

## SCIENTIFIC VISUALIZATION AND VIRTUAL REALITY TECHNIQUES INTEGRATED TO CAD/CAE SYSTEMS FOR ILLUMINATION DESIGN

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### ABSTRACT

For a same project, engineers tend to use different software to perform different tasks such as geometry modeling, database management, numerical analysis and data visualization. This may cause decrease of productivity and losses of information during the conversion process between different data file formats. In, most lighting analysis tools for example, the geometry modeling and pre-processing features does not provide all the capabilities available in a CAD (Computer Aided Design) system. Also the presentation of numerical results does not allows a rich and interactive data exploration/visualization such as is provided by Scientific Visualization tools and Virtual Reality systems. The aim of this paper is to describe an lighting analysis application which is an add-in for a 3-D CAD system which integrate all CAD modeling features, algorithms for mesh generation, numerical processing and post-processing of scalar fields, management tools for fixtures database, and a VRML (Virtual Reality Modeling Language) writer/exporter. Basically the application use the workspace of the CAD system as a 3-D interface for to plan the lighting scheme (luminaires choice and positioning), to process the illumination in 2D or 3D meshes chosen by the user, and then, to visualize and explore the results through scalar field scientific visualization techniques (p.e. contours, cut, slices, color mapping). Therefore, the application developed consist of a lighting analysis tool which integrate features for pre-processing, processing and visualization of illuminance fields with rich and intuitive visual interactivity. The method used for the algorithms developments are described and two examples of application are presented, a power substation and a simple house lighting plan.

### KEYWORDS

Illumination design, Scalar field post-processing, Scientific Visualization, CAD and CAE integration, CAD3D, VRML.

### 1. INTRODUCTION

For a same project, engineers tend to use different software to perform different tasks such as geometry modeling, database management, numerical analysis and data visualization. This may cause decrease of productivity and losses of information during the conversion process between different data file formats. Important industries, such as energy, oil and gas, are looking for computational systems that allow users to view and transfer geometric models, numerical results and others data quickly and efficiently. In this sense, visualization technologies can be used as powerful communication tools. Unfortunately, many of the facilities (techniques and algorithm) provided by the Visualization Toolkits available today (e.g. VTK and OpenDX) are not yet fully exploited in most CAD/CAE systems. Some of the well-known CAD programs, such as AutoCAD, Microstation, SolidWorks, Catia and Pro-Engineer have they own file format making data difficult to exchange. Furthermore, in many cases is desirable to visualize geometric CAD models and computational simulations results simultaneously, in order to increase the understanding of a phenomenon under study. But not ever this kind of visualization model is easily constructed. Many software for numerical analysis do not support CAD format files or not allow the interaction with

numerical data simultaneously to display the CAD model. Thus, tools that can handle almost all engineer numerical procedures is expected.

On the other hand Virtual Reality and others interface paradigms have been used as support tools for communication and planning in Architecture, Engineering and Construction – AEC (Savioja et al., 2003; Bouchlaghem et.al, 2005). Visualization tools can cover the whole lifecycle of a product from presentation of initial concepts to the final stages of production and can also be extended to maintenance issues (Facility Management). The 3D visualization techniques can be indeed a powerful technique to show large amount of information compactly and, moreover, suggesting behaviour and affinity among different entities given their placement in the virtual world (Malandrino et al., 2007). Thus, virtual reality models can be used to communicate design intent, and to compare and evaluate design options.

In this paper is described an lighting analysis application which is an add-in for a 3D CAD system which integrate all CAD modeling features, algorithms for mesh generation, numerical processing and post-processing of scalar fields, management tools for fixtures database, and a VRML files writer/exporter. Basically the application use the workspace of the CAD system as a 3-D interface for to plan the lighting scheme (luminaires choice and positioning), to process the illumination in 2-D or 3-D meshes chosen by the user, and then, to visualize and explore the results through scalar field scientific visualization techniques (contours, cut, slices, color mapping, etc.). The final visualization model can be exported in a VRML. The models in the VRML standard file format facilitate the communication and transfer of 3-D content on the web because the user can visualize and navigate into the 3-D model using a simple internet browser. Therefore, the application developed consist of a lighting analysis tool which integrate features for pre-processing, processing and visualization of illuminance fields with rich and intuitive visual interactivity. We believe that the major contribution of this work is to describe a way to create a computer application that integrate differents tools, needed in differents tasks of an lighting project, using a open source scientific visualization toolkit and customizing a comercial CAD system.

