectors, multi-textures).

#### **4.4 SE-WORKBENCH Fluxes transfer**

Within the framework of a simulation managed through a SE-WORKBENCH scenario (.SCNX ), the coupling has to allow SE-WORKBENCH to supply to RadThermIR the environmental fluxes.

The potential interest of such mechanism would be to allow RadThermIR to exploit fluxes most closely with the real complexity of the environment that those coming from the local environment (reduced to an average ground and a sky).

#### **4.5 RadThermIR temperatures calculations and influences**

There is are two types of RadThermIR calculations:

- Temperature calculation with temporal evolution of targets integrated or not to a local environment.
- Calculation of the temperature evolution of an environment which is due to the presence of one or several targets.

In the first case, RadThermIR computes temperatures on the target, step after step, these temperatures are simply projected on the SE-WORKBENCH geometry during the visualization.

In the second case, it is considered that RadThermIR is not capable of calculating entirely the temperature of the SE-WORKBENCH scene (from a point of memory cost, CPU time consumption, but also cost of preparation of the RadThermIR scene). The calculation of the scene temperatures (environment) thus stays in charge of SE-WORKBENCH by the use of the thermal affectations. The environment used by RadThermIR is an extract of the SE-WORKBENCH scene prepared by the user to be compatible of RadThermIR.

To allow the temperatures of the environment to evolve in the presence of targets while insuring the continuity of the temperatures on the whole scene, two RadThermIR runs are made for each time step:

- a first run on a RadThermIR zone of environment without targets,
- a second run on a RadThermIR zone of environment with targets.

The information extracted by SE-WORKBENCH of these two runs is on one hand the temperature of targets and on the other hand the difference of temperatures between the environment with targets and the environment without targets. The difference of temperatures on the environment has to translate the influence of targets on their environment. This difference is applied to the environment of the target in the SE-WORKBENCH scene.

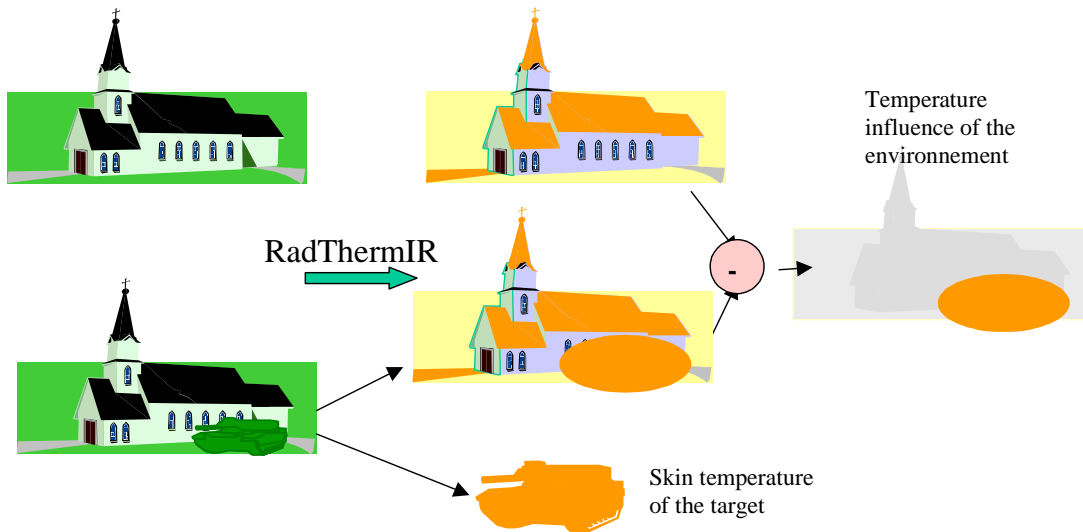


Figure 6: computation of the temperature influence of the environment

#### 4.6 Infrared image rendering in SE-WORKBENCH

The SE-WORKBENCH image rendering can be made by using as well SE-RAY-IR as SE-FAST-IR. Both software allow to exploit the temperatures of targets as well as their influence on the environment calculated by RadThermIR. In both cases, "user" DTH which are exploited to allow the update of the temperatures during the progress of the simulation.

### 5. THE BASE COUPLING

SE-FFT-TDF and SE-FFT-2TDF are command line converters. A parameterization GUI is also provided to help the inexperienced user.

