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DEVELOPMENT OF A COLLABORATIVE PRODUCT DEVELOPMENT TOOL FOR PLANTS DESIGN

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1 Introduction

The gas turbine plants for the industrial production of energy have been undergoing an important role in this decade, achieving, in the simple cycle configurations, efficiency values closer to the typical ones of the more efficient steam power plants. This strongly encouraged their wide application.

The plant design process is a set of complex and iterative decisional activities and analysis which involve heterogeneous “actors” with different competencies. The first design results are achieved after time-consuming analysis of thermodynamic and acoustic plant characteristics. Then, the functional solution (the plant layout and the ducts geometry) has to be verified from the structural viewpoint. If design modifications are needed, analysis processes have to be newly performed. Finally, the manufacturability analysis can imply geometric modifications which can influence structural behaviour and performance, as a consequence further process iterations are required.

This evident *seriality* of design activities leads to a remarkable waste of time causing relevant delay in plant building. On the other hand the design process, in many cases, is still based on the use of traditional tools and methodologies such as 2D CAD drawings and 2D flow analysis simulations.

On the contrary, from the early stages, the multi-disciplinary design team should be supported by tools to exploit concurrent and collaborative methods in order to manage the plant development process and the different plant views related to their own specific roles.

In this context, the paper focuses on three main goals: 1) the study and development of a design tool for the automatic configuration of the gas turbine plant design, 2) the study of a design system able to create selectively the information indispensable for the different analysis activities (structural analysis, thermodynamic analysis, acoustic analysis) and able to regenerate the plant configuration in according to the analysis results, 3) the study and development of a framework to support the concurrent design process.

The work has been carried out in collaboration with an Italian company (VGF S.p.a.) subsidiary of the General Electric group.

2 Modular product configuration

There has been a relatively recent awakening in the research community to the benefit of the modular products development process. The methods presented in literature are useful for product platform development or product families definition process. However, for the detailed configuration of a product variant, when the product model itself needs to be instanced, the current literature provides little insight.

Considerable research attention has been dedicated to the product architecture and how it can be used to support customization. An interesting classification of modular product architectures (bus, slot, sectional) can be found in Ulrich and Eppinger [1]. Many researchers point out the advantages of designing products based on platforms, also through the description of practical examples. The product platform definition, the application of re-configurable products, the product family configuration and the analysis of commonality to manage the product variety, are different aspects under investigation in the industrial and research world. According to Simpson et al. [2] a product platform can be defined as a set of parameters, features, and/or components that remain constant from product to product, within a given product family. Thus, it is a product representation from which product family members can be instanced. However, the study of the product platform has to be related to the product function definition phase, in fact, the product platform architecture can be represented as a set of functional modules that are collected to achieve a generic overall function. To satisfy the specific customer requirements (that is the specific overall function) it is necessary to construct an appropriate assembly of module instances.

The design process of a configurable product takes place in two steps: the *design for configuration* and the *configuration of the solution* [3]. Design for configuration is the process which defines the product platform. During this phase, the designer establishes functional and technological properties as well as dimensioning and assembling the rules of the basic and optional components that can be combined to form the final product. The knowledge acquired during this design phase (*configuration model knowledge*) specifies the set of possible configurations of the product. It is important to note that the detail of the geometrical information required, during this phase, is quite limited: raw shapes, bounding boxes, axis locations, etc. The *configuration of the solution* is the process that defines a specific member of the product family in order to meet the user's needs. During this phase, the domain expert must select the best solution among many options (sometimes hundreds or thousands) and he/she must immediately understand the impact that each single selection has on the final product, in terms of costs, parts compatibility, functionality, performances, marketing constraints, etc. From a practical perspective, this last step should be handled with tools that simultaneously manage the design knowledge base (design rules, functional constraints, etc.) derived from the design for configuration process, and the detailed geometrical model of the product. Research done in this field is described in literature [4], [5], [6].