The organization of the paper is as follows: section 2 presents some basic concepts of visualization technologies and tools, including the Visualization ToolKit (VTK) and Virtual Reality Modeling Language (VRML). Section 3 describes the point-by-point method used for numerical processing of illuminance field. Section 4 details the application developed. Section 5 present two examples of application. Section 6 summarises the authors conclusions.

## **2. BASIC CONCEPTS IN VISUALIZATION TECHNOLOGIES AND TOOLS**

### **2.1 SCIENTIFIC VISUALIZATION**

Using visualization humans can recognize states, objects structures and models behaviour. Different kinds of visualization are used to communicate complex content and support decision processes. In Scientific Computing, Visualization is the area interested in to transform data and informations in representative pictures. The term Scientific Visualization (SciVis) refers to the sub-area dedicated to displaying physical or scientific data, usually obtained through numeric simulations or sensors. The first definition for SciVis was introduced by McCormick et al. (1987) at the panel "Visualization in Scientific Computing" presented at SIGGRAPH Conference: "Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science."

The goal of SciVis is to enhance scientific productivity by utilizing human visual perception and Computer Graphics techniques. Therefore SciVis is a support technology that enables scientists and engineers to understand complex relationships typically represented by large amounts of data.

Many visualization techniques and algorithm have been proposed in the literature (Brodie et. al, 1992), some may be more appropriate for scalar data others for vectors or tensors. Some techniques are based in texture others in geometric reconstruction such as line and surface contours. According to Collins (1993), some techniques of SciVis have their first records dating of the XII century, and are still used and implemented in many computational tools. Some well-known techniques for visualization of numerical data are mapping scalar values into colors (colormap) and contours (level curves and surfaces).

The process of displaying datasets usually walk through three basic steps, which are: data acquisition, transformation (filtering and mapping) and rendering (Schroeder et al., 2004). Therefore visualization techniques involve data processing algorithms, which extract the data of the sample of interest and convert into a form suitable for representation.

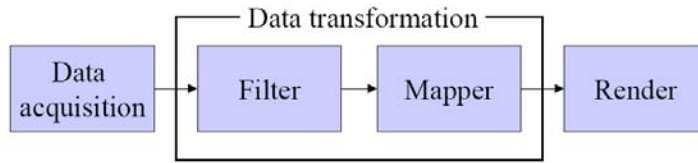


Figure 1: Data flow in scientific visualization algorithms

Visualization algorithms and applications can be more easily developed using visualization toolkits or libraries. In this work the VTK - Visualization Toolkit ([www.vtk.org](http://www.vtk.org)) was used. VTK is one of several visualization toolkits available currently but some advantages make VTK a good choice, such as are described below.

## 2.2 VTK - THE VISUALIZATION TOOLKIT

VTK is an open source, freely available software system for 3D computer graphics, image processing, and visualization. Consists of a C++ class library, and several interpreted interface layers including Tcl/Tk, Java, and Python. Some advantages of VTK is the support to a wide variety of visualization algorithms including scalar, vector, tensor, texture, and volumetric methods; and advanced modeling techniques such as implicit modeling, polygon reduction, mesh smoothing, cutting, contouring, and Delaunay triangulation.

VTK provides a variety of data representations including unorganized point sets, polygonal data, images, volumes, and structured, rectilinear, and unstructured grids. It comes with several reader/importer and writer/exporter to exchange data with other applications (including 3DS and VRML formats). Hundreds of data processing filters are available to operate on these data, ranging from image convolution to Delaunay triangulation. VTK's rendering model supports 2D, polygonal, volumetric, and texture-based approaches that can be used in any combination.

Using VTK is possible to develop visualization algorithms connecting filters and mappers through input/output process in such a way as to create a visualization pipeline or, alternatively, a visualization network. For example, we may wish to read a set of unorganized points, create a polygonal mesh via Delaunay triangulation, then display the mesh using polygonal (surface) rendering. Connections may only be made when the input/output types match.

VTK consists of two major pieces: a compiled core (implemented in C++) and an automatically generated interpreted layer. Data structures, algorithms, and time-critical system functions are implemented in the C++ core. Common design patterns such as object factories and virtual functions insure portability and extensibility. Since VTK is independent of any graphical user interface (GUI), it does not depend on the windowing system. It hooks into the window ID and event loop to let developers plug VTK into their own applications. An abstract graphics model achieves graphics portability. The graphics model forms an abstract layer above the OpenGL graphics language to insure cross-platform portability (see Fig. 2).

