

Development of CAD Tool for Layout with 2D-3D Interactive Functionality

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ABSTRACT

In the process of designing industrial products, it is important to be able to review designs while referring simultaneously to 2D and 3D forms, and to be able to mutually reflect the results of these reviews in both 2D and 3D, in particular during layout work when the shapes of parts are formulated before specifications have been established. Functionality helping to enable these procedures to be conducted efficiently is demanded of the design tool, computer-aided design (CAD). Based on design procedures and the concrete methods employed in them, the operations that can be considered as necessary in CAD were outlined with a focus on the relationship between operations in 2D and 3D. A concept and functional requirements were formulated for new functions enabling these operations to be conducted, and these functions were realized as standard CATIA V5 functions. The use of these new functions, combining layout functions and 2D-3D association functions, has increased the efficiency of the design process from the concept stage to the layout stage.

1. Introduction

With recent marked advances in computer performance, 3D models have come to be widely used in the design and manufacture of large-scale assemblies such as automobiles and motorcycles. 3D CAD systems can be seen as playing an increasingly important role in enhancing the efficiency of the design process, a key factor in the competitiveness of product development.

3D CAD advanced significantly with the introduction of the concept of feature-based parametric modeling. Parametric modeling is a method that treats not only completed forms, but also incorporates conditions that produce and constrain the forms (not limited to dimensions, but also including dimensionless numbers and non-numerical conditions such as design intentions). Responses to various design changes are affected by varying these conditions. "Feature-based" means that, rather than editing forms using topological units such as edges and faces, 3D forms able to be categorized semantically, such as bosses and ribs, are treated as individual units. Saving these units as a history in the order of their generation increases workability when forms are modified. The use of these technologies in 3D CAD has helped to enable design intentions, expertise, data employed in the production process and other elements to

be incorporated in CAD models. In addition, the automatic reconstruction of forms when the design is modified, based on the saved constraint conditions, has reduced the man-hours necessary for the modeling of 3D forms. However, in many cases whether or not these technologies will be used efficiently is affected by the level to which the 3D modeling procedures developed by the user have anticipated design modifications. In addition, the challenge of determining suitable 3D modeling procedures concurrently with design work represents an issue in terms of increasing the efficiency of design using the technologies⁽¹⁾.

Honda employs CATIA as its core CAD system. In order to achieve further front-loading of product development and a higher level of workflow integration by means of the use of 3D data, the company has made the transition from Version 4 ("V4" below) to Version 5 ("V5" below), and has worked to formulate high-efficiency 3D design methods using the feature-based parametric modeling functions in V5.

As these efforts proceeded, it was recognized that V5 displayed insufficient functionality to help enable the efficient operationalization of methods in which 3D spaces where the forms of parts were expressed and 2D spaces where cross-sectional forms and projected forms were expressed to be referred to simultaneously without mutual

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contradiction. This represented an issue in terms of increasing the efficiency of product design using V5.

This paper will first describe the design work involved in product development. It will then consider the necessary CAD procedures for each of the processes conducted during conceptual design and layout, when the forms of parts are shaped prior to the determination of specifications. Following this, the paper will introduce the concepts of the new functions projected as being necessary to conducting these procedures efficiently, and the developed functions themselves.

2. Status of Product Design and CAD Work

To provide an example of procedure, this section will describe the design work and the specific CAD procedures involved in a body-in-white development.

2.1. Main Product Design Procedures

Considered in sequence from the commencement of the development process, design procedures can be divided into conceptual design and layout.

Conceptual design involves collecting the data that forms the precondition for the conceptual design, outlining the demands for the design based on this data, and establishing a plan that will help enable their realization. The data that forms the precondition for the conceptual design includes styling sketches, clay model measurement data, packaging, parts from previous models, and new technologies to be introduced. The conceptual design process results in the formulation of diagrams that provide a visual representation of the structure and arrangement of parts, and rough definitions of forms in representative planes of projections and cross-sections. As an example of an outcome of the conceptual design process, Fig. 1 shows a diagram of the parts structure for a tailgate.

In the layout process, positionings and forms of various part which become a standard for the parts are

examined (termed “layout” below), helping to enable the results of the conceptual design process to satisfy various requirements. The form of the product is then determined based on the layouts. The first part of the process is sometimes termed the rough layout, and the second part the detail layout. The various requirements cover a broad range, taking in clearance between parts and with tools, and production considerations such as formability, assemblability, cost, weight, and laws and regulations. The necessary data includes design data, the results of reviews of the conceptual design, and the rough layout of peripheral parts. Figure 2(a) shows an example of a cross-section of the hinge section of a tailgate at the rough layout stage, and Fig. 2(b) shows an example of the formulation of an internal tailgate frame at the detail layout stage.

