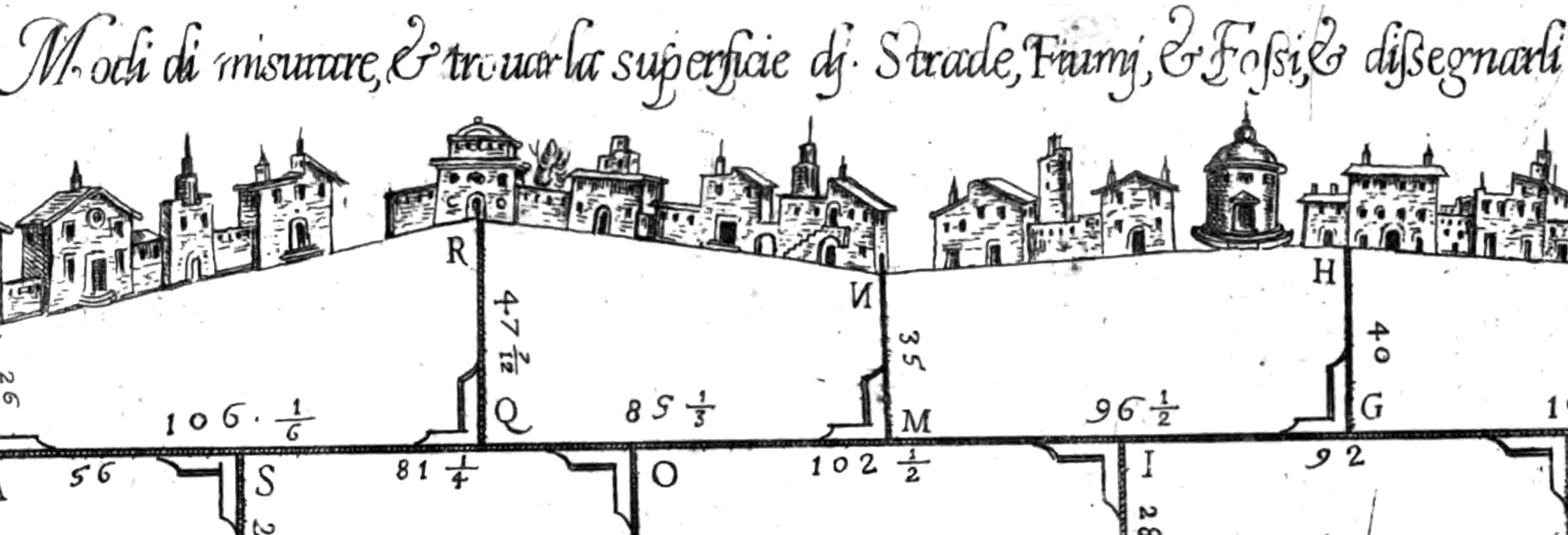
diségno 7.2020

unione italiana disegno
7.2020

diségno

ISSN 2533-2899

english version



diségno

7.2020

DRAWING AND MEASUREMENT

disėgno

unione italiana disegno

Biannual Journal of the UID Unione Italiana per il Disegno Scientific Society
n. 7/2020
http://disegno.unioneitalianadisegno.it

Editorial office
piazza Borghese 9, 00186 Roma
rivista.uid@unioneitalianadisegno.it

Cover
Pomodoro G. (1599). Geometria prattica, tratta dagl'elementi d'Euclide et altri auttori..., Roma: Stefano de Paolino. Tav. XXXIIII, detail.

