A Digital Pattern Approach to 3D CAD Modelling of Automotive Car Door Assembly by Using Directed Graphs

S. Patalano, F. Vitolo and A. Lanzotti

Abstract The present paper deals with methods for product development aimed to support designing activities and to re-use company know-how. The work is addressed to complex products i.e. products characterized by several components and dependencies among them. Then, the paper presents both the methodological approach and the application to the 3D CAD modelling of an automotive car door assembly. The work uses directed graphs and a series of algorithms to provide a Graphical User Interface (GUI) able to support a designer by reducing the development time of new car door assemblies and increasing the accuracy of the design activities. According to a digital pattern approach, the GUI is used to determine the set of changes to 3D CAD models that typically occur in the automotive field, during the development of new car door assemblies.

Keywords Digital pattern for product development · CAD modelling · Directed graphs · Automotive car door design and development

1 Introduction

In the automotive and railway field, advanced methods for 3D CAD modeling increasingly concern the development of complex products i.e. products characterized by several components and dependencies among them. A *top-down* approach to CAD modelling is a useful way to deal with the designing of complex products. In fact, such an approach provides criteria for breakdown structure by identifying less complex and independent sub-assemblies as to define the datum features necessary for product development [1].

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Several researchers worked on a top-down approach to designing and modelling. Chen et al. [2] developed a multi-level assembly model that is useful to capture information and define dependencies in different levels of the decomposition. The way to integrate a *top-down* approach to designing methods was also tackled in [3], with a particular reference to subsidiary industries. A top-down approach could also be applied to easily control the degree of approximation of dimensional and geometrical modeling of turbomachinery rotor [4].

Some CAD-CAE environments provide tools to explore and manage component relations but often this task is time consuming due to the high number of components, features and related dependencies. Furthermore, some tools available in commercial CAD-CAE environments allow a simple visualization of existing dependencies providing file part names. In some cases, a graph representation is also used but no tools are available for the designer to address existing dependencies between selected components or features. In such a context, graph theory [5] and related algorithms [6] can be used to accomplish the interactive search of dependencies.

Some works in literature are aimed to integrate tools based on graph representation within CAD systems. In [7] a tool for a quick checking of tolerance specifications, directly assigned to a CAD model of an assembly, were proposed. In particular, graphs provide the right abstraction from the CAD model while preserving the accuracy of the dependencies and the interconnections between features. Lockett and Guenov [8] present an approach based on graphs for a module integrated in a CAD system and aimed to feature recognition, addressed to molded parts. In [9], a designing approach based on graph theory and a related *Graphical User Interface* (GUI), are presented. In particular, the approach allows the management of company know-how according to a *Knowledge Based Engineering* (KBE) point of view and provides an easy-to use graphical interface based on directed graphs for the designing of automotive gearboxes.

The challenge of reducing designing time for new mechanical assemblies, especially in the context of large companies, encourages the use of methods and tools aimed to support designing activities and to re-use company know-how. Furthermore, the design choices must be rapidly checked to avoid errors that could cause delay or expensive re-designing. Therefore, some large companies, operating within automotive and railway fields, have deepened the tools and methods to accomplish "digital patterns for product development" viz. geometrical data and models, to be reconfigured and re-used in different but similar design activities [10, 11]. These patterns are generally supported by a series of tools, as for example, "quality and standard checkers", "predictive engineering wizards" and "cost advisors" that are part of a decision support system. Graph representations and a related algorithm could act as a part of such a decision support system.

The present paper tackles the methods of re-using company know-how, related to the development of automotive car-body assemblies. The paper proposes a method based on graphs to integrate company knowledge into 3D CAD models, by means of an approach to Digital Pattern (DP) for product development.

The paper is arranged as follows. Section 2 presents the DP approach to 3D CAD modelling and the role of the analysis based on graph representation; Sect. 3 provides the application to the case of an automotive car door assembly; Sect. 4 draws the Conclusions.

2 The Digital Pattern Approach to 3D CAD Modelling

The Digital Pattern (DP) approach aims to develop models, to be reconfigured and re-used in similar designing tasks. Therefore, the DP models are geometrical and numerical models, preconfigured and parametrical, able to be adapted according to the constraints of a new designing task. Then, the designer, by means of DP models, reduces the development time of new complex products and increases the accuracy of the results as the tools of a decision support system determine and suggest to the user. Specific models, international standards and company rules are used to develop such tools.