The process of determining the layout involves a repeated sequence of establishing temporary settings for the form definitions (“temporary settings” below), verifying whether or not the provisional form fulfills the various requirements (“verification” below), and reflecting

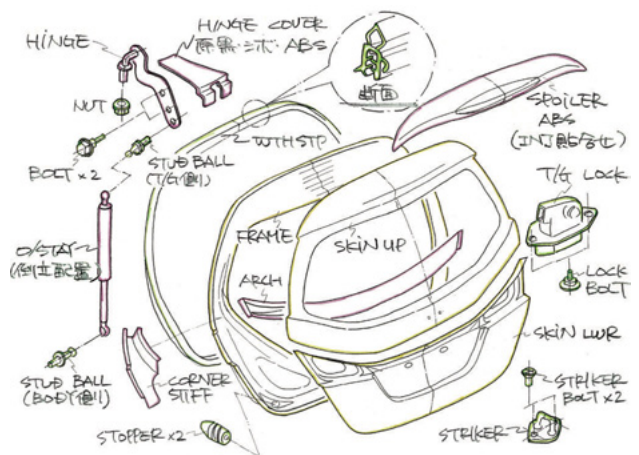
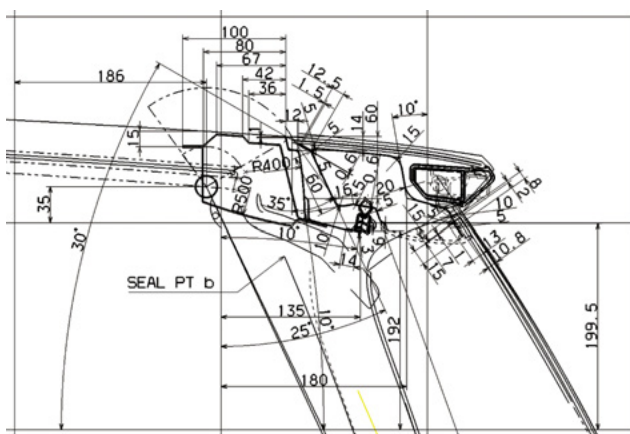
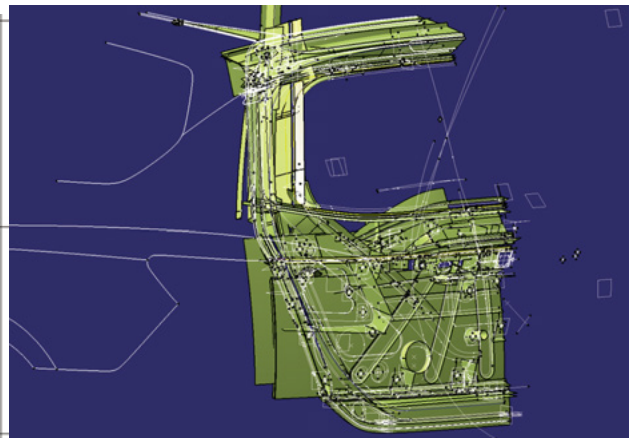


Fig. 1 Concept of parts structure



(a) Rough layout (hinge section)



(b) Detail layout (frame)

Fig. 2 Layout

the results of the verification in the temporary settings. Depending on the circumstances, this repeated process may be conducted simultaneously at multiple sites of a part, or may involve multiple proposals at a single site of a part.

At the layout stage, it is frequently necessary to respond to modifications of design data or the rough layout of peripheral parts, and to redefine forms in order to fulfill the necessary requirements. Designers should seek to determine the optimum layout and create the forms of parts under conditions in which frequent changes are made by themselves and others, and time is limited.

Because of this, it is important that designers be able to rapidly examine the parts they are working on in response to changes in their own situation or changes around them, revise the temporary settings, and conduct another verification.

2.2. Operations in 2D and 3D and their Association

This section will discuss specific methods of examination and CAD operations used in the design procedures described in Section 2.1.

2.2.1. Conceptual design

The main process at the conceptual design stage is the examination of forms in terms of representative planes of projections and cross-sections. During this process, it is important for designers to overlay 2D rough form definitions and 3D forms for previous model data and peripheral parts, and to refer to these while examining their own part. By this means they are able to recognize at an early stage the necessity for adjustments in relation to peripheral parts, and to formulate proposals for form definitions based on the existing expertise. Figure 3 shows an example of the process of overlay with parts designed by other designers. In this case, a layout of the

