Software Integration for Heat Transfer Simulation of Electronic Circuits

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Abstract: Thermal and fluid flow simulation have become increasingly important in the design and operation of electronic circuits, improving the performance and preventing their failure. The paper presents a software integration tool for coupled thermal-Computational Fluid Dynamics simulation of power electronics. The purpose is the extension, customization and integration of a platform, based on ANSYS Workbench interface to automatically create, simulate and explore the heat transfer during operation of electronic circuits. The authors examined recent literature, technical solutions, user's profile, as well as new software functionalities. New trends on the topic were identified, but also drawbacks of the simulation tools available for power electronic components. The main objectives were to find a simple and efficient tool to perform the design, the multi-physics simulation of the electronic circuits and the verification of the results. The design of the electronic circuits has automatically been completed using virtual libraries and devoted software. Compatibility and format conversion have also been discussed. The platform includes acquisition instruments for experimental data that can be employed as input parameters in model preparation stages. The connectivity with the optimization procedures and further developments of the platform were explained. A case study, comprising a forced convection cooling for a printed circuit board, taking into account the heat generated by the active MOSFET components and the film coefficient generated by the fan proved the reliability of the platform.

Keywords: Software, Integration, Simulation, Heat, CFD, ANSYS ICEPAK, 3D CAD, EDA, MATLAB.

1. Introduction

Heat transfer is a milestone for electronic circuits design and combines the use of software involved in mechanical, electronics, fluid dynamics and material sciences. Computer Aided Design (CAD) in these fields has a very different approach (Garimella, 2012). Often the simulation takes place in stand-alone products, apart by the Electronic Design Automation (EDA) packages (Tatchell, 2013).

The demand of simulation software integration appeared as a result of the collaborative engineering in Product Lifecycle Management (PLM) paradigm (Oh, 2015).

Recent reports on software integration for heat transfer simulation of electronic circuits (Gargiulo, 2014) are focused on model reuse, metadata annotations and search functions, to assure control over the shared data for complex web-based platforms. Other attempts (Sempolinski, 2015) aim to overcome the increasing programming difficulties with recent Computational Fluid Dynamics (CFD) codes on parallel computers for large systems, as well. Problems regarding the integration between computational codes and experimental data were analyzed for design activities of multiple collaborating designers (Adrianne, 2013), but solutions refer to high speed flow regimes. Flow diagnostic tools for experimental validation such as Particle Image Velocimetry (PIV) are expensive and require expert operators (Ishizuka, 2012). These are usually restricted to large academic or industrial research and development groups.

A simulation environment for the integration of large-scale system levels for industry has been described (Whitfield, 2012) and a discussion about the coupling possibilities of the software was included. Open-source candidates, realization of the geometry, mesh, case configuration, boundary and initial conditions, solvers and visualization parts have been analyzed, but future work is still expected.

All these solutions are suitable for products with an increased number of components, where tens of thousands parts are included.

Literature and market analysis (Infinity Research LTD, 2015) pointed out that new needs and challenges are now to broaden the usage of the heat transfer simulation and to deepen the integration and interoperability with new software tools used in the design process of the power components for fixed and portable electronic circuits.

Nowadays two types of simulation driven solutions are available for medium-sized companies:

- Sophisticated platforms, with plenty of modules dedicated to different types of circuits, that come with turnkey systems (Mentor Graphics, 2013), which involve sustained training and expertise;
- Plugged-in solutions (Man, 2010), that are integrated in the CAD system. The latter seemingly help the user to swiftly handle the model, but bring other inconveniences: less accuracy and long computation time. For these attempts a correspondence of the simulation results with the reality within 3-10% is considered acceptable if the device is not used to the heat limit (Nunnally, 2014), so the results are far less accurate.

Another important issue regarding the thermal management of the electronic circuits is to decrease the heat generated by the electronic components in order to minimize their impact on climate deterioration (Alexandru, 2013). This has to be done in respect to rules and protocols addressed by the ICT Challenges and Issues in Climate Change.

Literature overview pointed out that affordable, accurate and easy-to-use solutions are still expected by the users working in confined PLM market segments. Concerns are focused on the integration of the EDA with simulation and experimental tools.

The current paper presents a simple, but efficient solution for the integration of a Computer Aided Engineering (CAE) interface with EDA systems and libraries, as well as data acquisition tools and virtual instrumentation. The workflow allows a multi-physics approach, with stress computation and optimization procedures. This attempt brings the following benefits: the solution is simple, extendable, implies minimum costs, assures accurate simulation results, is flexible and allows rapid validation of the results.