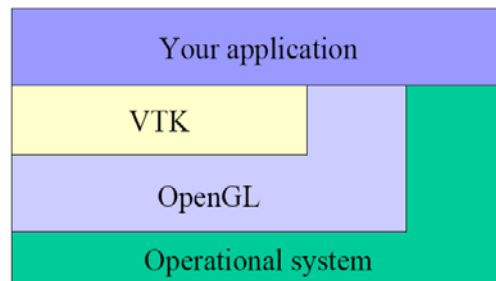


Figure 2: The VTK layer

In this work was used VTK for develop two main visualization algorithms, one for 2D scalar color mapping and image generate, and other for 3D scalar mapping and isosurface generated. Additionally a color table (lookup table) image also had to be generated, in each case, for the correct interpretation of results in the final visualization interface (3D CAD and VRML viewer).

### **2.3 VRML - VIRTUAL REALITY MODELING LANGUAGE**

The Virtual Reality Modeling Language (VRML) is a non-proprietary ISO standard file format for describing interactive 3D objects and worlds. VRML is designed to be used on the Internet, intranets, and local client systems. VRML is also intended to be a universal interchange format for integrated 3D graphics and multimedia. VRML may be used in a variety of application areas such as engineering and scientific visualization, multimedia presentations, entertainment and educational titles, web pages, and shared virtual worlds (Web3d, 2008).

Three-dimensional information can be easily generated and transferred through the Internet by this technology. VRML models can be displayed in several freely available browsers and integrate with web browsers as plug-ins. Information in a VRML file is encoded in ASCII. The VRML's latest incarnation is X3D, which updates the specification to more modern standards, including additional graphics features and an XML encoding.

VRML describes 3D models in the form of 'nodes'. Nodes generally define 3D physical descriptions that may be made up of 3D primitives, such as spheres, cube, cones and cylinders, or of complex polyhedra composed of polygon facets. In addition to these form descriptions, nodes can also define materials, colours, texture maps, lighting, shape transformations and viewing criteria. An important characteristic of VRML files is the ability to compose files together through inclusion and to relate files together through hyperlinking. Another essential characteristic of VRML is that it is intended to be used in a distributed environment such as the World Wide Web.

### **3. ILLUMINANCE FIELD PROCESSING AND VISUALIZATION**

An appropriate lighting plan in home and industrial environments is important to provide confort and good working conditions, besides generating economy in many ways, such as energy efficiency. Engineers and contractors are using lighting software programs to assist in the design of new construction projects and in planning the retrofit of existing facilities. In general, lighting application software programs use the point-by-point method of calculation, which is very accurate and precise and which can also be used for graphic renderings.

Point-by-point method is a design procedure for determining the illuminance at various locations (or at a mesh) in a lighting system using luminaire photometric data, for example, an IES file (IESNA, 2008). These files are in the Illuminating Engineering Society (IES) standard format, so that files of fixture products from just about any manufacturer can be put into the database. In addition to photometric data the point-by-point method need the geometrical information project (location and direction of focus of each light source), which can be obtained from the CAD model. In this context, a 3D virtual environment can provide a great 3D graphical interface for illumination planning software application. The Fig. 3 shows a example of geometric information needed in the illuminance field process.

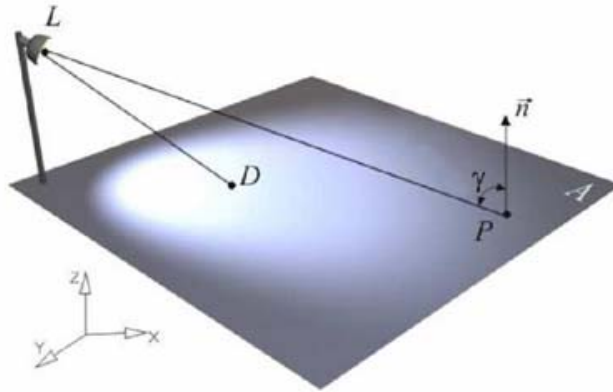


Figure 3: The geometric information needed for the illuminance process.

In Fig. 3, L is the point of light source, D is the focal point, P is the point of interest, n is a normal vector of plane A and gamma is the angle between PL and n. Whereas already built the CAD model, the lighting design can be built using the geometry of the CAD model to define the points of installation of fixtures and point of focus. Thus, the coordinate system used in the processing method of point-by-point will be the same coordinate system of CAD model.