From a technological point of view, to support the modular product configuration, the evolution trend of design systems has moved from geometry-based systems (Parametric/Feature-based CAD systems) towards Knowledge-Based systems, with the aim of representing not only the product itself, but also the product design process. By using a Parametric/Feature-based CAD system, the designer interacts with the system in order to define the product shape in terms of basic entities (geometric features), which can be eventually associated to a functional or technological meaning. However, these systems, that can be used to produce a geometrically detailed design solution, made by thousands of features (with related parameters), are not able to capture and store the complex reasoning that leads to the definition of that particular solution (what is still missing is *why* the designer has used those features and parameters). This lack of information makes very difficult to re-use the model because it is not easy to understand which features and/or parameters should be modified in order to generate a new and stable model variant. Conversely, Knowledge-based (KBE) and Knowledge-aided (KAE) engineering systems have a generative approach. The final shape of the product is automatically generated by the system on the basis of a predefined decisions tree model, that must include different types of knowledge able to represent the *decision process* that the designer follows during the design of such a product. Once the decision tree model has been completely defined, the KBE application allows the automatic generation, in a short time, of the different alternative configuration solutions represented by the valid paths along the decision tree model. These kinds of systems are very effective in the generation phase, but they are very limited in providing support during the definition of the decision tree model, that is the premise to use this technology. Moreover, if a valid variant has not been included into the decision tree, it will never be generated.

In this context the present work illustrates a solution developed to support the turbine gas plant configuration on the basis of the product platform definition. The research intent is to automate the configuration phase so that the designer can analyse the different possibilities in a short time. Thus, this paper shows an industrial example where the integration between theory and the practical implementation of a modular product configuration system has allowed to reach promising results.

3 Plant configuration system study

The functional analysis of numerous gas turbine plants typologies allowed to identify the modularity nature of the system, in according to the methodologies reported in Otto and Wood [7]. The extensive research work done in the field of techniques [8] and IT tools [9], also for SMEs applications, related to modular product management provided a meaningful background to approach the specific problem. In particular a product platform has been determined and it has been represented in a product model structure. A complete classification of modules and sub-modules has been produced. Five main modules have been identified (exhaust duct, inlet duct, filter chamber, turbine housing and support structure) and 38 sub-modules. Each sub-module can be instantiated in different configurations, thus, an high number of variants has to be managed.

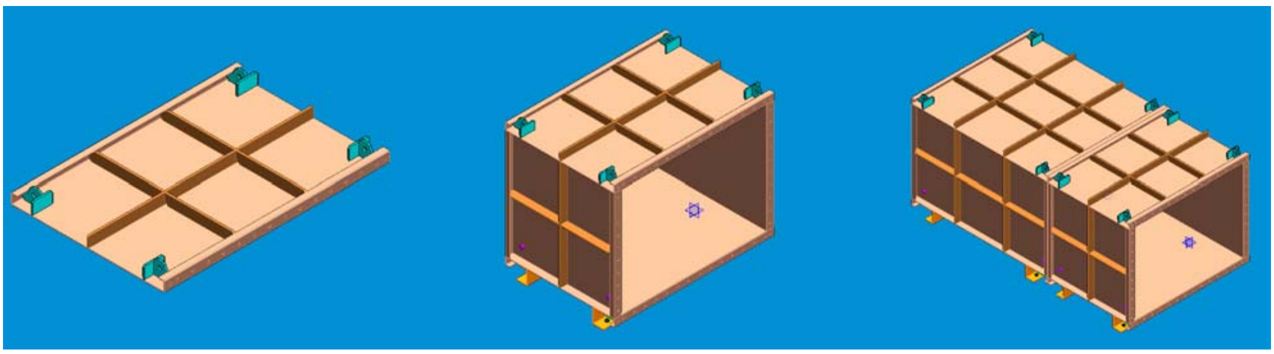

Figure 1. The basic module (single panel, at left), the basic duct of the plant (center), and a example of assembly (right).

The product platform contains all the information and rules useful for the detailed plant geometric configuration and for a selective and immediate data extraction (geometric and non-geometric), used as input for the analysis tools. In figure 1 it is highlighted the basic module. It is a panel that embodies *interfacing* functions and *internal* functions, as defined in [10], it assumes different configurations for circular ducts, curves, joints etc., but they are all based on the same functional definition. The interfacing and internal functions can be instanced in different solutions, that are guided by rules (if-then-else, dimensioning, manufacturability, …) encapsulated within the module definition.