The paper is organized as follows: the next section, entitled *Model preparation peculiarities in thermal electronics simulation and user's profile* highlights specific modeling tasks in respect with the user background. The actual solutions foster appropriate simulation environments to include verification instrumentation. Then, our proposal, *A software integrated architecture* is presented, where the modules are described and the adaptability of the suggested scheme is explained. Section 4 contains a *Case study* that illustrates the efficiency and the accuracy of the simulation results using the proposed workflow. The *Conclusion* section summarizes the main contributions of the study and includes hints about future work.

2. Model Preparation Peculiarities in Thermal Electronics Simulation and User's Profile

Coupled thermal-fluid simulation revolutionized the electronic components design. Electronic devices today have smaller footprints and unique power requirements that call for superior thermal designs (Kadam, 2015). Overheated components degrade product reliability, resulting in costly redesigns. According to a study in the industry (Song, 2013), a significant percentage of all failures in electronic systems are related to temperature issues.

When simulating the heat transfer for electronic circuits, problems arise not so much due to the calculation time, but because model preparation stages. These have a direct impact on the accuracy of the results or tangle the solver and the convergence fails. Completely stair-steps models, virtual parameterized blocks and streamline connectivity between objects are crucial for properly running the simulation.

Recent studies (Tatchell, 2013) pointed out that useful tools exist for single disciplines like circuits and controls, heat transfer and fluid dynamics high-frequency electromagnetics or electromagnetic fields, but an efficient coupling, that takes into account multi-disciplinary aspects of power electronics design is still challenging.

Software to realize general coupled simulations is difficult to handle for non-scientists and/or limited in performance (Garimella, 2012). Therefore companies don't develop complicated interfaces for this category of users. Besides, the costs of the software license are high and few medium-sized power electronic companies buy this tool or employ analysts for CFD simulations (Shahjala, 2014).

Over the years, specialists have observed that there is a trend in heat transfer simulation to slip away from the centralized CFD specialists to small design teams, as a distributed activity. As a consequence, the simulation is used by just one person on a part-time basis, as part of a small multidisciplinary design team, alongside their other responsibilities, for example the mechanical integrity/reliability of the product. Therefore the software needs to be tailored to rapid model building for electronic purposes to support the needs of such individuals. This is referred in (Tatchell, 2013) as User Interface Versatility.

The users are mechanical designers rather than CFD analysts - they work in a fast-moving, multi-disciplinary workflow - and they need to collaborate with electronic designers using devoted software for electronics and with mechanical engineers using CAD systems. In addition, "the software is expected to contribute at all stages of the design process, from concept, through design exploration and optimisation, to final verification" (Wang, 2013).

3. A Software Integrated Architecture

The platform presented in Figure 1 connects the graphical user interface of ANSYS Workbench with external EDA and data acquisition tools in a collaborative and user-oriented workflow. The integration relies on the flexibility of each independent package to share information. As software today is an outcome of process standardization, each application allows multi-input and multi-output connections with other software or platforms. The actual representation is a result of an interdisciplinary development in the field of the information technology. At first, using an electronic circuit evaluation software, a schematic plot of the model can be generated and the computation of the steady-state or time dependent behavior of the power sources can be performed. Then, the desired components of the integrated circuit (IC) are downloaded from a library and the model is completed and saved in a neutral file format to be exported to the CAD system.

The model is further deployed in the CAD system by selecting the appropriate components for the heat fluid model, as not all the objects are necessary for the thermal CFD simulation. Geometry simplifications also consist in: de-featuring, splits, topology clean-up, enclosure creation and generation of axis aligned bodies.

An alternative way to run geometry simplifications are ANSYS tools, which automatically perform model simplifications on different levels. Although the solid bodies are usually identified and the process runs fast, problems arise when surface bodies are considered and the user has limited intervention options.