#### 4. THE APPLICATION DEVELOPED

The illumination field numerical processing, as mentioned, needs some input information such as photometric data of light sources, the project geometry (includes coordinates of each luminaire position and focus direction) and coordinates of grid points which the illuminances will be calculated. For input this informations was used a CAD system (SolidWorks) workspace as a 3D interface. This allowed a easy and interactive choice of light source, localization and focus direction. Whith the 3D CAD model interface the user can select points in objects of the model by simple mouse pick and then insert light sources chosed from files from database. This process can be repeated as often is desired. The light point and focus coordinates are stored in a input file for the illuminances fiel processing. The SolidWorks customization (add-in developed) allowed also create graphical interface features for access and edit the database containing IES files of many light source models.

The SolidWork add-in implementation was make in four modules. The first is for register of luminaires in a SQL database. The second is for the geometry illumination project definitions such as lights localization and focus direction. The third module is for a mesh choise and illuminace fiel processing. Finally the last module is for the visualization of results and export the complete visualization model to a VRML file for publish.

For the first module was extended the SolidWorks GUI (*Graphics User Interface*) using the API (*Application Programming Interface*) available, Fig. 4. A graphical interface (page in the SolidWork environment) was created for add luminaires/lamps models and few information of light sources in database.

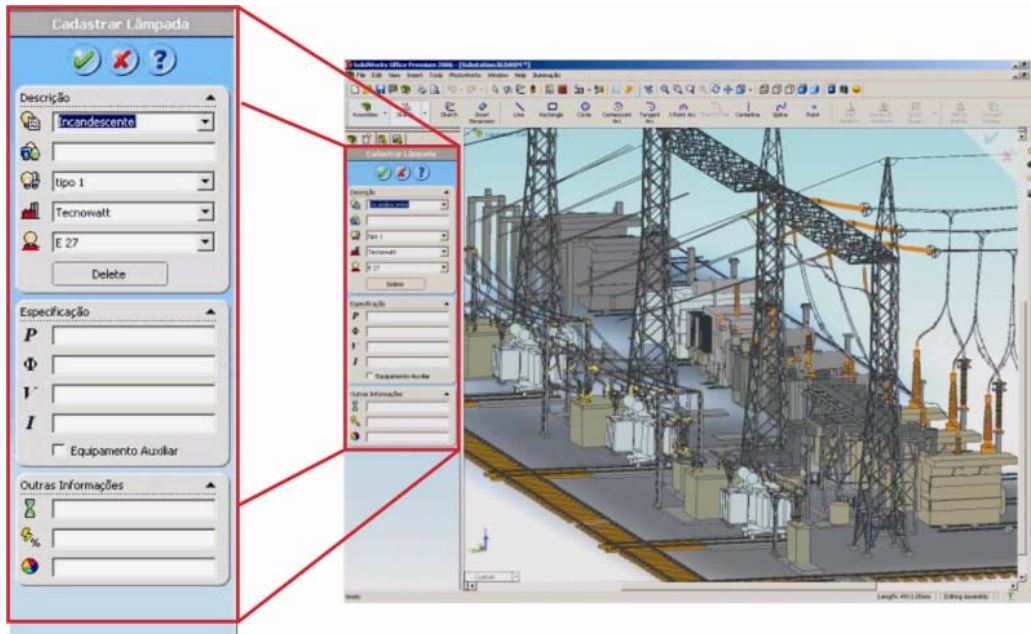


Figure 4: Interface for edit IES files database

The second module was developed using CAD features for the points coordinates capture and was create pages for the luminaires choose and insert in the digital model. Once defined a “illumination scheme” is possible save it for subsequent restore and/or edit. Many illumination designs can be created and compared for get the best result. The third module use the saved illuminations schemes for process de illuminances in a mesh defined by the user. The mesh is regular set of points evenly distributed in any plane or box (volume) desired. The point-by-point algorithm will be calculate the direct lighting at each point. Finally, the last module will be post-processing the illuminance field trough the visualization algorithm (contours, colormap, slice planes, stream lines, etc.).

The use of SolidWorks is only an alternative way to input the data in illuminance field processing algorithm. The input also can be made through an ASCII file, therefore the use of SolidWorks is not mandatory. The numerical algorithm can read the input information into an ASCII file and generate a output file in VTK *Legacy* format. This format can be easily read for a visualization algorithm written using the VTK library.