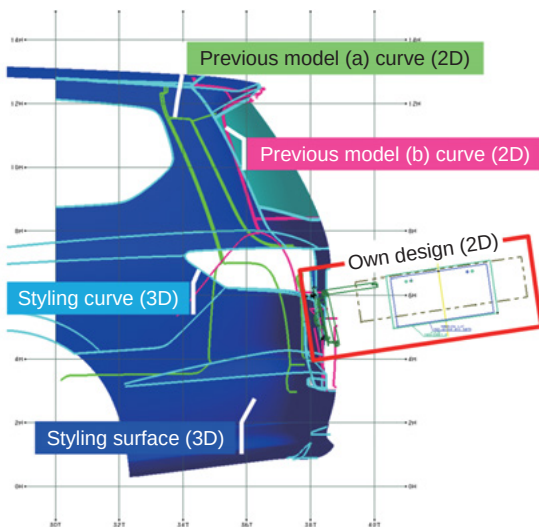


Fig. 3 Overlay

designer's own license plate part was examined, with overlays of 2D forms of the previous model and the 3D forms of the exterior design.

The inclusion of dimensions, comments, extension lines and the like ("annotations" below) and the use of printouts in order to make the concept and orientation of the rough form definition easily graspable by the other people involved in the project is indispensable for the sharing and coordination of information, and it is preferable to employ 2D data for these purposes. Figure 4 shows an example of a 2D layout with various annotations.

2.2.2. Rough layout

As in the case of the conceptual design stage, during the rough layout process, numerous operations for the formulation of standard forms and the determining of positions are carried out in 2D. With design data as a benchmark, trigonometric methods are employed in the formulation of projected views including side, plane, and back views ("views" below), and cross-sectional views ("sections" below). These are laid out, and, as previously at the conceptual design stage, the views and sections are overlayed on other forms to provide a reference as the process of temporary settings and verification is repeated.

However, work in 3D is also added at this stage, because the results of the process should be correctly reflected as positions and forms in 3D data. Figure 5(a) shows an arrangement of views with design data as a benchmark, with the rough forms of the seal sections formulated in each view. Figure 5(b) shows the formulation of synthesized curves in 3D based on the 2D data, used for the examination of the form of the frames.

2.2.3. Detail layout

When the detail layout stage is reached, procedures to generate the detailed 3D forms are added to the process. The main workspace therefore changes, and the majority of formulation and verification of temporary settings is conducted in 3D. However, operations in 2D are also

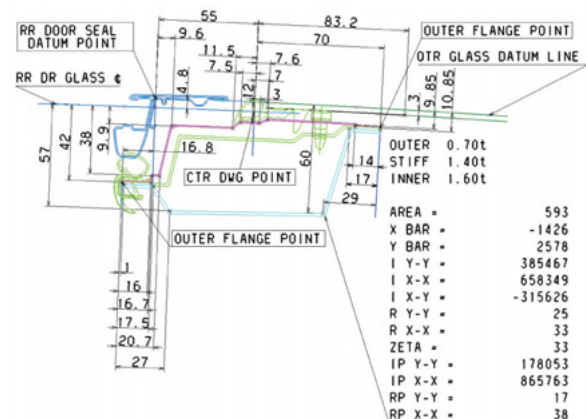


Fig. 4 Annotated 2D layout

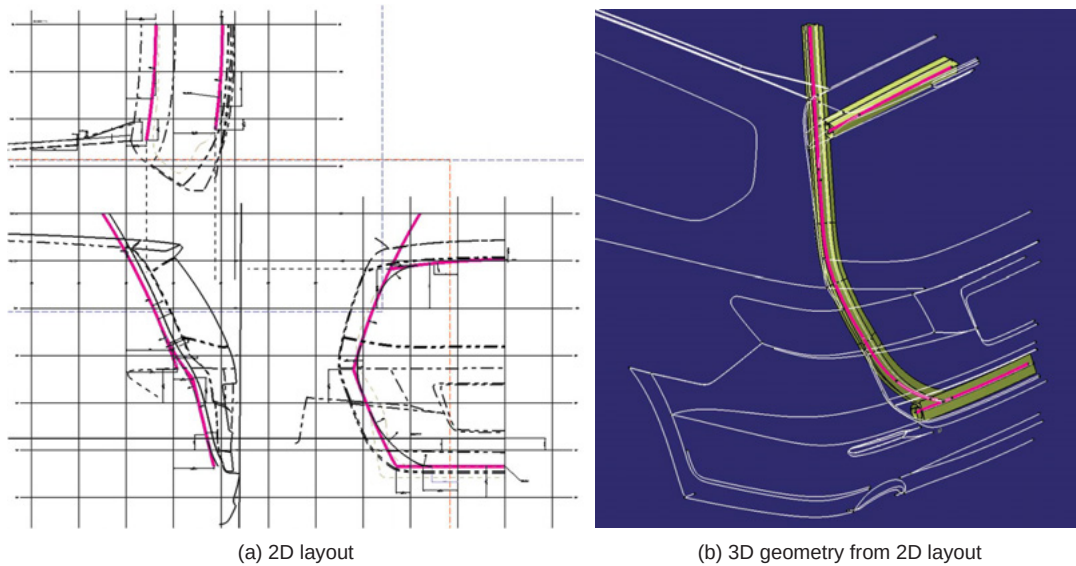


Fig. 5 3D geometry creation from 2D layout

necessary, in order to check whether the generated 3D forms satisfy the various requirements on the standard views and sections.