Preprocessing involves mesh generation, material properties definition and boundary conditions setting, as well as the choice of the simulation parameters. Solvers are tested and certified. Therefore, if the accuracy of the results is doubted, model preparation is at fault. Results are displayed as graphs, tables, particle traces or contour plots by means of post-processing software. The Reynolds averaged Navier-Stokes approach ensures a fast design cycle, but simulation has to be supplemented with validation experiments and temperature acquisition devices. Specific temperature points are monitored within the cabinet of the electronic assembly. Simulation and experiments are compared by setting an

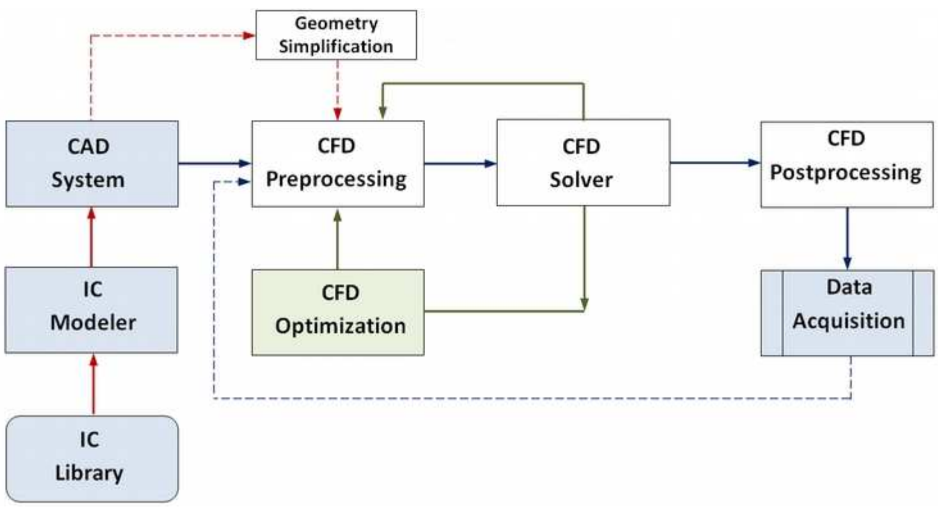

Figure 1. Software integration architecture

allowable fault margin. If this limit is exceeded, preprocessing steps are verified for errors and the workflow loop continues until optimal results are obtained.

Apart from the design, simulation and validation tools, the integrated platform includes optimization software, which enables enhancing the electronics cooling efficiency. The optimization procedure uses the results of the coupled heat-flow simulation as input data. By means of iterative or probabilistic algorithms, the optimizer chooses the best values of the defined parameters that satisfy the user's criteria.

The constitutive blocks of the proposed software architecture have specific requirements:

3.1 Electronic circuits schematics and simulation

At cloud storage level, information has to be easily accessed when defining input data. Thus, instant entries to extended electronic components and packages are provided. At this stage the user requires full access to the Printed Circuit Board (PCB) design, including the schematic capture, board layout and auto-router. To reduce the work and time a library that comprises footprints (device, symbol & package) information, can be accessed (see Figure 2). The model contains the following attributes:

– Graphical contour;
– Contact areas and positions;
– Dimensional tolerances;
– Overall dimensions including height;
– Identification number.

The model in then exported for case design and fitting.

3.2 CAD system

This system allows the user both to edit the model in a more appropriate way for the coupled field analysis and to streamline the translation to ANSYS ICEPAK, where predefined bodies and primitives may also be added for complementary reasons.

The components have to be defined parametrically to accommodate configurations and solutions in an innovative design. The PCB geometry involves a large number of objects and distinct faces, at extreme disparities in scale, from millimetres to micron scale. Therefore editing the model in the favourite system helps the analyst. Although it brings an additional stage, this step is a key factor to achieve an adequate computational model and the compatibility EDA-CFD.

3.3 CFD preprocessing tools

The computational model is usually prepared in a two-step procedure: preparation of a reduced model appropriate for the analysis and creation of the computational mesh.

A wide range of fluid dynamic solvers are now available, such as: FLUENT, CFD++, OPENFOAM, FLOTHERM, CFX, STAR-CD, etc. The solvers have general fluid dynamics capabilities, but special features are needed for mesh generation of the true shape of the electronic components, such as: hexahedral mesh generation algorithms for proper geometry representation, multi-level meshing, density controls of the mesh, cutting cell techniques,