In this way, from the input information, the numerical algorithm process the iluminance field and store the results in a VTK *Legacy* file. Then, the visualization algorithm read, generates the color mapping and contours, and also, export the final model to the VRML format. Therefore using the SolidWorks interface was possible to perform several simulations for different lighting systems for different cases and compare them. The steps for the use of the application developed are: after registering the IES files in the database, for all light sources which will be used, to choose and to insert in the 3D digital model the points of light desired; select or create a face (plane) or a volume (box) where will be performed the analysis; choose the density of the mesh points to be generated and, finally, process the iluminance data and get the visualization. The mesh generated is the type structured and have cells square (pixel cells). This structure allows from the result of the color mapping to generate an image file in JPG, BMP or PNG and therefore can be inserted into the model as a texture, which usually more "economic".

It was also possible using methods of the SolidWorks API perform the simulation taking into account the existence of opaque bodies which block the light in some points of mesh. The methods used were the *RayIntersections* and *GetRayIntersectionPoints* allowing given a point and one direction, see if there is any object in that direction. With these methods were unable to examine whether or not there is any object from the point of installation of light source and the point of the loop in which the illuminance is calculated. If there is an object, the influence of this source of light will be disregarded, or will only be computed the influence of the sources of light whose light rays focus directly on the point. An example of a simulation performed and displayed in the CAD environment, considering the obstructions, is shown in Fig. 5a and texture generated is shown in Fig. 5b.

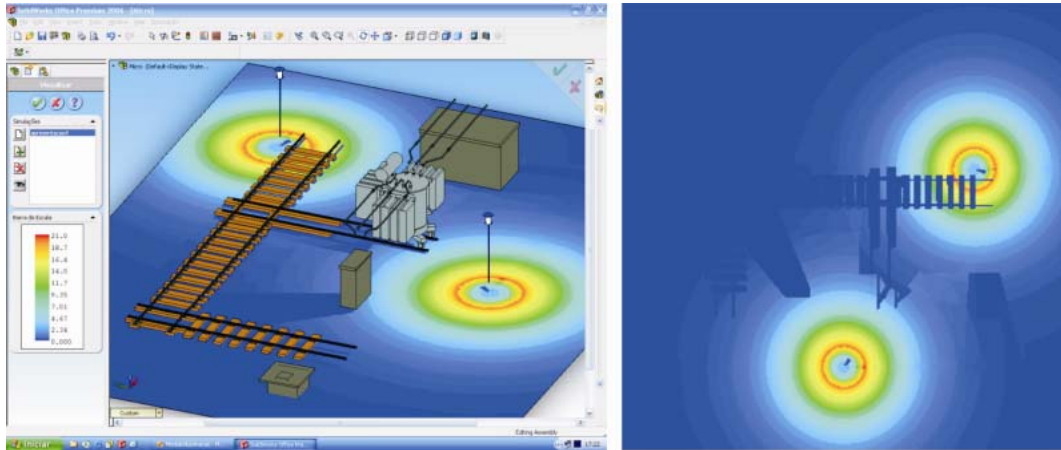


Figure 5: (a)Result of simulation performed considering the opaque bodies obstructions and (b) the image generated for visualization of illuminance field

This approach is without the influence of the light sources whose luminous intensity does not directly reach certain point. However, due to the computational cost needed for the processing, it was only possible to simulate in parts of the substation, or in smaller models. A use diagram of application developed is showed in Fig. 6.