At this stage also, changes can be made to the design data that forms the standard or to peripheral parts and other areas, and it becomes necessary to revise settings in 2D after the changes in the 3D data have been accurately reflected in the views and sections in 2D. Figure 6 shows an example of the correction of definitions in 2D due to changes in design data. In this case, changes in the form of a glass section are projected on 2D data, and the form of the internal structure is modified.

Given these examination procedures and work functions, it is clear that work in 2D and work in 3D are closely linked, and that as the design process proceeds, the main design workspace shifts from 2D to 3D.

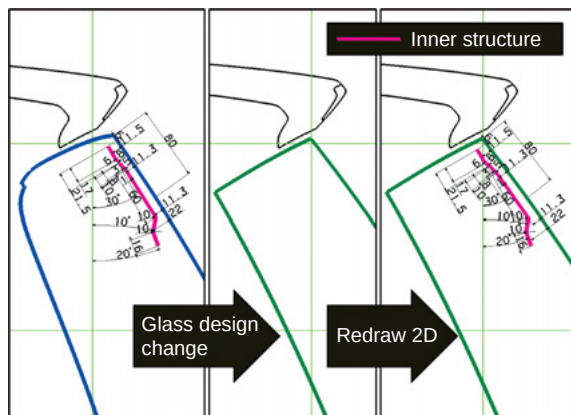


Fig. 6 Modification of 2D data due to styling design change

2.3. Necessary Operations in Conceptual Design and Layout

The necessary operations at the conceptual design and layout stages, as described in Section 2.2, can be summarized as follows.

- (1) The arrangement of the various views and sections based on graphics procedures [Fig. 5(a)]
- (2) The recording of annotations on the 2D forms, and printing as necessary (Fig. 4)
- (3) Overlays on views and sections irrespective of whether the data is 2D or 3D, and use of these as a reference (Fig. 3)
- (4) The creation of 3D forms based on the 2D forms, and the changes in the 2D forms reflected in the 3D forms (Fig. 5)
- (5) The creation of 2D forms based on the 3D forms, and the changes in the 3D forms reflected in the 2D forms (Fig. 6)

At the conceptual design stage, the majority of operations fall into categories (1) to (3), while the layout stage involves operations from (1) through (5). In other words, all of these operations are demanded of CAD, and if designers were able to perform these operations efficiently using CAD, the efficiency of the design process itself could be increased.

3. Existing CAD Systems: Characteristics and Issues

The CAD systems employed to date have been unable to efficiently conduct all of the work procedures described in Section 2.3. The specific issues displayed by the systems are discussed below.

3.1. Insufficient Functionality for Layout: V4

V4 offers a space mode (3D) and a draw mode (2D). Draw mode provides sufficient functionality to conduct the work operations in categories (1) through (3) in Section 2.3, and layout work could be conducted efficiently in 2D. In addition, the use of the AUXVIEW2 function helped to enable 2D forms to be created based on 3D data, and changes in 3D forms to be reflected in 2D (category (5) in Section 2.3).

However, while the 2D forms created in draw mode could be output to space mode (DRW->SPC), there was no update function and it was therefore necessary to regenerate the 3D forms in the event that changes were made in the 2D forms. In addition, the 3D form generation function was insufficient – for example, it was challenging to modify a 3D form after it had been created. These issues prevented the system from being used to efficiently conduct the work in category (4) in Section 2.3 and the subsequent layout work in 3D. As a result, the creation of 2D forms that are directly related to the drawings was prioritized, and it was not possible to create 3D forms concurrently, in a time-efficient manner.

3.2. Insufficient Functionality for Layout: V5

V5 offers feature-based parametric modeling functions displaying a high level of completeness. The basis for 3D forms with dimensions and geometric constraints (“2D profiles” below) can be created mainly using the sketcher function, following which layout work in 3D can proceed using various workbenches. The sketcher is able to create 2D profiles while providing transparent displays of 3D forms and other 2D forms, and can thus be used to conduct the operations in category (3) in Section 2.3. In addition, movement in both directions between 2D profiles and 3D forms can be automatically synchronized. Specifically, changes in 2D forms are automatically reflected in 3D forms simply by shifting from the sketcher workbench to another workbench, and changes in 3D forms can be reflected in 2D forms by means of the “Use-edge” function. These functions make it possible to efficiently conduct the work operations in categories (4) and (5) in Section 2.3.