#### 5.1 SE-FFT-TDF

SE-FFT-TDF allows converting TDF files generated by the software RadThermIR in the SE-WORKBENCH format.

This tool was developed in the main purpose to extract "the temperature of skin" from a TDF file. It also allows to convert the physical materials in a SE-WORKBENCH multi-domain library .

SE-FFT-TDF reads a TDF file.

SE-FFT-TDF generates the following files:

- A geometry file (BDD file).
- Thermal definition files (ATH file and DTH files)
- Material files (XML file and MAT files)



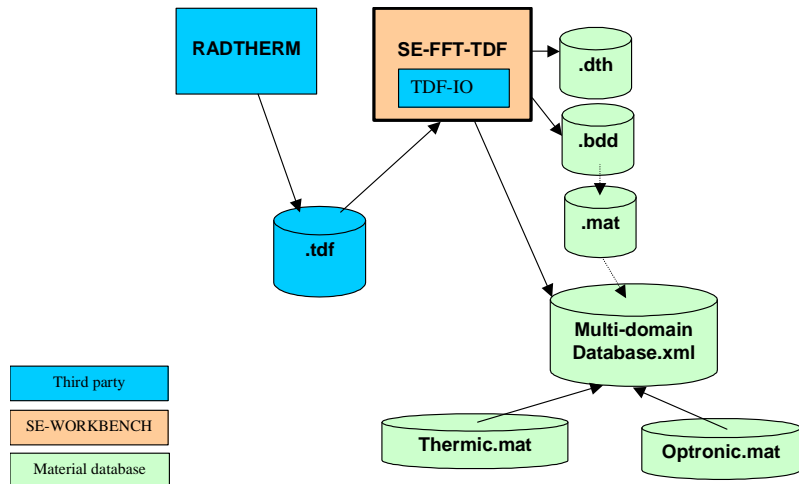


Figure 7: SE-FFT-TDF architecture

The following plan presents the methodology recommended to import a skin temperature in SE-WORKBENCH:

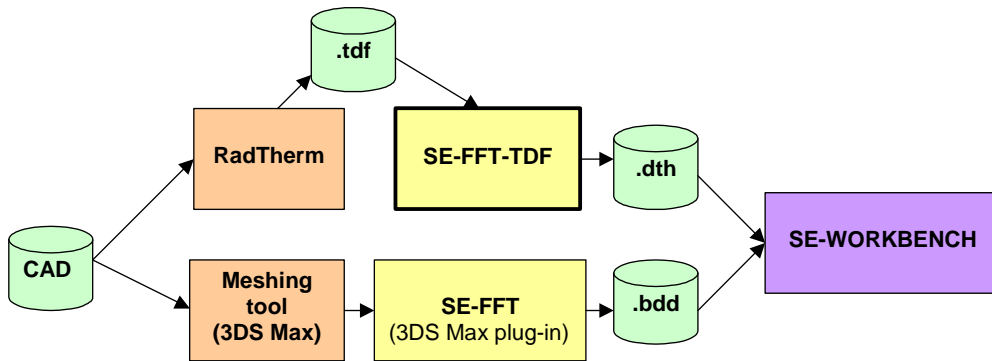


Figure 8: methodology to import a skin temperature

In that case, the user has to have the geometrical model of the CAD to generate a model adapted for RadThermIR and another model adapted for SE-WORKBENCH. This methodology allows to have independent treatments between the thermal and geometrical aspects of objects.

SE-FFT-TDF also allows to obtain the RadThermIR geometry. However, the RadThermIR geometry, adapted to the RadThermIR thermal solver, is not adapted to SE-WORKBENCH.