Figure 1 depicts the DP approach. In particular, the exchange of contents between *parametrical CAD models* and the *tools of the decision support system* is cyclic as it deals with the continuous development of each updated CAD model aimed to fulfill the complex product requirements.

The cyclic relationship between *parametrical CAD models* and *the tools of the decision support system* has to bring within the product/process development both the set of constraints coming from the adoption of a specific manufacturing process as well as the results of simulations performed on preliminary models i.e. design archetypes. The CAD models of a complex product, that are continuously updated, use a directed graph or *digraph* called Design Digraph (DD) as the cornerstone for

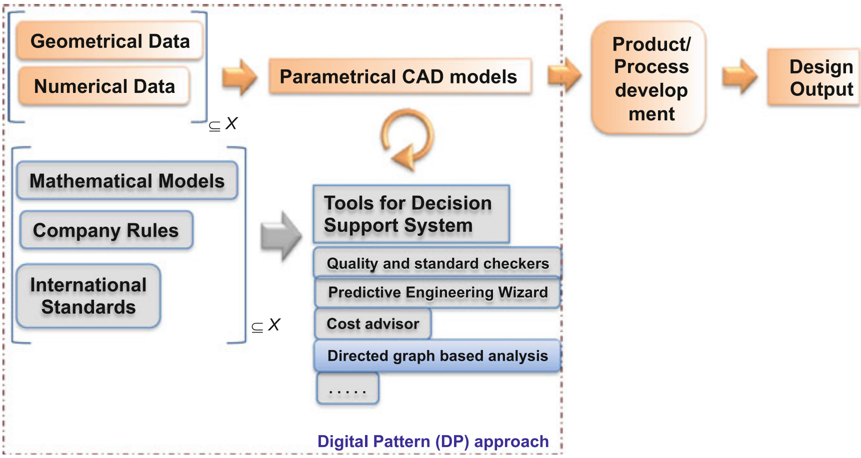

Fig. 1 Contents and operational flow of the DP approach for product/process development

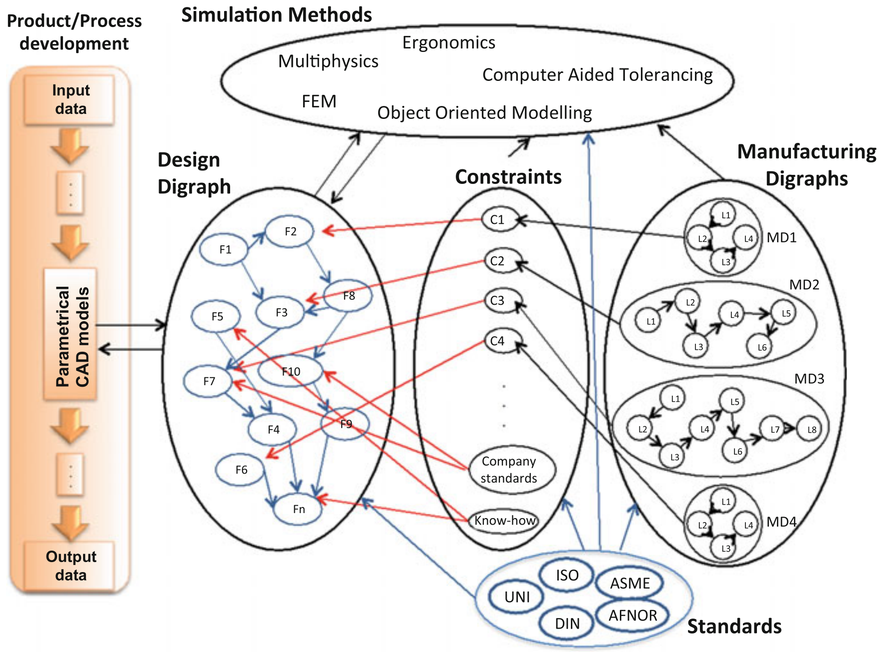

Fig. 2 Map of links existing among DD, alternative manufacturing digraphs, constraints, standards and simulation methods

the exchange process of designing information. Figure 2 shows the links between DD, alternative Manufacturing Digraphs, Constraints, Standards and Simulation Methods.