However, the sketcher function is a function for the creation of 2D profiles in a single plane, and multiple 2D profiles created in different positions cannot be simultaneously aligned for reference. In addition, despite the fact that dimensions can be applied to the generated profiles, text, tables, and various symbols cannot be interpolated. These deficiencies in functionality prevented the work operations in categories (1) and (2) from being conducted using the sketcher.

On the other hand, while the drafting workbench, a function for the creation of 2D drawings, was provided with functions helping to enable the arrangement of views and sections [category (1)], the interpolation of annotations and printing [category (2)], and the generation

of 2D forms from 3D forms [category (5)], the fact that it possessed no functions making it possible to generate or update 3D forms from 2D forms [category (4)] or to overlay 3D forms [category (3)], and that 2D forms were saved in separate files to 3D forms, made it also unsuitable for layout.

Ultimately, V5 was also unable to efficiently conduct the layout work in categories (1) through (5).

4. Concept of New Functions and Functional Requirements

In Section 2.1, it was indicated that a repeated cycle of establishment of temporary settings and verification of their suitability was important in establishing the optimum layout under conditions of limited time and numerous changes to the designer’s own part and other parts. Section 2.2 pointed out that work in 2D and work in 3D are closely linked, and that as the design process proceeds, there is a transition from 2D to 3D as the main design workspace. This means that it is vital to conduct work operations that span 2D and 3D as efficiently as possible from the conceptual design stage, the first stage of the design process, to the detail layout stage, the later stage of the process.

In addition, the operations that are necessary for the conceptual design and the layout, as outlined in Section 2.3, demonstrate the functionality that is necessary in order to conduct work operations that span 2D and 3D.

Based on the above, the concept for the development of the new functions was formulated as the realization of CAD functions that helped to enable work procedures with mutual linkages between 2D and 3D from conceptual design to detail layout. The achievement of the mutual linkage between 2D and 3D can be summed up in the following functions:

- (a) 2D function equivalent to drawing function
- (b) Function for transparent background display of 2D and 3D forms
- (c) Associativity from 2D forms to 3D forms
- (d) Associativity from 3D forms to 2D forms

Functions that satisfied these conditions from (a) to (d) would help to enable all of the operations described in Section 2.3 to be conducted. The development program was therefore conducted on the basis of these conditions.

5. Development of 2D Layout for 3D Design

The ability to be operated on the V5 platform was a prerequisite in the development of functions that would satisfy conditions (a) through (d) in Chapter 4. For this reason, the development was conducted in cooperation with Dassault Systèmes, the developer of V5. The use of existing V5 functions to the greatest extent possible was established as a development guideline in order to reduce the time necessary for development. On the 2D side, the

drafting function was used as a base in order to obtain the drawing function (a), and the sketcher function was incorporated in the 2D-3D association functions [(c) and (d)]. However, a new development was necessary in the case of (b), because no existing function realized a simultaneous drawing function and transparent background display. On the 3D side, it was decided that switching with the existing 3D workbench would be utilized. These functions were incorporated in a standard workbench that could be operated on the V5 platform. The functions were termed “2D layout for 3D design” (2DLO). Table 1 compares existing and 2DLO functions, and Fig. 7 shows the 2DLO screen structure.

When the 2DLO workbench is activated, a 2D layout sheet is formulated in the parts data file (CATPart), and views and sections related to positions in 3D can be generated and arranged using trigonometric methods as shown in Fig. 8(a). Annotations can be added, and each sheet can be printed [condition (a) in Chapter 4]. 2D forms can be generated on views and sections, and at the same time a “Display Backgrounds” function helps to enable transparent display of other views, sections, and 3D forms in the CATPart file [condition (b) in Chapter 4]. Figure 9 shows an example of a study involving the overlay of data for two previous models and related 3D design data on the sections for the designer’s own part.

In addition, a “3D Profile” function makes it possible to use 2D forms as 3D forms, and an update function

Table 1 2DLO functional advantages

Category	Item	V4	V5 SKT	V5 DRW	V5 2DLO
Layout functionality	Drawing functionality	Yes	N/A	Yes	Yes
	2D overlay	Yes	N/A	Yes	Yes
	3D overlay	Yes	Yes	N/A	Yes
2D and 3D associativity	2D->3D	N/A	Yes	N/A	Yes
	3D->2D	N/A	Yes	Yes	Yes

