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3D DESIGN TECHNIQUE TO REDUCE REDESIGN TIMING

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Abstract: The current industry imposes a dynamic market in which the requirements are no longer clear from the first phases of project development, so the designed products require improvements and changes that sometimes totally change the appearance of the products. The present paper proposes a case study on a 3D design technique to reduce the time and costs of redesigning. Using the basic skeleton technique, designers build a parameterized system on which they build the 3D model. The technique is part of the top-down -based product design concept and is often mandatory in the 3D design of products. This paper proposes an ECU module product designed in the Catia V5 R16 design software as example to evaluate the impact on development costs and times. The study resulted in a significant reduction in research and development effort and costs.

Keywords: Top-down design, Computer Aided Design, skeleton technique, work efficiency, parametric design.

1. INTRODUCTION

3D design must be dynamic so that it responds easily to changes. Mechanical design engineers must consider that in order to succeed, to innovate, a series of failures are needed to lead to results and success. For this, certain techniques and methodologies must be used in 3D modeling to help with design flexibility, coherence in complex assemblies, optimization of the development process, simplification of change management, reduction of development time and costs.

The product design modeling is classified into two types depending on the approach: one is bottom-up-based, and one is top-down-based approach. In design process, the hybrid approaches are usually adopted. [1]

a) Bottom-up-based product design process

The bottom-up-based approach is that a part model is established according to the results of conceptual design, then these parts are assembled together according to their assembly relationships, and finally the assembly is simulated and analyzed. Since this design method starts with the components when the whole model is not entirely defined, some problems might occur in the analysis of the

overall structure. Especially, once design requirement changes, the product model might not achieve the linkage modification of the relevant parts. This method is not starting from the whole system to capture the product quality and functionality.

b) Top-down-based product design process

The top-down design approach is that designers first establish the overall functional model of the product according to the results of conceptual design, the functional model is then analyzed and optimized. On the premise of ensuring functional model to meet the requirements, the overall layout is carried out and the corresponding parts are designed in detail [1].

2. PREVIOUS WORK

The benefits of using this technique have also been studied by researchers such as Bin H. and Pengchang Z. They have demonstrated the advantages of using the top-down design and the increased efficiency rate in terms of design timing. The parametric skeleton model-based design modeling method could be used to resolve the integrating design and analysis problem in product design. The integrated

design and analysis of a complex product exemplified a 25% reduction in the design cycle time. This outcome highlights the methodology's effectiveness in enhancing the associativity between design and analysis models [1].

Researchers like Lowhikan S. and Mallikarachchi C. have emphasized the importance of employing a top-down approach in fields such as civil engineering. This approach underscores the necessity of a unified platform capable of producing structurally optimized CAD models, as CAD models play a pivotal role in the development and manufacturing processes of most industrial products [2].

Other researchers such as Dexin C., Guolin L., and Xuening C. have analyzed and refined the skeleton technique for top-down design in complex products. In their article, they introduced a novel top-down design approach based on a multi-skeleton model. This methodology defines three key skeleton models: the location skeleton model, the published skeleton, and the design skeleton model [3].

2. METHODOLOGY

2.1 Skeleton technique

The skeleton consists of abstract geometric entities that serve as references for the construction and organization of the components of a model. These entities may include:

- Axes - to define directions or points of rotation;
- Planes - to create base surfaces or guide the positioning of parts;
- Reference points – for locating key elements;
- Lines and curves – for guide routes, edges or functional profiles;
- Simplified surfaces and volumes – to represent the overall shape of the piece or assembly.

The skeleton acts as a common base that controls the main dimensions, positions, and relationships between components. Any change made in the skeleton is automatically propagated in all parts or assemblies that depend on it.

The Skeleton Modeling technique is specific to the Top-Down Based Product Design Process approach.

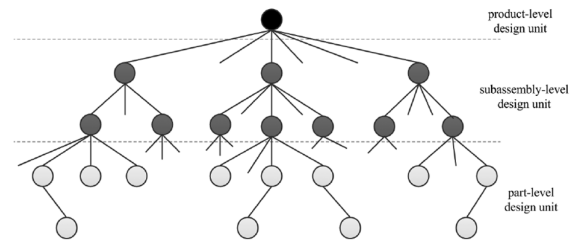


Fig. 1. Hierarchical decomposition of complex products for top-down design [3].