The classification of design information, managed also by the analysis tools, in relation with the configuration of product variants, have allowed to implement suitable change propagation mechanisms. In such a way, the automatic regeneration of the instantiated product model can take place coherently with the change management constraints represented in the product model structure. In fact, plants modifications can be classified as dimensional variations, shape variations, presence or absence of a module and presence or absence of a component. A changeover is never required. Thus, the change management can be performed by an hierarchical organisation, as a tree structure, of dimensional parameters, where the first high-level nodes are independent variables. They are linked also to the analysis results. On the other hand, from the plant layout point of view, assembly rules of modules, sub-modules and single components, are managed by geometrical and topological constraints that can vary coherently with each dimensional modifications. Furthermore, as described in the next section, a two level configuration system facilitates the changes related to the presence or absence of a specific module. During the first phase the designer decides the plant layout, then, in the second phase, each single module is configured. When he/she decides to add or eliminate a module, it is sufficient to redefine the first phase and the modules accomplish themselves in according to the new layout.

This structure has been used as a base to develop a plant configuration tool (figure 2).

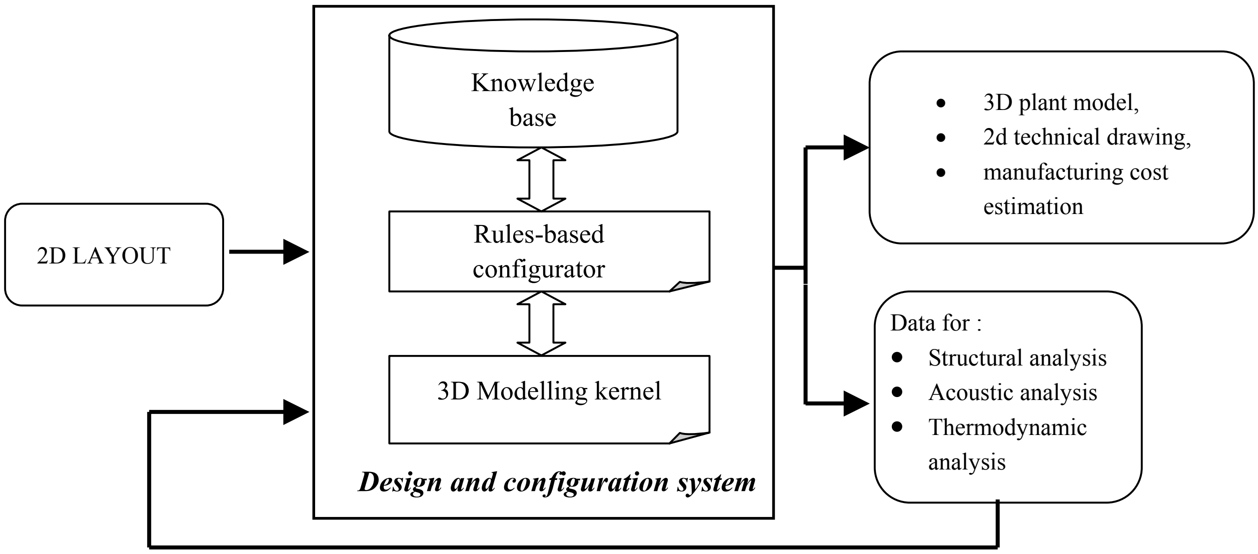

Figure 2. Information flow along the plant configuration process.

In particular a software package has been implemented to manage modules, sub-modules and related rules; it has been interfaced with a commercial 3D modelling kernel and a relational database. Users can interact with the system using a simple windows-based user interface; the result is the automatic configuration of detailed 3D CAD models, the automatic generation of technical documentation (2d drawings, bills of materials, quotations, …) and the definition of all information for the analysis tools. In the context of project, these last tools have been developed and customised to satisfy the specific partners needs and to support the complete interaction, inputs and output data, with the configuration tool. A workflow management tool assigns the tasks as the project evolves and it activates the design team for the collaborative phases (ideation and results evaluation)

4 Configuration system development

By employing a first implementation of the concurrent engineering framework developed and of the related software tools for configuration and analysis, basic goals of our industrial partner to significantly reduce product development by speeding up the time required to design individual modules and later correctly arrange them in a final detailed assembly, has been achieved. The plant configurator semi-automatically generates the plant design and it stores data in different structured representation to activate the analysis phases, which are carried out on different geographic sites.