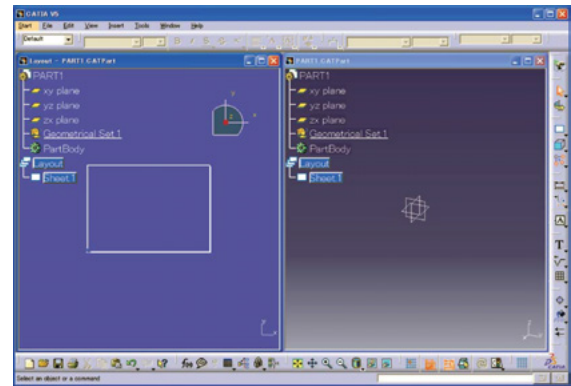
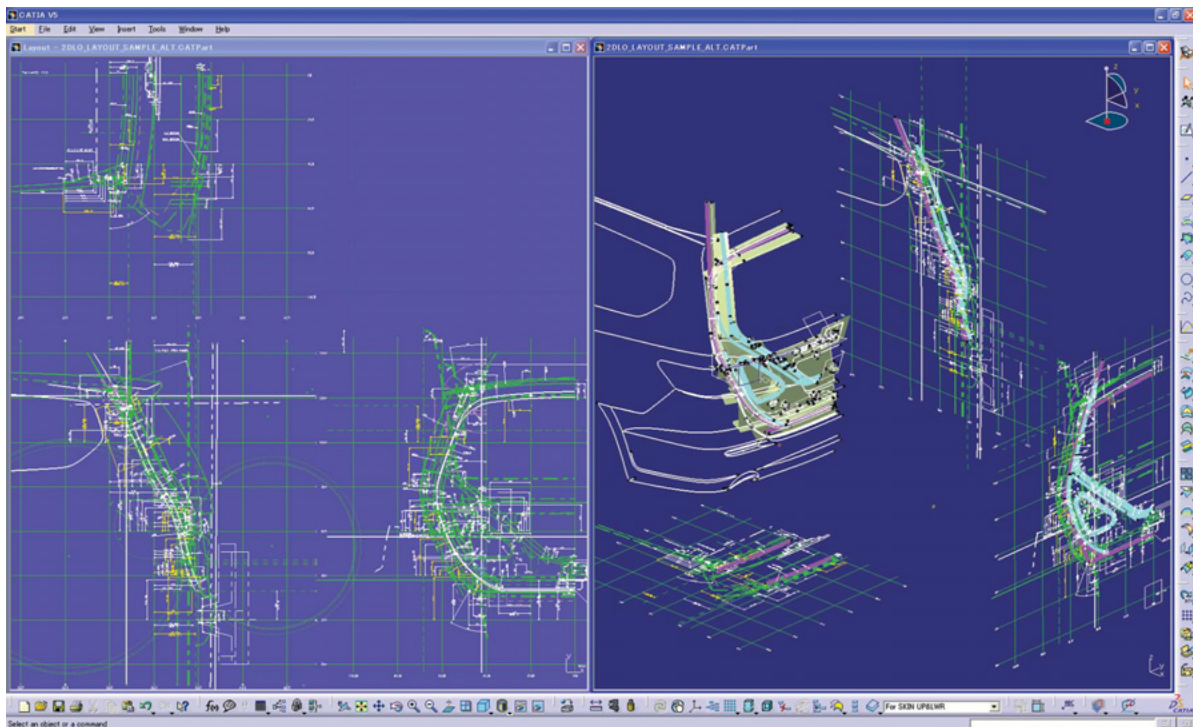