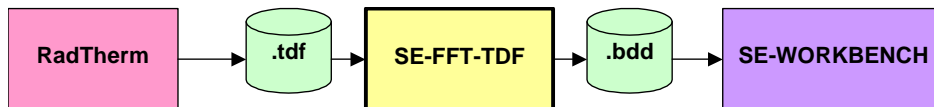


Figure 9: obtaining the RadThermIR geometry

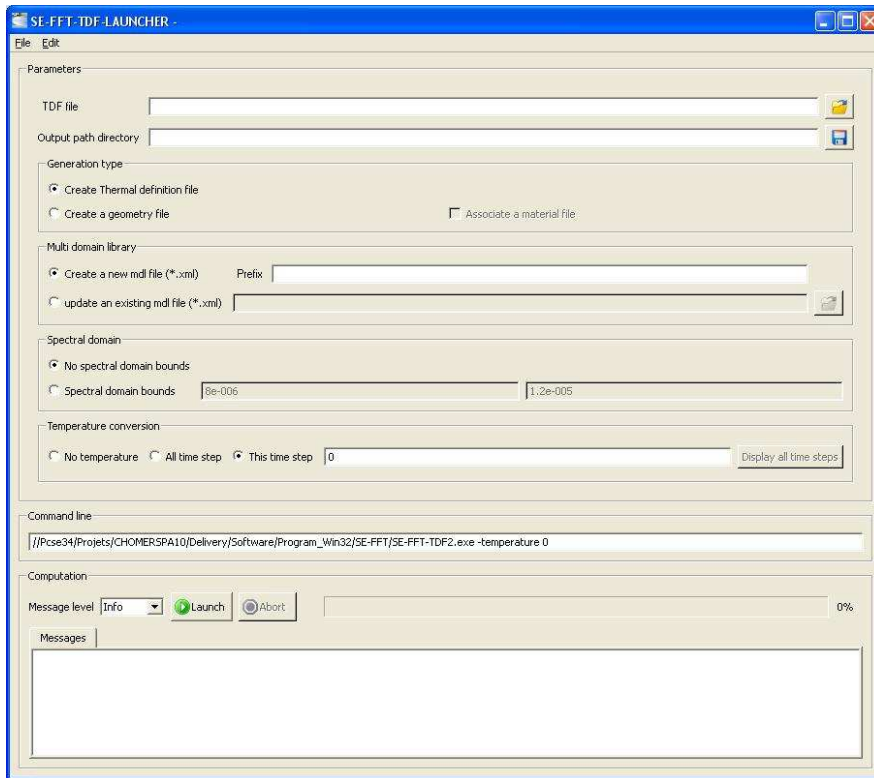


Figure 10: : SE-FFT-TDF launcher GUI

## 5.2 SE-FFT-2TDF

SE-FFT-2TDF allows converting thermal computation data from SE-WORKBENCH multi-domain library (in the XML format) to RadThermIR data (in the TDF format). The main application of the tool is to export thermics data, optronics data, and atmospheric conditions from a multi-domain database to RadThermIR data (TDF file). SE-FFT-2TDF also gives the possibility of converting materials of a multi-domain database (XML file) in a RadThermIR material database (TDF file). The user must create a “.obj” file and export this file in RadThermIR. After the user can save this file in “tdf” format. The file which is created like that doesn’t have any property. The user must have to convert the thermics, optronics, and roughness properties of each part, which the name is referenced in a multi-domain library.