4.1 The turbine gas plant configurator

The configuration software system has been organised in a two level structure. The first level allows to generate a three-dimensional plant layout sufficiently detailed to evaluate its impact on the installation site. But it is useful also for preliminary acoustic and fluid dynamics analysis, in fact the dedicated analysis tools can use data deriving from simplified 3D models to perform simulations. The second level inherits the layout data and allows to compute the detailed design three-dimensional models. In the following figure the configuration system architecture is reported.

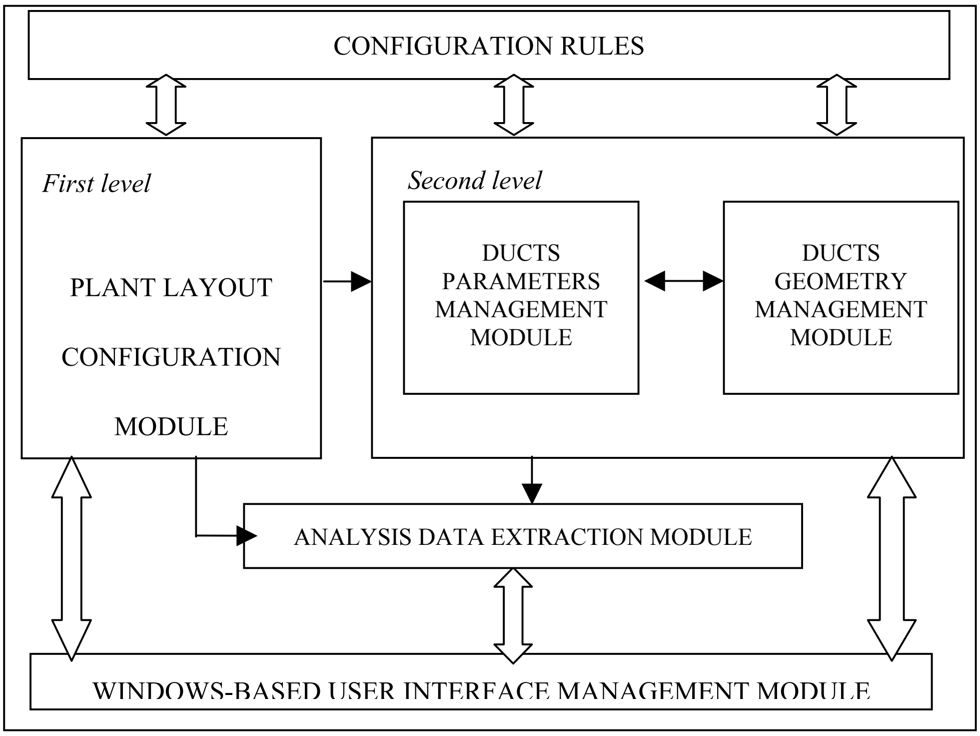

Figure 3. Configuration system architecture.

The configuration system has been implemented using Visual C++, as programming language to develop the different modules. The 3D modelling has been made thanks to a geometric kernel of a commercial software system, while database have been developed using Access by Microsoft.

In figure 4 the first window of the user interface is reported. In the upper part of window the designer can add, delete and define the modules order and their dimensions; some modules require additional information as insulation thickness and/or silencers number. This information derives from the customer needs. Such data are sufficient to generate a first 3D layout and the information for acoustic and thermodynamics analysis. Command buttons, on the left part of window, allow to generate suitable text files (see figure 9). When the layout is established, the designer can adopt two modelling strategies he/she can generate each single module/duct separately ("*Generate selected item*" button) or generate the complete plant assembly ("*Duct assembly*" button). In both cases the software proposes further interfaces to input the necessary data.