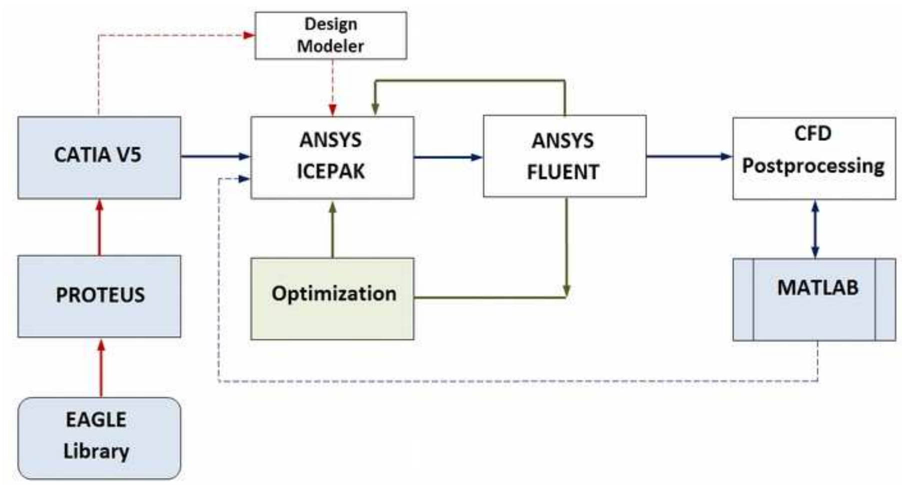

Figure 2. Customized integration architecture

slack blocks, definition of conformal or non-conformal mesh strategies, mesh quality evaluation and verification tools. On the other hand, generalized grid topologies (unstructured meshes) and integration of the grid with the topological information, defining the connectivity between neighbouring surfaces are required. In addition, specification of grid-resolution is supported by advanced geometry feature detection algorithms. These functionalities are provided by ANSYS ICEPACK.

3.4 Results viewer

This package is integrated in the processing system, but an external tool may be accessed, such as META or TECPLOT. Velocity vectors and contours, fluid particle traces, iso-surface displays, cutting-planes and x-y plots, fan and blow operating points, as well as image and animation tools are required.

Figure 3 shows an expanded view of the external software connections. A customized architecture leaves the analyst great flexibility in choosing the favourite package, for design, optimization and verification tasks. If necessary, complementary packages can be easily added at each stage of the workflow.

3.5 Result verification tools

Most heat transfer simulations are supported by both analytical data input, as well as experimental set-up for results validation.

3.6 Optimization tools

Are useful to find the appropriate location of the components, as well as the power and temperature limits for the best settings. Common optimization targets are also costs, volume and weight. The present approach, based on software specific requirements for multi-physics and experimental purposes, presents a conceptual diagram that can be tailored according to the user's preferences for ANSYS multicriteria optimization procedure or an external optimizer, such as TOSCA or Hyperworks. The usability of this procedure has been tested and work is in progress to tune the computational costs of meta-model generation with an efficient response surface algorithm and the genetic optimization routine. Direct optimization procedures are also available. This is a cutting-edge topic, included in the larger concept of the simulation driven design strategy.

Detailed or simplified models may be further used as input for the heat-fluid simulation. Browsing tools, solution monitoring and updates are also available to synchronize the CFD model with the CAD evolution.

4. Case Study

In order to prove the presented concepts a heat flow simulation, comprising a forced convection cooling for a PCB was performed.