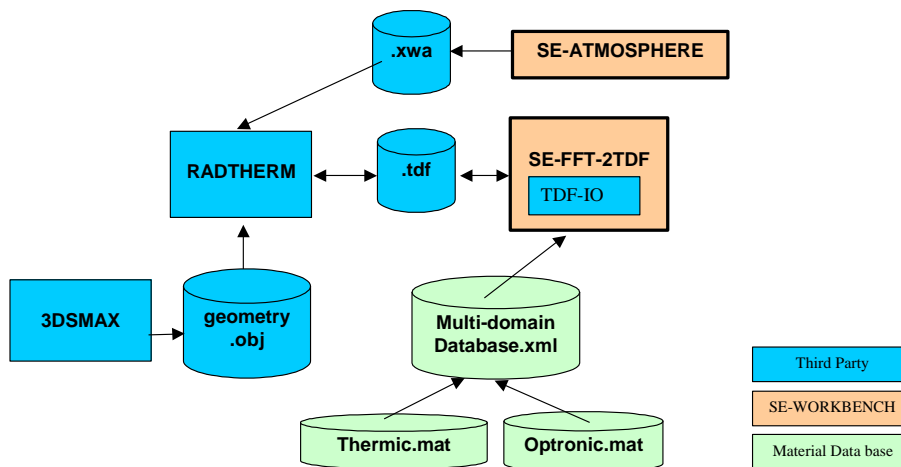


Figure 11: SE-FFT-2TDF architecture

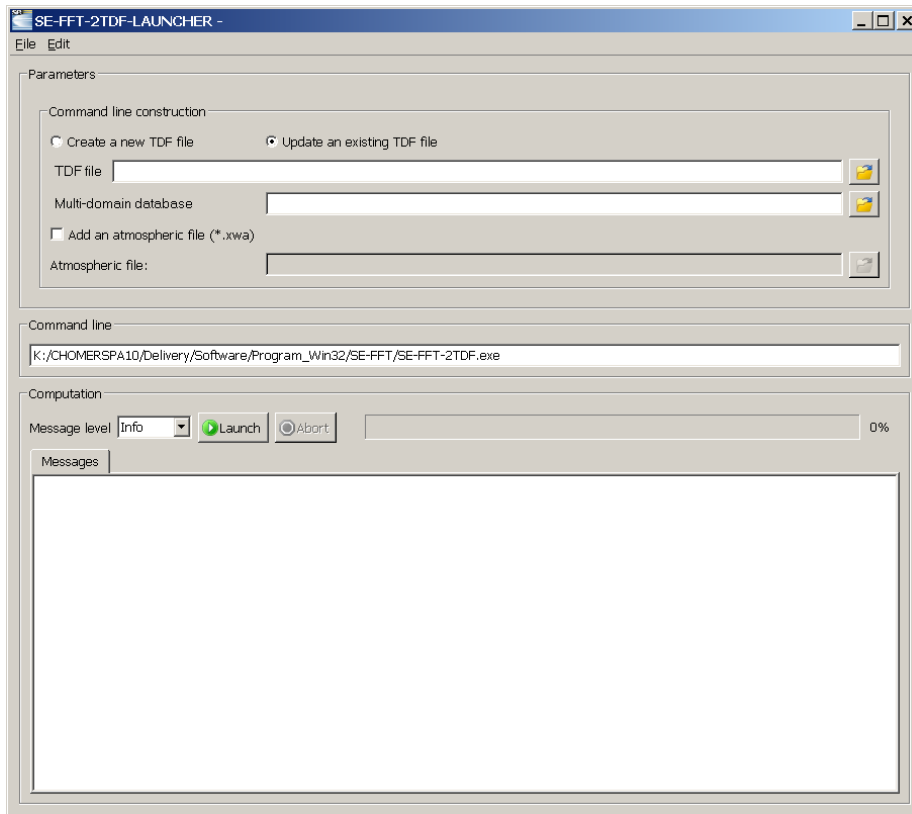


Figure 12: SE-FFT-2TDF launcher GUI

This GUI allows the user to easily build and execute a command line launching the SE-FFT-2TDF converter. The user can define the TDF file, and the multi-domain database with a file explorer. An option has been added to allow the user to choose an atmospheric file with a file explorer. The data to be converted can be saved allowing the user to find his configuration.

## 6. THE ADVANCED COUPLING

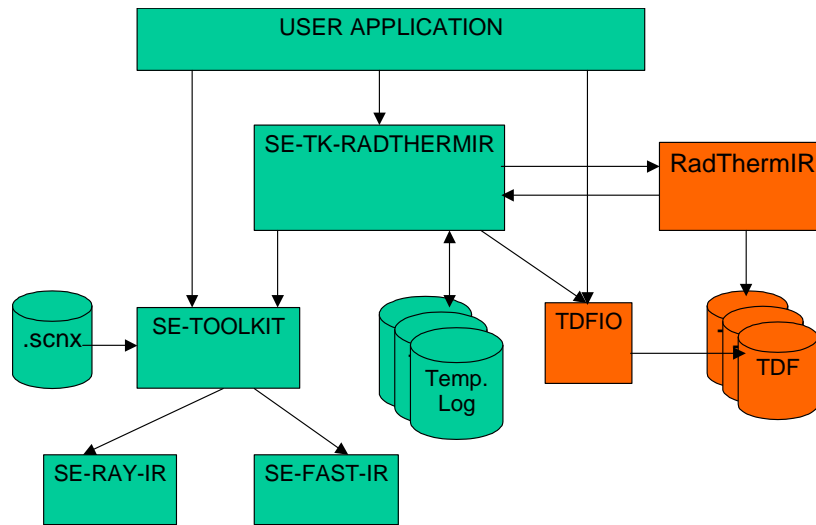


Figure 13: Advanced coupling architecture

The SE-TK-RADTHERMIR has for objective to allow a dynamic coupling between SE-WORKBENCH and RadThermIR but also to make the “replay” of a previously simulated scenario.

The SE-TK-RADTHERMIR is a C API containing the following features:

- targets declaration,
- environment zones declaration,
- configuration of weather conditions and initial simulation date,
- configuration of the computation flux mode,
- configuration of the computation temperature mode,
- computation of the temperature until the next time step
- TDF structure access to allows inner changes of the target (motor, speed, ...)