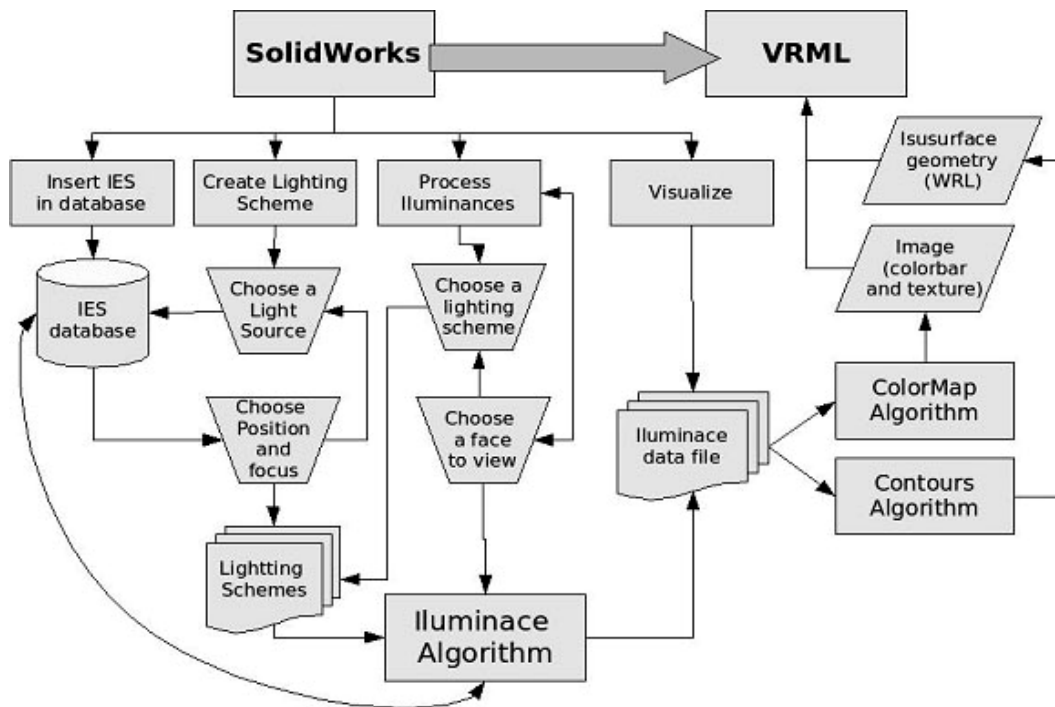


Figure 6: Dataflow of application developed

The main advantage of application developed, compared with other existing, is that its fully integrated with 3D CAD Solid Works and was designed with an open source toolkit VTK making it more flexible and more expandable, and free.

##### 5. CASE-STUDY: LIGHTING MEASUREMENT FOR A POWER SUBSTATION

During the R&D project “3D Virtual Reality System Applied to Power Substation Activities” with ANEEL (Brazilian National Agency of Electric Energy) funds and support of Furnas Centrais Elétricas, it was developed a joint cooperation with LACTEC (Institute of Research for Development). In this collaboration the add-in sub-system for illuminance field was tested. The project goal was to develop a system of Virtual Reality for several plans, such as cargo transportation, using the three-dimensional model to access information that is often not available due to the impossibility (technical and safety) to do the lighting through traditional methods. The application was tested in the 3D model of the electrical power substation located in the city of Jacarepaguá, State of Rio de Janeiro, Brazil. The cited transmission substation have capacity for 600 MW.

The digital model used was obtained through laser scanning performed by a contracted company. The technology of laser scanning employed allows generation of models with geometric precision of 2 to 6 mm. The product of scanning process is a dense point cloud (given into x, y, z coordinates) captured at a speed of 1800 points per second. The point cloud is passed through a process that generates a corresponding CAD model. The CAD model is then analysed, corrected and converted in a VRML file to be viewed in available free browsers.

The data had been initially in DWG format file (native of AutoCAD software, version 2004) in five parts: area\_of\_capacitors (33MB), area\_of\_trafos (29 MB), area\_128KV\_a (47 MB), area\_128KV\_b (49 MB) and area\_345KV (121 MB). The DWG models was imported in SolidWorks in pieces where different equipment/parts was separated by layers and imported separately. Each part was then converted in a VRML file using the SolidWorks and later meeting through *Inline* VRML nodes. This process allow create a distributed virtual reality model and implement techniques for up the navigation performance such as LOD (Level Of Detail) and FOG.

As initial data, the developed add-in uses a given plan of the lighting system (number, type, location and direction of focus of the light sources). In sequence, an algorithm calculates the three-dimensional field of



horizontal illuminances, and then some visualization techniques (slice planes, isocontours and colormap) are applied. To illustrate the operation of the developed application, a simulation was performed for a system of lighting, using the 3D model of the case-study power substation. Several configurations could be tested varying the position of the light sources, different luminaire and lamp types. Fig. 7 and Fig. 8 show both illuminance field visualization and substation CAD model in a VRML virtual environment.