Fig. 7 2DLO screen structure



(a) View alignment

(b) 3D geometry from 2D layout

Fig. 8 2DLO 3D geometry creation from 2D layout

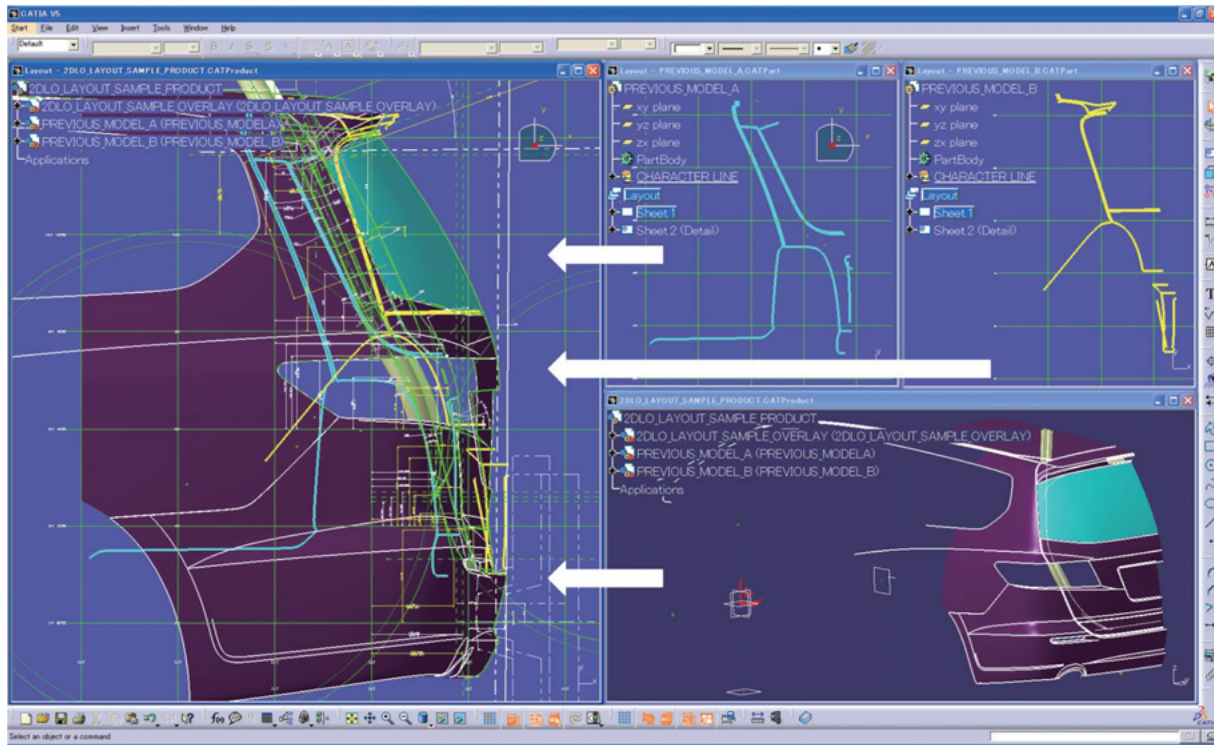


Fig. 9 2DLO overlay

helps to enable the results of editing 2D forms to be instantly reflected in 3D [condition (c) in Chapter 4]. As an example, in Fig. 8(b), 3D curves have been synthesized based on the 2D forms generated using the views in Fig. 8(a), and a frame form has been generated in 3D from this.

Further, when 3D forms have been modified using the “Use-edge” function, the update function is able to instantly reflect the latest status in the projected forms and the section forms generated on the views and sections on the basis of the 3D forms [condition (d) in Chapter 4].

In the example shown in Fig. 10, the design of a glass section has been changed, and the sectional definitions of the frame form generated based on the glass section are automatically updated without any necessity for regeneration.

These abilities confirm 2DLO as a CAD tool that helps to enable work operations to be conducted while referring simultaneously to 2D and 3D forms, and, by means of the update function, changes to be mutually reflected in 2D and 3D forms. It is a tool that satisfies the necessary functional requirements for conceptual design and layout.

6. Effects and Status of Use

6.1. Effects in Product Development Process

The effect of the use of the CAD tool in product development can be summarized in the following four points:

- (1) Work efficiency has been increased because the tool helps to enable procedures from conceptual design to the 3D formulation of the product to be conducted using identical functions as part of an integrated process.
- (2) Fewer man-hours are necessary for data correction due to discrepancies between 2D and 3D and correction of standards.
- (3) Greater sharing of concepts and design intentions has been promoted.
- (4) With the diversification of applications of the tool, the use of the same format has simplified data exchange.

With regard to (1), the new tool has helped to enable

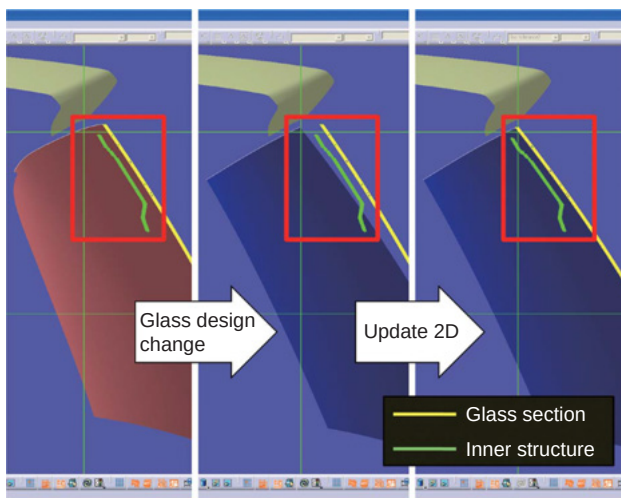


Fig. 10 2DLO Use-edge

efficient layout work with cooperation between 2D and 3D work in concept formulation, rough layout, and detail layout. This covers a wide range of product design procedures, from the stage before the specifications and surrounding forms have been determined to the formulation of 3D product data.