The designing activities that have to be performed on parametrical models induce use of datum and a top-down approach as key factors for 3D CAD modelling. Designing activities, in fact, need to explore and control the consequences of a series of changes to parametrical CAD models to accomplish new and updated releases of such models, assuring the fulfillment of standards, manufacturing constraints and costs. Therefore, primary datum are usually imported as source nodes within the DD.

3 The DP of an Automotive Car Door Assembly

The DP approach was applied to the development of an automotive car door. In particular, the present Section deals with the 3D CAD modelling activities performed to accomplish the development of the automotive car door assembly. We considered a reference car door model containing the set of primary characteristics that are common to all car door assemblies. The reference car door model is

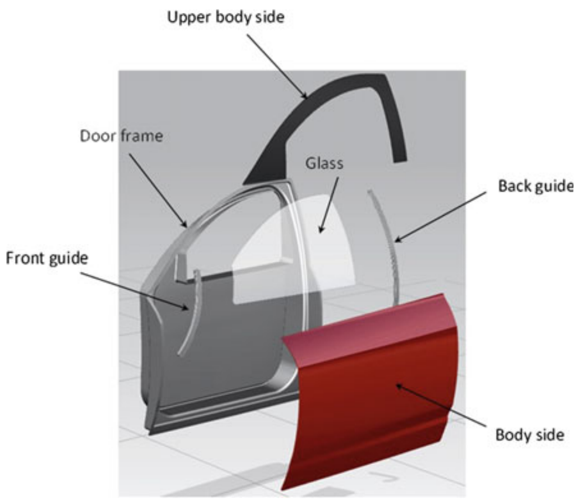

Fig. 3 Exploded model of the car door assembly used as reference

characterized by a set of parts (as depicted in Fig. 3): door frame; front and back guide; glass; body side and upper body side. Therefore, a preliminary functional decomposition could be used to address all car door parts and related assembling relationships between them.

Figure 4 shows the functional decomposition of the car door assembly by using a tree representation. In particular three levels are depicted: the first is related to the

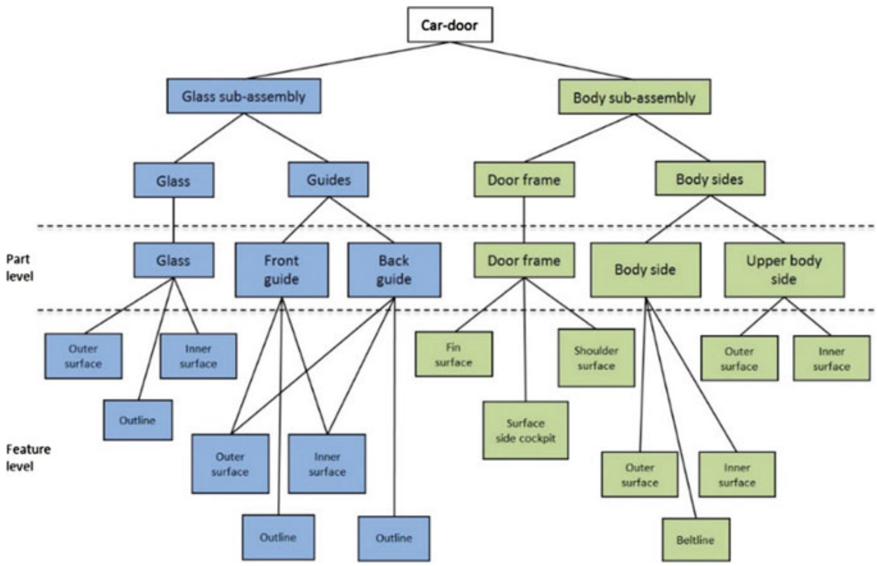

Fig. 4 Tree representation of the car door assembly

main assembly and sub-assemblies; the second is related to the part level and, finally, the third is related to the feature level.