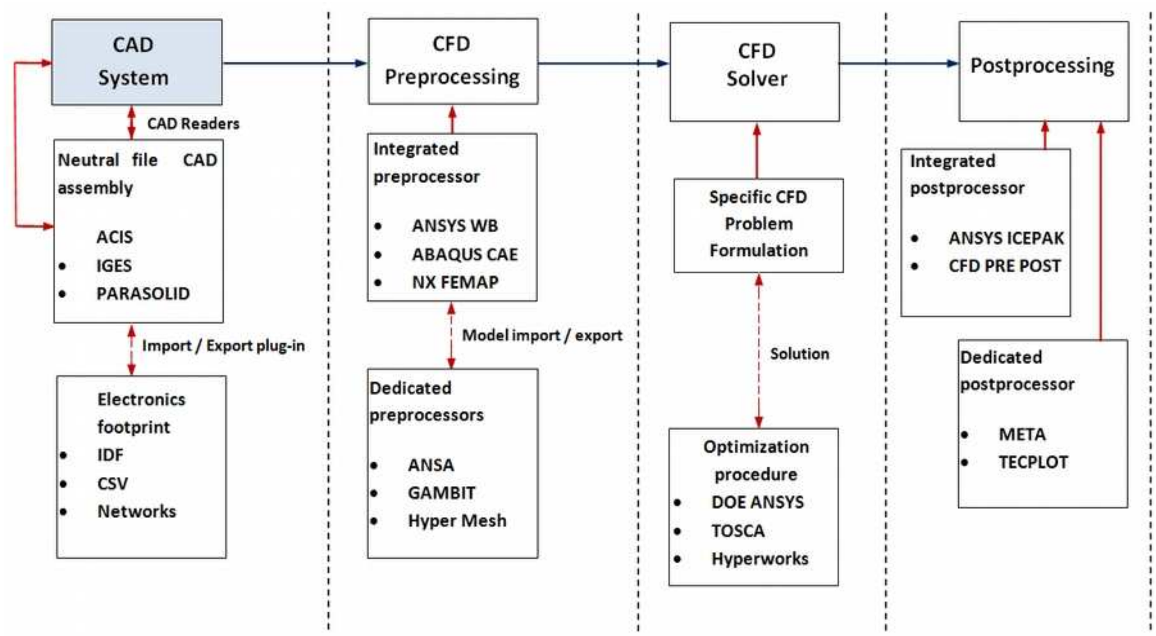

Figure 3. Expanded processing tools

The simulation takes into account the heat generated by the active MOSFET components and the film coefficient generated by the fan. The geometry consists of a test board, two heat sinks, an enclosure and a cooling fan (see Figure 4).

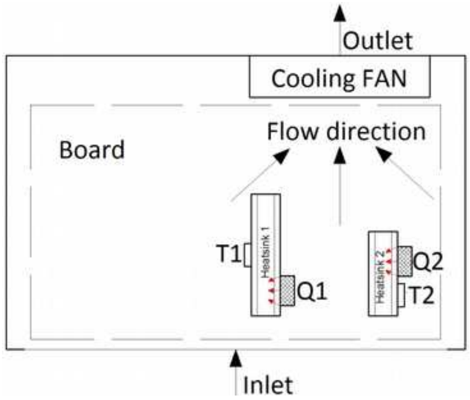

Figure 4. Experimental setup Q_1 and Q_2 - MOSFETs, T_1, T_2 - Sensors

EDA design was assured by using EAGLE Library. Both electronic footprint files and analysis input data are generated at this stage. The electronic components were selected from PROTEUS, based on the EDA footprint and exported as individual 3D CAD files. All the selected components were assembled and edited in CATIA V5 system. The setup was inspired by a common layout of an ATX switching power supply. An axis aligned box fully encloses the input body. One bounded box was created for each part. Because a coarse level of simplification was used, the converted geometry and the resulted model contained the minimum number of components.

The model was further processed in ANSYS ICEPAK. Material properties were assigned in respect with the software catalogue data. The Finite Element Model (FEM) was simplified by removing the housing, the fan and redefining them with virtual parameterized blocks. The mesh was generated using a non-conformal meshing technique with high-dominant options. Slack blocks and appropriate boundary conditions were imposed. Mesh quality was checked and improved successively.

The simulation input conditions were the EDA results of the MOFSETS power emissions. A steady-state analysis was performed. Two thermal probes were placed as validation points in the simulation, corresponding to the location of the temperature LM 35 sensors used during the experiments (see Figure 5). An external data acquisition board, combined with a MATLAB procedure were integrated for results validation.

The analogue signal from the sensors was read and the temperature evolution during time was plot, until the steady-state regime was reached (see Figure 6). A good match, with an acceptable error of ± 0.4-0.6% was achieved.