In Top-Down design, the project begins with an overview of the product, defining global structures, relationships, and constraints that subsequently guide the design of individual parts as identified in Figure 1.

A skeleton structure can be defined in several ways depending on the degree of complexity of the product. In Figure 2 you can see a comparison between the traditional skeleton and the multiple skeleton.

2.2. How to apply

a) *Skeleton Creation* - Define the basic structure using geometric entities. They do not directly represent the final shape of the piece but serve as a guide for further construction.

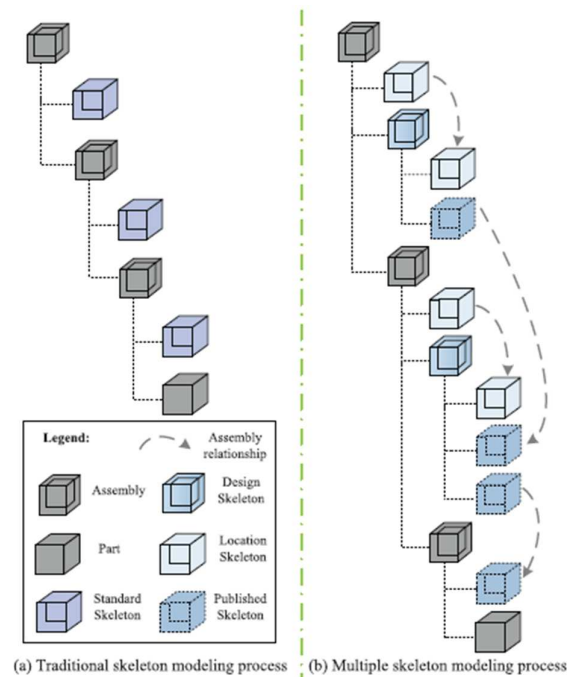


Fig. 2. Different skeleton modeling processes [3].

b) *Construction of parts and assemblies* - Components are designed or positioned in

relation to the skeleton. This ensures consistency between components and allows for the use of common references. Points, planes and other geometric elements will serve as reference elements in the creation of each part, using certain geometric constraints such as coincidence, coaxiality, etc.

c) *Change management* - Any changes made in the skeleton model are automatically propagated to all components that depend on it, which simplifies the process of updating the parts and implicitly the assembly.

An example of working with this technique is given in Figure 3.

The skeleton technique fits this approach perfectly, because:

- The skeleton structure serves as the foundation for the entire assembly.
- The individual components are developed in relation to the skeleton, which ensures perfect integration between them.
- Changes in the skeleton automatically propagate to the dependent parts, making the design more efficient and coherent.

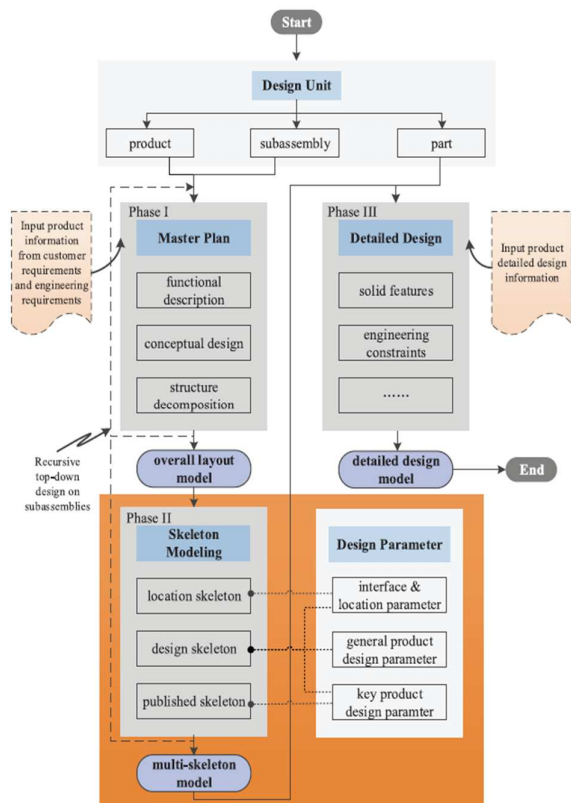


Fig. 3. Top-down design process based on skeleton model [3].