Furthermore, the functional decomposition enables the development of graph representation related to relationships that exist among components (called *part level*) and among features (called *feature level*). Besides, also the related geometrical references i.e. datum could be represented by means of the same digraph (DD), as well as a set of significant parameters (such as glass thickness and body side thickness) addressed according to manufacturing constraints, as depicted in Fig. 5.

The nodes represent features and geometrical parameters characterizing the assembly, while directed edges represent geometrical and functional dependencies among features and parameters.

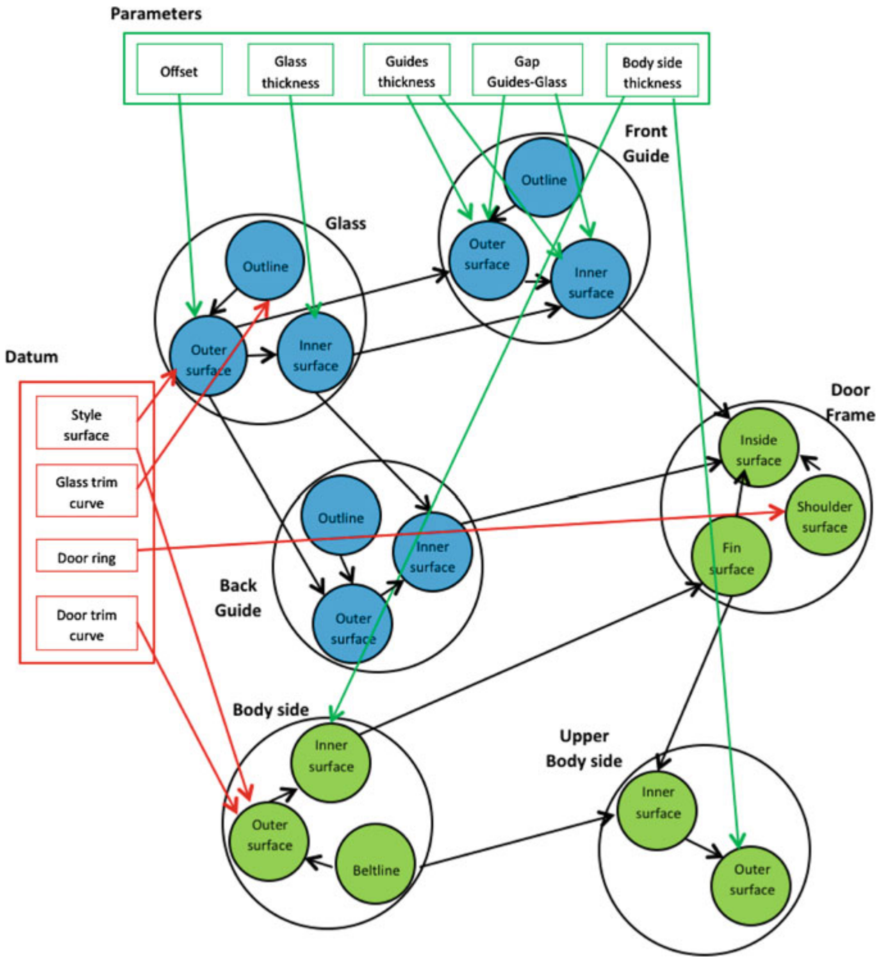

Fig. 5 Car door design digraph

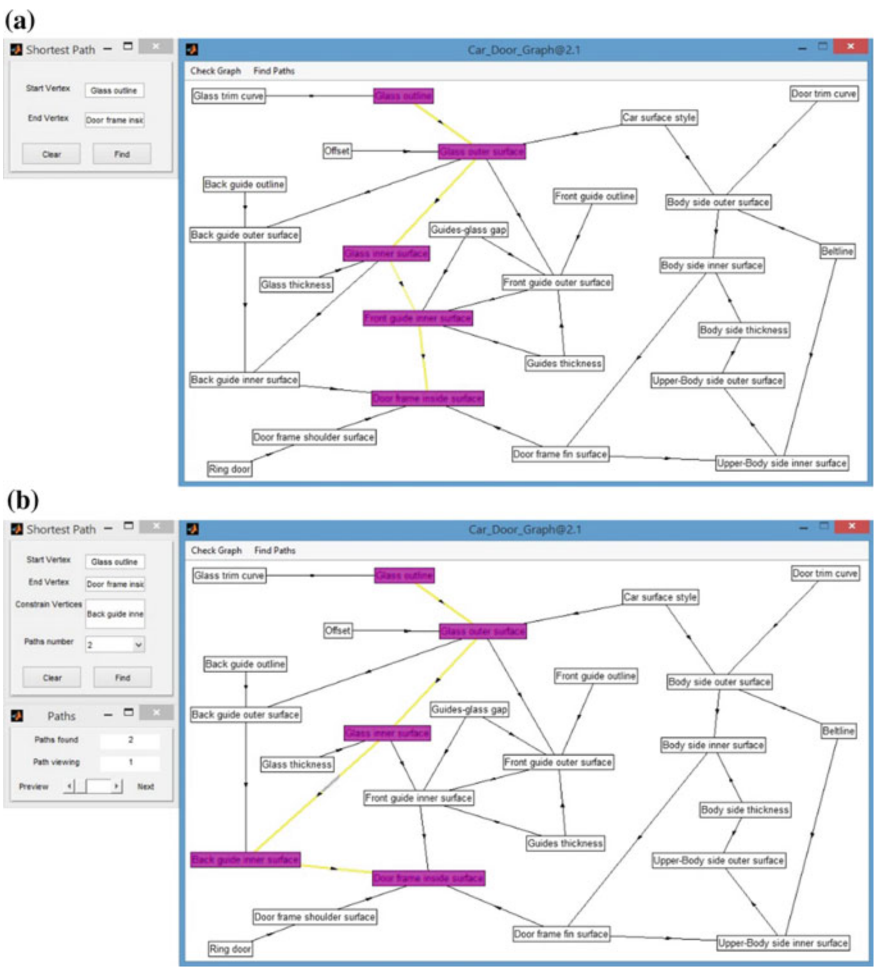

Fig. 6 GUI operating for: **a** the shortest path between two nodes; **b** the shortest path between two nodes through a constraint node

To accomplish the generation of DD and to analyze dependencies between nodes, a *graphical user interface* (GUI) was developed (Fig. 6). In particular the GUI, developed within a MATLAB environment, is able to support the designer by means of a series of algorithms. The algorithms implemented within the interface are the following:

1. The *algorithm for the shortest path* by Dijkstra [6]; the algorithm finds the shortest path by selecting two existing nodes within the DD.
2. The *algorithm for ordered paths*: the algorithm finds and sorts out in ascending order all possible paths between two selected nodes (an example of use of such algorithm is depicted in Fig. 6a).

3. The *algorithm for ordered and constrained paths*; the algorithm finds and sorts out in ascending order all possible paths, between two selected nodes, that fulfill one or more selected nodes as constraint (an example of use of such algorithm is depicted in Fig. 6b).