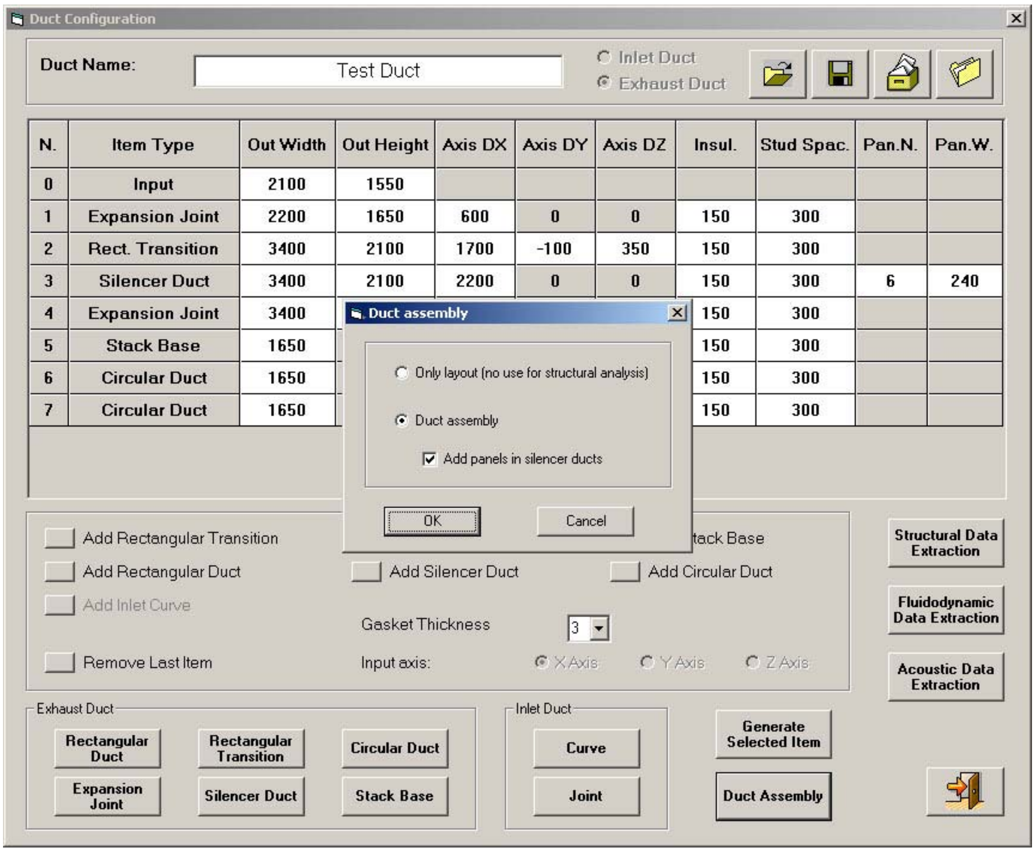

Figure 4. User interface of the software tool for the automatic plant configuration.

Each module is characterised by the same user interface, in figure 5 we report the "*transition generation*" window. The commands order suggests to the user the right operations to be performed. The designer can choose, in according to the principle of maximum system flexibility, to generate a part of duct or the whole duct, and he/she can hide parts not considered relevant in the specific design phase.

Returning to the main window the data for structural analysis can be rapidly extracted and exported in the more appropriate exchange format.