2.3. Advantages

a) *Modularity and flexibility*: Components can be modified or replaced without affecting the entire structure.

b) *Accuracy*: Geometric relationships are maintained, reducing errors in design.

c) *Efficiency*: Allows reuse of skeletons for similar components or subsequent projects.

d) *Reduction of repetitive work*: Changing a single parameter in the skeleton updates the entire model, saving time and effort.

e) The simplicity of the basic model leads to ease of implementation. [4]

Skeleton models can improve how engineers do their design. As models become more complex, it is important to have clear best practices for skeleton models. This approach significantly reduces wasted time by eliminating the need to load complex assemblies or re-link subassemblies.

Skeleton models provide a interface between components within an assembly. In this way engineers can start with a concept, break down the design into skeleton parts, and then assemble components in relation to those skeletons [5].

The ability to customize objects in CAD systems is essential for designers and engineers to meet specific requirements and preferences of their designs. Real-time object customization in CAD systems is at this time mandatory due to the complexity of products and the dynamic market where the customer's requirements are changing often. With the skeleton technique, designers can improve the design for testing in Computer Aided Engineering (CAE) applications for Finite Element Analysis (FEA) or for thermal management according to applications [6].

3. SKELETON MODEL FOR ELECTRONIC CONTROL UNITS (ECUs)

3.1 Concept description

The ECU module consists of two housings made of plastic, assembled by clipping. The enclosures protect the electronic components populated on the PCB (Printed Circuit Board). The module is connected by a series of pins made of copper alloy and usually plated with tin.

For the integration of these components, it was necessary to use the Skeleton technique.

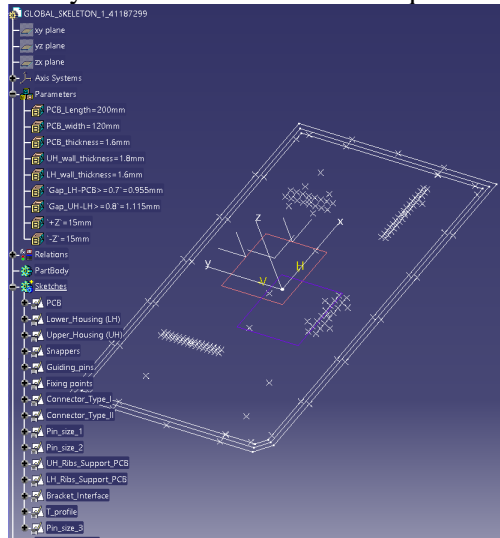


Fig. 4. Skeleton model created for ECU.

To exemplify, an example with applicability in the automotive industry for an ECU module has been made in this paper. The components of this assembly are interconnected and depend on each other. Thus, at the time of design, all the constraints between the elements and their assembly method must be taken into account. The skeleton system is useful for this. Figure 4 shows the skeleton containing the parametric design, sketches and points used for creation.

3.2 Components of the skeleton

Design using the skeleton technique also involves parametric design that continues a series of parameters that can be modified:

- *PCB length* - controlling the length.
- *PCB width* - controlling the width.
- *PCB thickness* - controlling thickness.
- *UH (Upper Housing) wall thickness* - controlling the wall thickness of the upper housing.
- *LH (Lower Housing) wall thickness* - controlling the wall thickness of the lower housing.

The sketches and points used are:

- *PCB* - it is only the border of PCB. The length and width are linked to the parameter.
- *LH* - is the maximum dimension of the lower housing. All constraints between lower housing and PCB are made with a formula (considered the parameters of wall thickness).

- *UH* - is the maximum dimension of the upper housing. All constraints between the upper housing and PCB are made with formula (considered the parameters of wall thickness).
- *Guiding pins* - sketch with position of the guiding pins from UH. This sketch will be used in UH, PCB and LH.
- *Connector type I* - sketch with the position of the same connector type I, it doesn't matter the coding. This sketch will be used in UH, PCB and LH. To the points of this sketch will guide the position of the pins and the position of the lower housing ribs below connectors.
- *Connector type II* - sketch with the position of the same connector type II, it doesn't matter the coding. This sketch will be used in UH, PCB, and LH. To the points of this sketch will guide the position of the pins and the position of the lower housing ribs below connectors.