4. The *algorithm for the shortest path to a source node*; the algorithm finds the shortest path from a selected node to a selected source (or independent) node.
5. The *algorithm for the shortest path to source nodes*; the algorithm finds the shortest path from a selected node to every source (or independent) nodes.

The implemented algorithms, operating with matrixes associated to graphs, actually do not take into account cost functions for assembly operations as the present work tackles the impact of geometrical changes due to redesigning tasks and occurring during development processes. Typical and frequent "evolutionary" processes in automotive design, in fact, consider the same assembling operations to avoid expensive changes of equipment but needs for a long series of interventions due to changes, for example, to style surfaces, glass trim curves, door rings and door trim curves. Characteristics of assembly operations, such as times and task complexity, could be introduced and managed by algorithms in order to take into account special constraints rising within the development of innovative assembling operations.

The implemented algorithms make designers able to address the right sequence of intervention to CAD model of car door assembly. Thanks to the implemented GUI, the analysis does not depend by the complexity i.e. by the number of components of the assembly.

The GUI was used to perform a set of changes to parametric CAD model of car door assembly, according to a Digital Pattern approach, by assuring the fulfillment of all design constraints. The changes to parametric CAD model of car door assembly fit some typical needs that in the automotive field occur. In particular the changes deal with (Fig. 7): the updating of glass and slot thickness; the updating of door ring; the updating of door trim curve and glass trim curve.