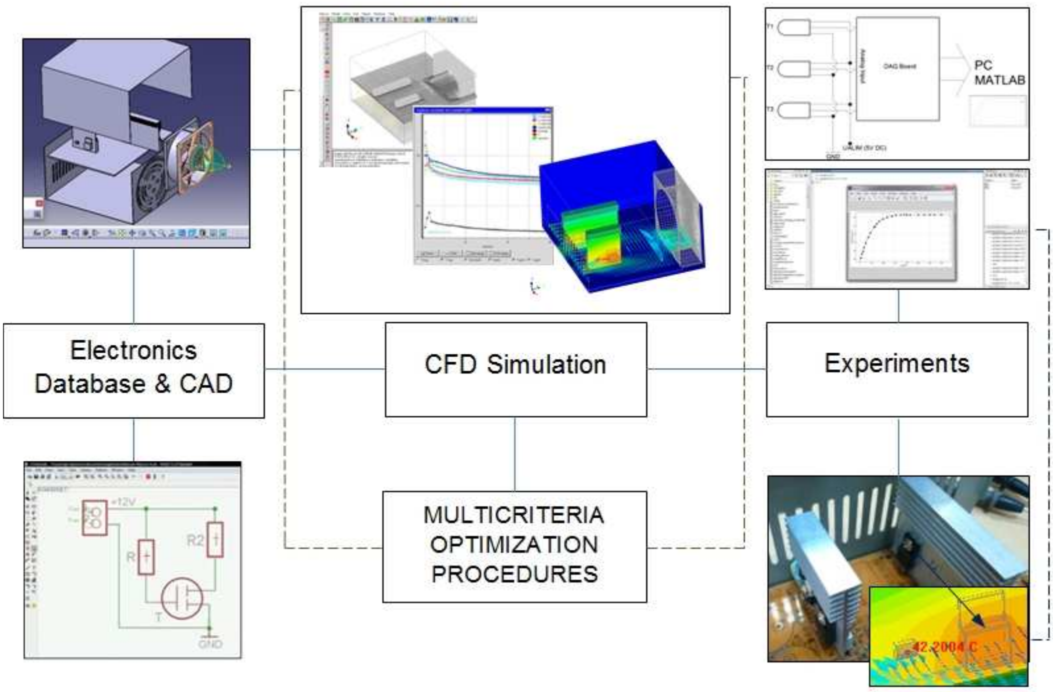

Figure 5. Virtual and experimental setup for CFD platform tests

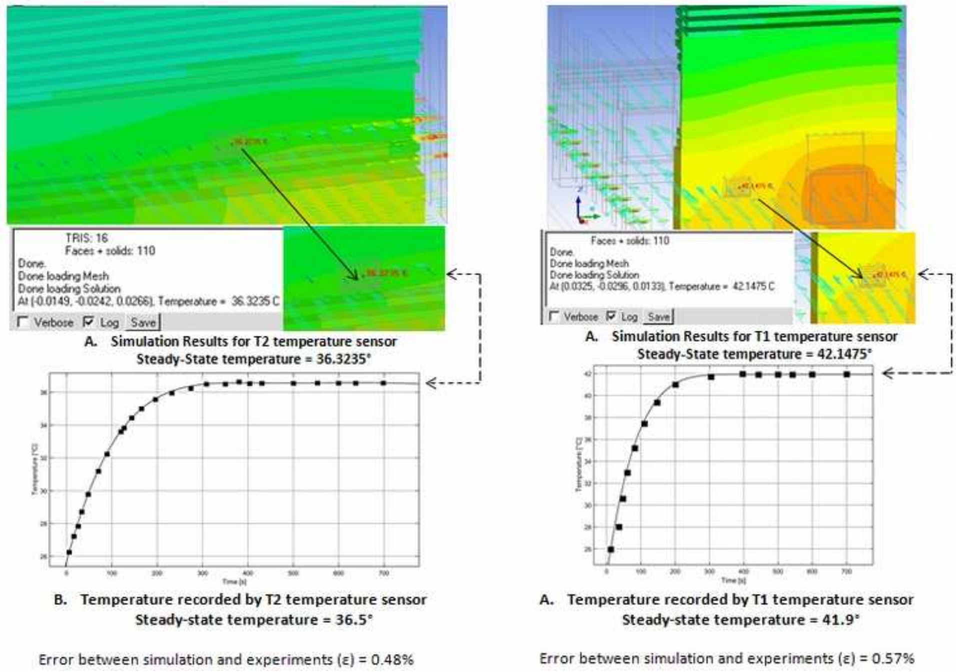

Figure 6. Validation points and comparison with the experiments

5. Conclusion

An advanced extension of ANSYS Workbench interface with both external appropriate EDA systems, libraries and data acquisition tools was proposed, providing fast and efficient model preparation stages, useful verification procedures and assuring accurate simulation results.

The proposed architecture offers multi-disciplinary tasks, such as thermal or fluid-structure interaction capabilities and is focused on packaging and reliability engineering in an easy-to use environment for electrical engineers. The solution is simple, assures a clean model transfer, without information loss and comprises processing tools according to user's preferences, not limited to a certain type of software. It avoids expensive equipment for result validation and can be further developed to include electro-magnetic tasks. A case study, proved the reliability of the platform. Optimization procedures have also been discussed. Further work will be focused on material library extension and the customization of the optimization procedure.

The present approach combines in a collaborative workflow the advantages of modern platforms, such as adaptability and flexibility for solving heat transfer simulations required both in research and in industry.

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