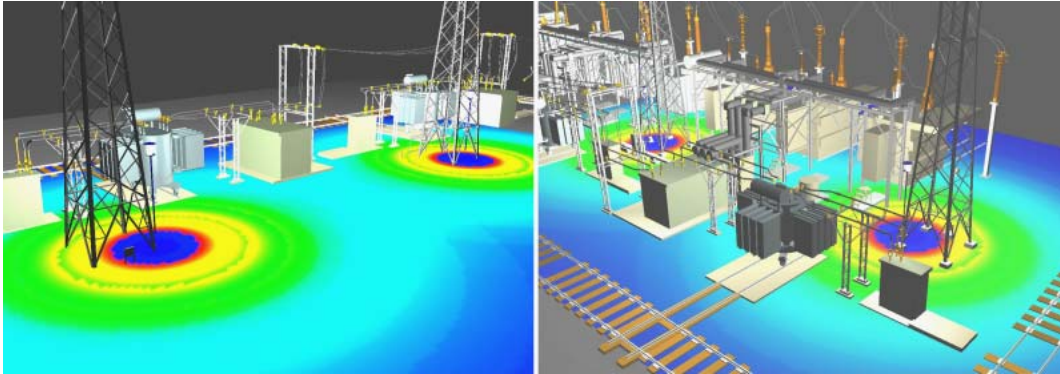


Figure 7: Illuminance field visualization and the power substation digital model

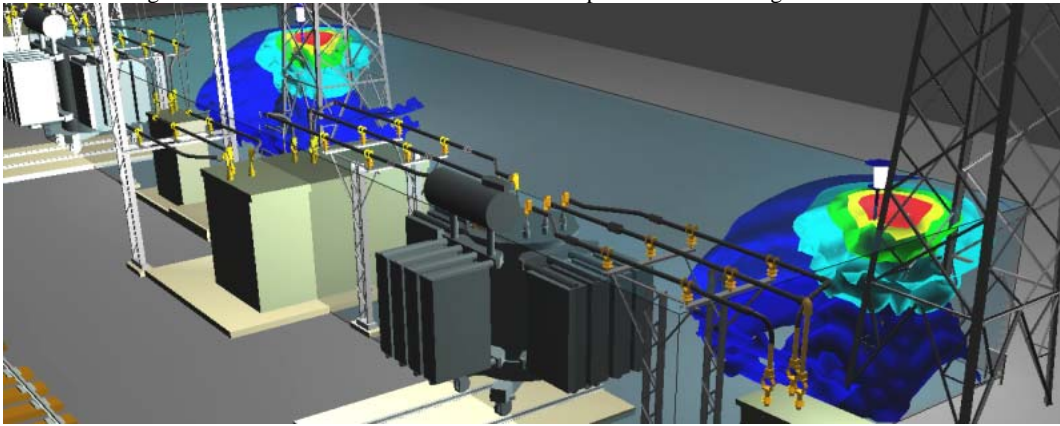


Figure 8: Isosurface illuminance field visualization

## 6. THE KICHTEN EXAMPLE

In order to study the potential of VTK for development visualization systems, a program has been developed, called PPGMNE DataViewer (Neto et al., 2006) - PPGMNE stands for the Numerical Methods Graduate Program at the Federal University of Paraná in Brazil.

The PPGMNE DataViewer or simply DataViewer (DV) is a VTK based visualization program which provides a graphical user interface for control several parameters of visualization algorithms. Using DV users can easily load a dataset (in VTK Legacy Format file) and, then, to apply visualization techniques such as slice planes, color mappers and contours. A sequence of filters and mappers can be applied for a visualization pipeline construct. The resulting model can also be exported in a VRML format file.

In order to illustrate an application of illumination field visualization, a house example was created. The geometric model was constructed in a CAD program and then exported for 3DS format. This format can be imported by the DV program. The illuminance field was processed separately and then the results loaded in DV were the resulting illuminance field was created. This procedure allowed a complete understanding of lighting data. The Fig. 9 shows some views obtained by some DV capabilities.