3.3 Example of using the skeleton

The ECU module is shown in exploded view in Figure 5. This module is the initial module designed with the skeleton in Figure 4. It took about 2 weeks to design.

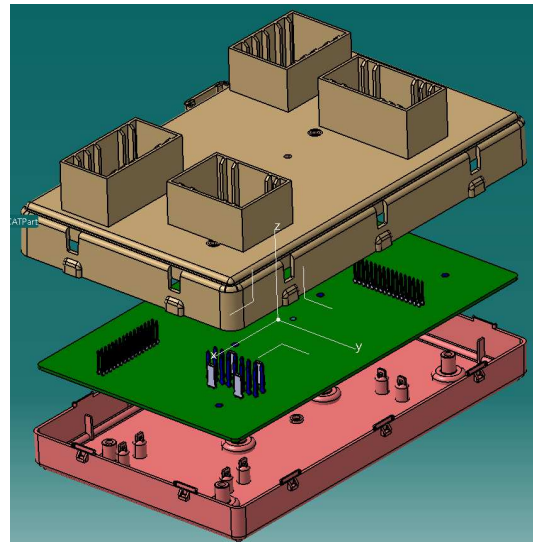


Fig. 5. ECU module with initial skeleton configuration.

In order to exemplify the advantages and efficiency of the skeleton technique, it is proposed to modify the assembly with other dimensions and another positioning of the connectors. Without a skeleton system, these

modifications are complex due to the need to modify all the components and the positions of the pins and connectors.

This method significantly reduces redesign time. When vehicle dimensions or requirements change, such as modifications to the space allocated for the ECU, the design team avoids reworking the entire ECU design. Instead, they adjust the parameters defining the skeleton's dimensions and external shapes. Parametric interdependence ensures that internal components automatically realign with these updates, enabling rapid adaptability and minimizing the need to restart the design process for each modification.

With the help of the skeleton, modifying the sketches, and the positions of the points, the new configuration of the module was made in about 30 minutes. The module with the new configuration is shown in Figure 6.

3.4 Scenario: Analyze of the impact on development costs and times

In a classic scenario, without the use of the skeleton technique, the team would have had to redo the entire design of the ECU to adapt to the changes in the size of the compartment. This would imply:

- Complete rebuilding of the ECU model.
- Additional testing and validation time.
- Possible design errors or incompatibilities that would have led to additional revision cycles.

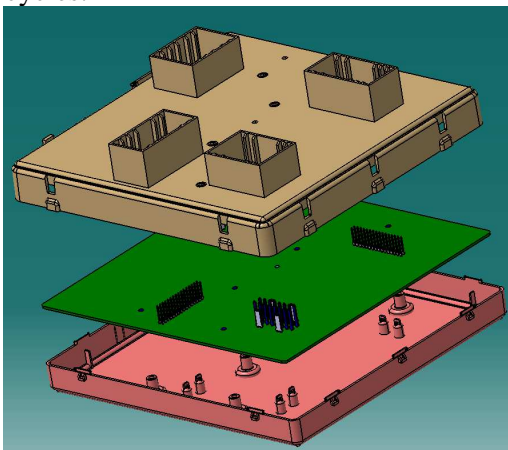


Fig. 6. ECU module with new skeleton configuration.

Compared to the skeleton approach, which only involves adjusting the parameters of the skeleton, the process is much faster and more

efficient. We estimate the following time and cost savings:

Total time required without skeleton (for complete design modification):

- Complete ECU design rework: 2 weeks.
- Testing and validation: 1 week.
- Estimated total: 3 weeks.

Total time required with skeleton (for complete design modification):

- Adjustment of the skeleton parameters: 1 day.
- Rapid prototyping and validation: 5 days.
- Estimated total: 6 days.

As mentioned, using design techniques, the times required for redesign and later changes are reduced. However, this type of design also includes a number of limitations. It can be mentioned that designing this way from sketch to final product requires workers with high experience in using CAD program for 3D modeling and the times are increased due to the need for organized work and the creation of multiple geometries that are integrated in the skeleton model.