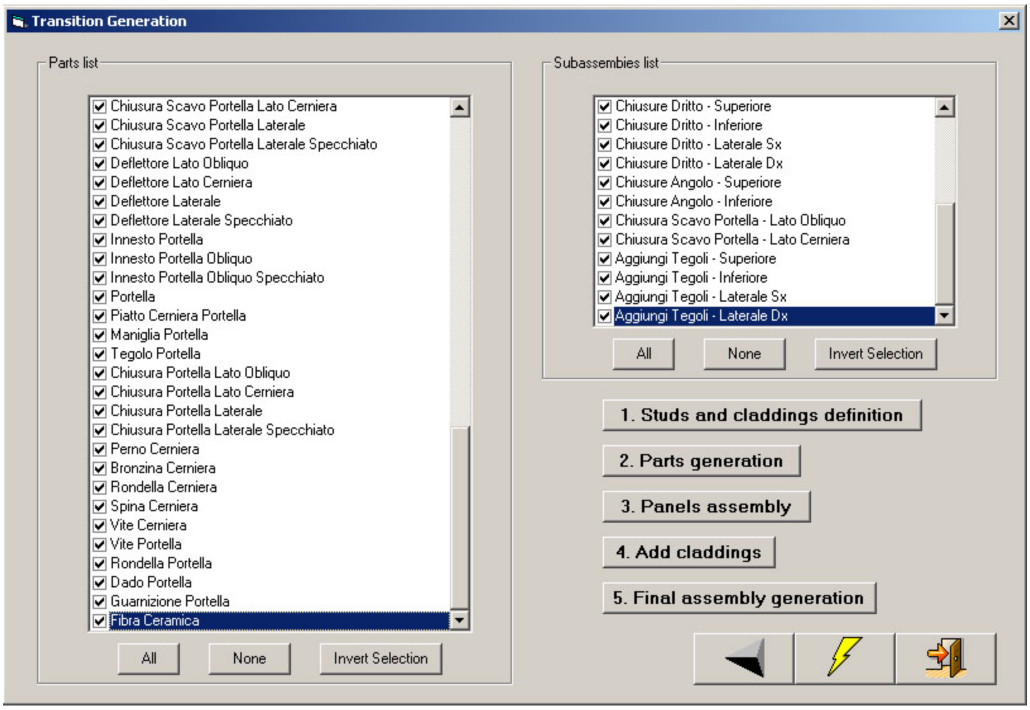

Figure 5. User interface to manage the parts geometric generation

4.2 Concurrent engineering tool

For improving the collaborative design, since as the design team is located geographically on different sites, we are working on a distributed system architecture [11] for sharing the design tools and the product knowledge base.

Currently, different users can access to a dedicated web site where all information (3D VRML models, analysis results, technical drawings ….) is stored. Furthermore, since data useful for the required analysis are properly structured, engineers can download such data and upload their results. In fact, by the web-based framework a workflow tool readily provides data to all members of the design team, which can perform simultaneously their activities. The rules that guide the product model reconfiguration retrieve the new values of technical parameters, such rules also check and assure the geometrical coherence of proposed modifications due to the different inputs.

The workflow management system involve the design team to evaluate and approve the new solution. A web-conference tool supports the interactive discussions on new plant design solutions.

5 Test case and results

The configuration and the concurrent engineering tools have been tested on different plant design processes, considering different plants architectures (horizontal and vertical). The product variability has been completely managed by the configuration tool. A couple of example are reported in the following figures.

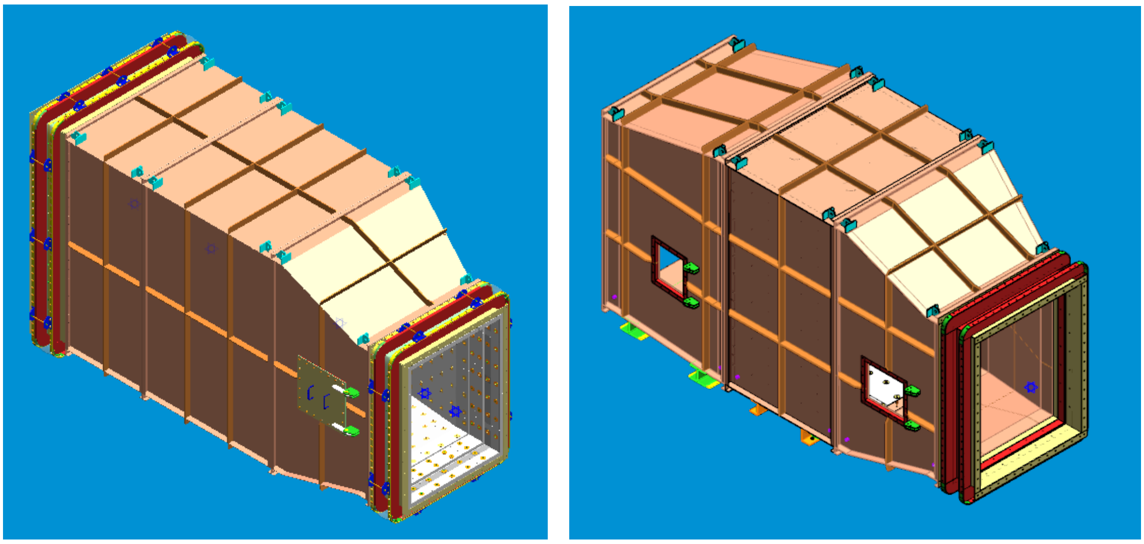

Figure 6. Two different configurations of three sub-modules of the exhaust duct module