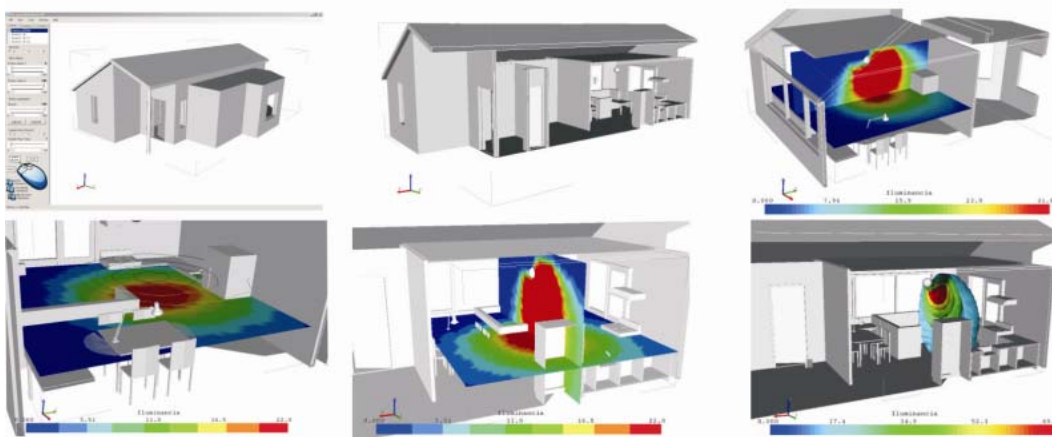


Figure 9: The visualization of illumination field in a house kitchen: (a) the CAD model; (b) a cut in CAD model; (c) two orthogonal slice planes of illuminance field and colormap (d) slice plane and isolines; (e) more two orthogonal slice planes; (f) isosurfaces

## 7. CONCLUSION

Through customization of a 3-D CAD system is possible to incorporate algorithms for pre-processing, processing and post-processing of numerical analysis in order to obtain an application that provides features of different systems into one. The conversion of the final model in a VRML format file provides several advantages from the point of view of communication and collaborative visualization/planning. The integration of features that are typical of different software into a single system (a CAD or a Virtual Reality system) is interesting to decrease the difficulties arising from the data transfer between different file formats. In particular, CAD systems are commonly used in engineering for geometric modeling and can be customized, so as to seize the geometry built to generate the mesh of points that will be used in numerical analysis. For this, tetrahedralization and triangulation algorithms can be used. In addition, CAD systems that support the use of textures, such as SolidWorks, allow numerical data to be represented as images in the 3-D model, as shown for viewing the illuminance fields through color mapping. Scientific visualization tools such as VTK, provide algorithms for mesh generation and scientific data representation which may be used in applications development and software customizations for creation of new functionalities. Finally, a conversion in a VRML file provides all the visualization and communication facilities.

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## REFERENCES

- Bouchlaghem D., Shang, H., Whyte, J. and Ganah, A. (2005) "Visualisation in architecture, engineering and construction (AEC)". *Automation in Construction*, Vol.14, No. 3, June 2005, 287-295.
- Brodie, K.W., Carpenter, L.A., Earnshaw, R.A., Gallop, J.R., Hubbard, R.J., Mumford, A.M., Osland, C.D., Quarendon P. (eds), *Scientific Visualization, Techniques and Applications*, 1992, Springer-Verlag.
- Collins, B. M. (1993) "Data visualization: has it all been seen before?" In: Earnshaw, R. A.;
- Watson, D. (Eds.) *Animation and Scientific Visualization: tools & applications*. Academic Press. p. 3-28.
- Lang, U., Wössner, U. (2004) *Virtual and Augmented Reality Developments for Engineering Applications*. Proceedings of the European Congress on Computational Methods in Applied Sciences and Engineering – ECCOMAS2004.
- Malandrino, D., Palmieri G., Scarano V. and Capocelli, R. M. (2007) *Visualizing processes on the web*. *Journal of Visual Languages and Computing Archive*, Vol. 18, No.6, 592-612. Orlando, FL, USA.
- McCormick, B. H.; DeFanti, T. A.; Brown, M. D. (1987) *Visualization in Scientific Computing*. *Computer Graphics (special issue)* Vol.21, No.6.

- Neto, M. A. S.; Buriol, T. M.; Scheer, S. Um Visualizador Interativo para Exploração de Dados Volumétricos Obtidos em Análise pelo Método dos Elementos Finitos. In: CMNE / CILAMCE, 2007, Porto. Anais do CMNE / CILAMCE 2007, 2007.
- Savioja, L., Mantere, M., Olli, I., Äyräväinen, S., Gröhn, M. and Iso-aho, J. (2003) "Utilizing virtual environments in construction projects". ITcon, Vol. 8, No.-, 85-99. Available at <http://www.itcon.org/2003/7>.
- Schroeder, W.; Martin, K.; Lorensen, B. (2004) The Visualization Toolkit: an object-oriented approach to 3D graphics. 3rd. ed. Kitware.
- Web3d (2008) Extensible 3D (X3D) international draft standards. ISO/IEC FDIS 19775:200x. Available at <http://www.web3d.org/x3d/specifications/index.htm>.
- IESNA (Illuminating Engineering Society of North America). Available at <http://www.iesna.org/>