These limitations make this technique a complex method that requires high implementation times. Thus, the design engineer and the project team must decide, depending on the application and necessity, which method they want to approach so that the time allocated to the design is necessary and worthing for the future of the project.

Usually, most known CAD applications for technical design allow the use of the Skeleton technique. Also, most 3D models from various industries (eg. automotive, aeronautics) can be made using the skeleton technique when there are links between at least 3 elements or geometries.

There are scenarios where for prototyping applications, sketching, various tests, when the project is in the development phase and speed and innovation is desired, classic modeling is preferred and can be done without respecting any design rule. In this case, the classic design can win, being usually called "Quick and dirty".

4. CONCLUSION

This paper aims to demonstrate the application of the Skeleton technique in the

design of automotive products, specifically for ECUs. To achieve this, the study developed an application alongside a 3D model of a product. The 3D model serves as a geometrical concept and can be adapted to meet specific customer requirements. The 3D assembly modeling was conducted using CATIA V5 R16, a student edition software.

The 3D model designed with skeleton technique is a clear illustration of how the skeleton technique can significantly reduce both development time and costs in ECU development projects in the automotive industry. The use of skeleton technique in an automotive ECU development project allows for rapid adaptation to changes in the vehicle design process, saving time and resources and ensuring efficient integration of new size requirements.

One key feature of the skeleton method is time reduction. The skeleton technique has allowed the adjustment time of the ECU design to be reduced from 3 weeks to just 6 days, saving about 10 working days. Another key feature is cost reduction. The rapid parametric adjustment of the design has led to cost reductions by eliminating the need for complete redesigns, repeated prototypes, and additional testing.

5. REFERENCES

[1] Bin H., Pengchang Z., Ningfeng Z., *Skeleton model-based approach to integrated*

engineering design and analysis, The International Journal of Advanced Manufacturing Technology, ISSN 0268-3768 Volume 85, Springer-Verlag London, 2015.

[2] Lowhikan S., Mallikarachchi C., Herath S., *Design-Informed Generative Modelling using Structural Optimization*, Department of Civil Engineering, University of Moratuwa, Bandaranayaka Mawatha, August 2023. Moratuwa 10400, Sri Lanka.

[3] Dexin C., Guolin L., Xuening C., *Multi-skeleton model for top-down design of complex products*, Advances in Mechanical Engineering 2016, Vol 8(6), pp. 1-20.

[4] Mengoni M., Germani M., Mandorli F., *Reverse engineering of aesthetic products: use of hand made sketches for the design intent formalization*, Journal of Engineering Design, special issue TMCE 2006 Conference.

[5] Cadactive, *Skeleton Model*, <https://cadactive.com/blog/2021/04/01/basic-s-of-skeleton-models/>.

[6] Tamasan M., Prada G., Pop A., Blaga F., *Integrated CAE/CAD system for parametric design of mechanical assemblies*, Acta Technica Napocensis, Technical University of Cluj-Napoca Series: Applied Mathematics, Mechanics, and Engineering Vol. 67, Issue Special II, April 2024.

Tehnica de proiectare 3D pentru reducerea timpilor de reproiectare

Industria actuală impune o piață dinamică în care cerințele nu mai sunt clare încă din primele faze de dezvoltare ale proiectului astfel că produsele proiectate necesită îmbunătățiri și modificări care uneori schimbă total aspectul produselor. Lucrarea de față propune un studiu de caz privind o tehnică de proiectare 3D pentru a reduce timpii și costurile de reproiectare. Utilizând tehnica scheletului de bază, proiectanții construiesc un sistem parametrizat pe care construiesc modelul 3D. Tehnica face parte din conceptul de proiectare de sus în jos (Top-down based) și este deseori obligatorie în proiectarea 3D a produselor. Lucrarea de față propune drept exemplu un produs modul ECU proiectat în software-ul de proiectare Catia V5 R16 pentru a evalua impactul asupra costurilor și timpilor de dezvoltare. În urma studiului a rezultat o reducere semnificativă a efortului și costurilor de cercetare și dezvoltare.

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