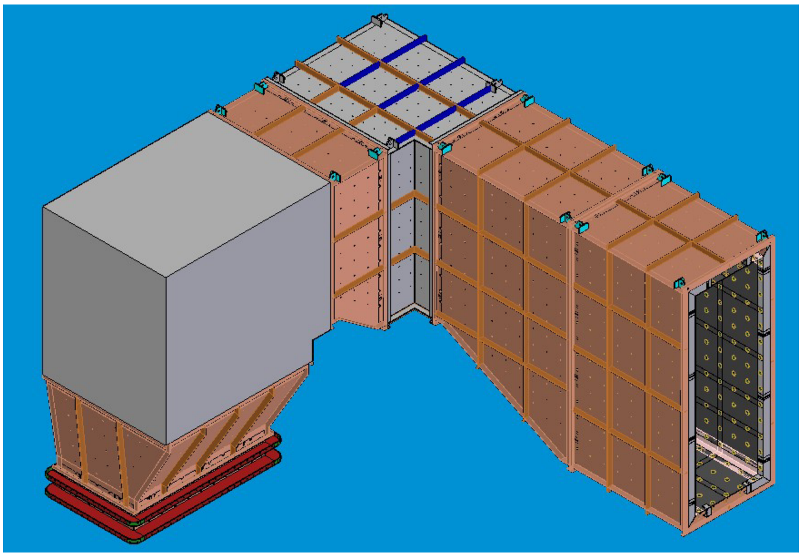

Figure 7. An example of a complete instantiation of the exhaust duct module

The time required for the configuration of an exhaust duct characterised by 5000 components, as in figure 7, resulted in 35 minutes, using a common graphic workstation.

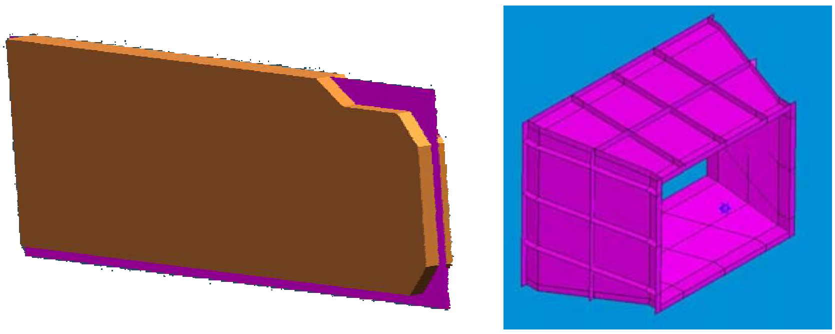

Figure 8. An example of automatic data generation for the structural analysis tasks: the surface model is linked to the solid model, in this way it remains coherent for each design modifications.

In order to provide the product representation useful for the structural analysis a model simplification has been realised. We premise that this product typology is not suitable for meshing with tetrahedral elements. Planar elements known like *shells* must be preferred. Thus, the volumetric geometry as represented by the solid modeller has been reduced in surfaces. The 3D model of geometry considered meaningful for the structural analysis (panels, reinforcements, …) has been enriched with parametric surfaces completely managed by the same rules of component configuration (figure 8, left). Further rules have been added to support the automatic meshing operations facilitating the mesh nodes overlapping, in fact it is evident in figure 8 the surface overextension if compared with the related solid model. The duct can be exported in such simplified representation and used for structural verifications. When the analysis has been performed (a dedicated verification system has been developed using a FEA commercial software, Ansys by …..) numeric values to set the configuration parameters are returned (for example panel thickness, number of reinforcements, inter axis between reinforcements, reinforcement dimensions, …)