With regard to (2), the ability to save 2D form definitions and 3D forms in the same file has made mutual reflection of changes a simple matter, reducing the potential for unintended contradictions or discrepancies between 2D and 3D, and thus reducing the necessity to re-perform layout work due to failures to respond to modifications. In addition, fewer man-hours are employed in regenerating forms due to changes in internal and external standards such as modification of design data or revision of 2D settings.

Concerning (3), because the system makes it possible, in addition to saving 2D form definitions and 3D forms in the same file, to refer to both simultaneously, the readability of layouts in which 2D and 3D data formulated

by different designers are mixed has been increased. This is also useful in helping designers to accumulate expertise in methods of reviewing layouts. In addition, the ability to print reviews that overlay 3D cross-sections, layouts formulated by other designers, and layouts formulated by the user, has reduced the man-hours expended on preparation when checks are conducted within the department or details are coordinated with other departments.

Concerning (4), in design processes other than the body-in-white development used as an example in this paper, the system's 2D functions can be prioritized in areas in which definitions in 2D are relatively important factor; in areas in which operations in 3D are more important, studies can be conducted using a transparent display of the 3D layout. This ability to realize a variety of uses while employing a single format has made data conversion unnecessary for data exchange between different departments.

6.2. Status of Use

In addition to being used as a method of generating 3D forms with initial sketches in 2D as a base – one of the aims of its development – the new system is also finding extensive application as a tool for verification of temporary 3D settings in 2D, with layout reviews being conducted in 3D from a comparatively early stage involving transparent display on views and sections. Printouts are also being used in review meetings and to assist in coordinating details with other departments.

In addition to the layout applications described above, 2DLO is also being widely used in applications such as the generation of 2D data for printing 3D annotated model (3DA) of individual parts (Fig. 11), and the formulation of blank layouts for cost calculations (Fig. 12).

7. Conclusions

- (1) The CAD procedures necessary for design work were elucidated, and a concept and necessary requirements were established for functions helping to enable the production of layouts. These functions combined layout functions including arrangement of views and sections and the overlay of data and 2D-3D association functions.
- (2) The use of the 2DLO developed on the basis of this concept and these functional requirements has helped to enable operations to be conducted consistently using a single integrated function set from the initial stage of design to the creation of the product form, with designers able to refer simultaneously to 2D and 3D data and mutually reflect changes in each.
- (3) In addition to increasing the efficiency of work procedures conducted while referring simultaneously to 2D and 3D data, the new CAD tool has also reduced the man-hours previously expended on regenerating forms, thus increasing the efficiency of the design process as a whole.

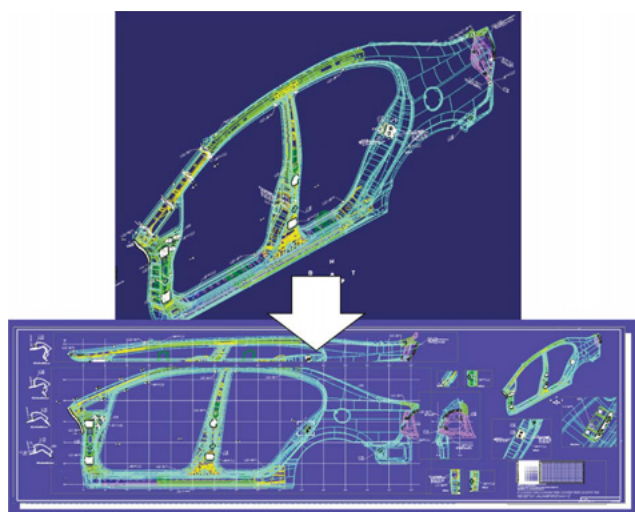


Fig. 11 2D viewing of 3DA for print

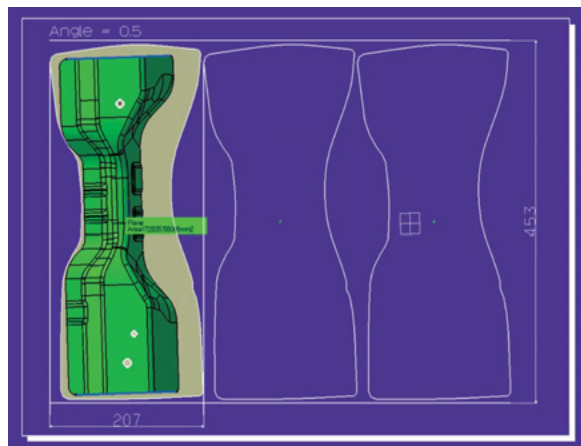


Fig. 12 Blank layout

Reference

- (1) Nikkei CG: Shin CAD no kisochishiki, Nikkei BP, p. 127-136 (1996) (in Japanese)

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