3.1 Discussion

Several aspects could be pointed out taking into account the car door assembly used as reference.

Characteristics of 3D modelling: to introduce a DP approach to 3D CAD modelling the use of a top-down approach is mandatory. Only the use of a top-down approach could assure the correct propagation of changes between features.

Application of changes to parametric models: the changes imposed to parametric CAD models are automatically accomplished.

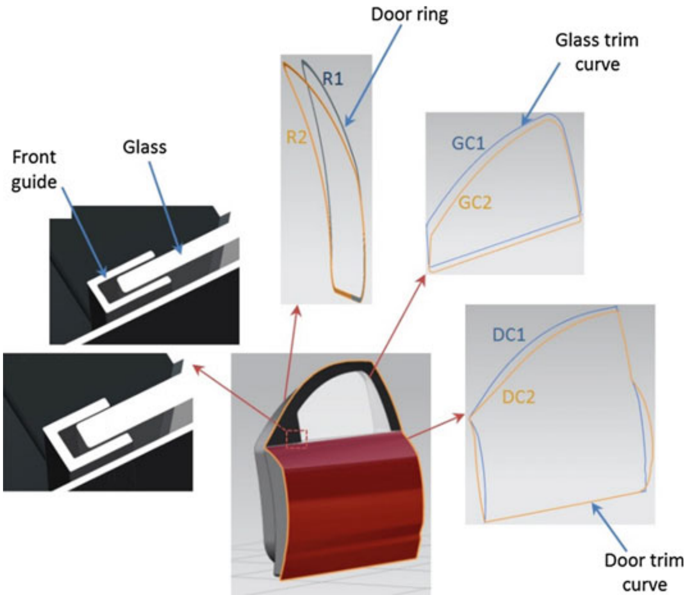

Fig. 7 **a** Increasing of glass and guide thickness; **b** updating of door ring; **c** updating of glass trim curve; **d** updating of door trim curve

GUI efficiency: GUI makes the designer able to quickly explore dependencies among different product features and, therefore, enhances the operations related to the updating of CAD models; the developed GUI demonstrates good efficiency, as the analysis of dependencies is independent by the complexity of assembly. The more complex is the assembly, the more useful is the developed GUI.

Enhancements due to graph representation: the graph representation allows pointing out the dependencies between parts or assembly features and related constraints coming from standards and manufacturing processes. Therefore, company knowledge could be continuously and easily added to graph representation and, then, to CAD models. This aspect has strategic meaning for large companies engaged in a continuous improvement of product development processes.

Increasing of assembly CAD models: the use of graphs allows the iterative increasing of CAD features to take into account further details of car door assemblies. The increasing of assembly CAD features is essential to guarantee the re-use of car door DD for the development of new releases of car doors, frequently occurring with automotive industries.

Graph generation: actually, input data of GUI are provided as arcs list, while the graph generation is automatic.

4 Conclusions

The paper presents a digital pattern approach, based on graphs, to 3D CAD modelling of automotive car door assembly. In particular, the approach proposes a directed graph based analysis as a part of a decision support system and the use of a top-down modeling to accomplish the successive steps of designing activities for product development. Therefore, the contribution of the present study is an approach to accomplish the development of CAD modelling for car door assemblies, dealing with several features and dependencies, to overcome the actual limits of tools implemented in commercial CAD software. These tools, in fact, allow only the one-by-one inspection of existing relations between features and therefore they cause time consuming tasks when features and related dependencies increase.

A GUI, implementing a set of sorting algorithms, was accomplished to support the designer during the analysis of dependencies between parts and features. The implemented GUI was tested on the case of a car door assembly, used as reference, to explore all existing dependencies among different parts and features, and to easily operate changes, in an automatic way, to CAD models. The GUI is now not embedded in any commercial CAD system to assure a wide use; on the other side the definition of arcs list needs for time and expert users. The efforts due to generate the directed graph are compensated by the possibility to use the same graph for different projects i.e. different releases of the car door assembly. Further developments deal with the GUI implementation as an add-on in a specific CAD environment. In such a way, it will be possible to directly import the dependencies coming from geometrical features and, finally, edit by means of an arcs list the dependencies due to standards and manufacturing constraints.

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