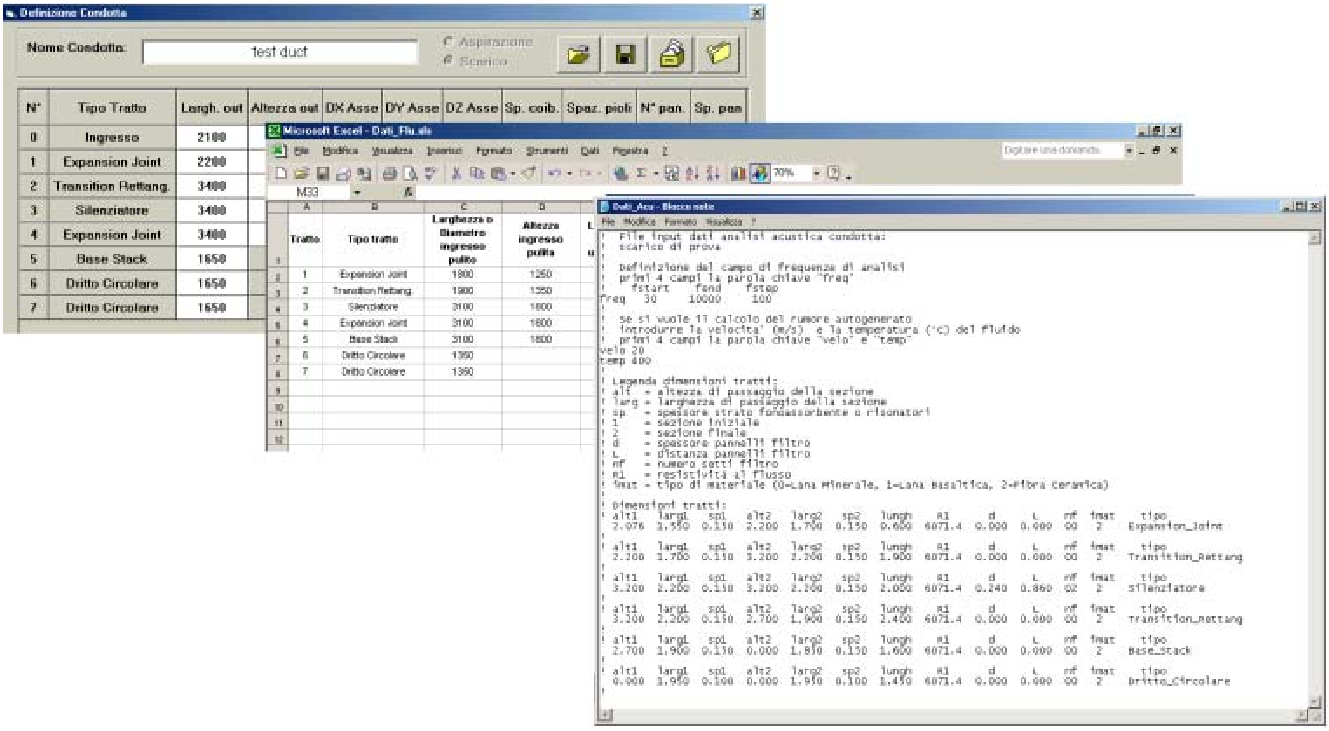

Figure 9. An example of data extraction to perform the thermodynamic and acoustic analysis. The text file contains the structured information to be used as inputs in dedicated analysis tools.

6 Conclusions

We have here presented a practical industrial application for configuring modular products in the case of turbine gas plants. The methods and tools developed confirm that theories about product modularization and configuration management can successfully provide optimal strategies for shortening time to market and cost. For the specific test case, we noted that the product development time has been largely reduced. The traditional design process, for an average duct complexity, needed of 80 man-hours; the new system achieves the sam results involving 15 man-hours. In fact the user interaction is required only in the plant ideation phase, in the data input phase and in the final result evaluation, concentrating the efforts towards the more knowledge-intensive activities. Along the modeling and analysis phases, only particular cases require the designer interactive decisions.

On the other hand, the low cost software technology used have shown an appreciable robustness, highlighting the possibility of implementing similar solutions in numerous other productive fields

By developing new customized tools dedicated to the specific analysis allowed to reach a full automate of those tasks. In fact, such tools have been conceived to retrieve automatically the information generated during the plant configuration stage, as structured by the configuration tool, and they perform automatically the calculations providing usable results and formatted data for plant reconfiguration.

Finally, the easy plant configuration carries out also an indirect advantage, in fact it allows to realize an high number of optimization analysis so that a better solution from the environmental and performance viewpoints can be achieved.

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