Except the optional manipulations allowing the manipulation of TDF files, the use of TDF files and RadThermIR is masked to the user. Also, the SE-TK-RADTHERMIR masks mechanisms used to calculate the environmental fluxes or affect the temperatures in SE-RAY-IR and SE-FAST-IR contexts.

The SE-TK-RADTHERMIR manages a "LOG" mechanism of the temperatures. These LOGS allow to make a “replay” of the thermal simulations. The “replay” mode contains several advantages:

- it allows to eliminate computation time of the thermal code during the simulation and makes thus possible in the future a " real time" simulation using SE-FAST-IR,
- During a replay the temperatures are interpolated between two time steps, which allows a computation less sampled in the phase of simulation than in the phase of replay,
- A TDF file already including time steps can be introduced into a simulation. If the replay mode is activated and no "log" is found, the temperatures contained in this TDF file are converted in a LOG compatible of the replay. The date of the first time step of the TDF file is then put in correspondance with the date of the first thermal computation made on the object,
- It allows finally to play a scenario running the result of thermal simulation without requiring a RadThermIR license on the computer.

## 7. RESULTS

The images below are in infrared (LWIR). The target follows a trajectory.



Figure 14: The target remained still during a long period.

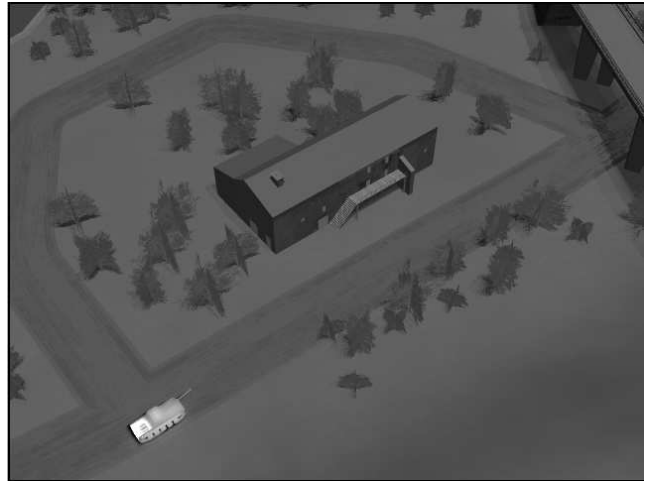


Figure 15: The target turns on the engine



Figure 15: The target goes to the building

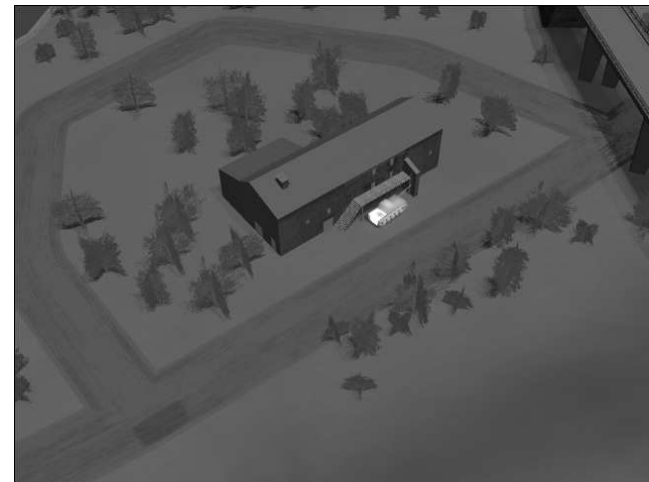


Figure 16: The thermal shadow of the target slowly disappears.

## 8. CONCLUSION AND PERSPECTIVES

Thanks to these recent developments fully supported by French DGA “Maitrise de l’Information” and MBDA France, SE-WORKBENCH is now fully operational for spatial research simulation.

A large community uses SE-WORKBENCH: army, research and industry.

SE-WORKBENCH presents a unique solution in the world that merges three technical complementary approaches that are: CPU, GP-GPU and GPU shaders and that combines the advantages of these three approaches.

A lot of work is still to be done. It mainly concerns the GP GPU implementation for SE-RAY-IR, the GPU shader improvement in term of functionalities and performances, the thermal tracks between declared environment zones. Plans are made also to improve the performances of the coupling .

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