The articles published have been subjected to double blind peer review, which entails selection by at least two international experts on specific topics.
For Issue No. 7/2020, the evaluation of contributions has been entrusted to the following referees:
Fabrizio Agnello, Piero Albisinni, Laura Baratin, Salvatore Barba, Marco Giorgio Bevilacqua, Carlo Bianchini, Fabio Bianconi, Maurizio Marco Bocconcino, Stefano Brusaporci, Marco Canciani, Cristina Càndito, Laura Carnevali, Andrea Casale, Emanuela Chiavoni, Alessandra Cirafici, Antonella di Luggo, Laura Farroni, Paolo Giordano, Carlo Inglese, Fabio Lanfranchi, Alessandro Luigini, Federica Maietti, Marco Muscogiuri, Leonardo Paris, Ivana Passamani, Fabio Quici, Michele Russo, Nicolò Sardo, Roberta Spallone, Graziano Mario Valenti.

English translations of the editorial and of the essays by Roberto de Rubertis, Francesca Fatta, Marco Gaiani, Ornella Zerlenga sono di Elena Migliorati.

Published in December 2020

ISSN 2533-2899

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The Process of Surveying Maquettes in Car Design

Fausto Brevi, Flora Gaetani

Abstract

This work grew out of a desire to investigate the digital surveying process used in phases to define the concept of a morphologically complex product such as an automobile.
This investigation was conducted by analysing the final steps of the first ten editions of the Specialized Master course in Transportation & Automobile Design at Politecnico di Milano University. In analysing the procedures to create the presentation models starting with clay studio models, four protocols were standardized and compared. Following this, some suggestions and guidelines were summarized to ensure that faithfulness to the design intent during the process would not fail.
The ultimate goal of this work is to highlight the critical aspects of a process that is based on a quantitative method (the digital survey), but that requires a qualitative approach to be truly effective.

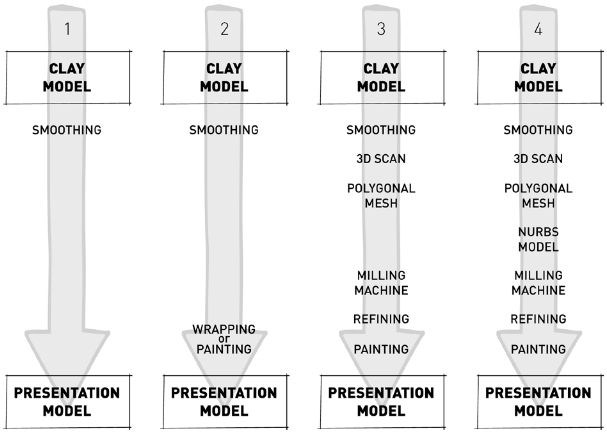
Keywords: 3D scan, car design, car concept, 3D modelling, physical modelling.

Introduction

Of all the industrial design processes, car design is one of the most complex and sofisticated. This is because automobiles are an industrial product in which design makes an important contribution to the project by attributing very clear aesthetic meaning to a product that is already very complex from the engineering point of view. Defining the design intent and remaining faithful to it throughout the design process is therefore a priority, in particular when the formal definition is still incomplete, that is when the concept design is being defined.
Given the complexity of the project and the economic implications for manufacturing companies, the concept phase is celebrated and brought to public attention at international motorshows. It is also investigated in the scientific realm in sectors such as design management as a tool for pushing towards the design of increasingly innovative products [Elmquist 2007].
It is therefore not surprising that, while car design teaching differs as a function of the national setting, school background, and chosen professors, the design output requested from students at all international schools is always a concept model in reduced scale [1]. The most common scale factors for creating physical models are 1:3, 1:4, and 1:5 [2] because they tend to be the best compromise for students when learning to deal with the complex form of the car as an object, while also maintaining a level of detail useful to fully understand the design intent.

In education, the process ends with the transformation of the maquette into a presentation model, while in business it is inevitably a longer, more detailed process in which the physical model intersects the digital model multiple times, with the resulting need to manage the conversion in both directions.
The need for an in-depth investigation of the relationship between the construction of the presentation model and the design intent as represented in the sketches, renders, and studio maquette still remains.
Experimentation in this sense was conducted by comparing the processes adopted by the Specialized Master course in Transportation & Automobile Design, which has been taught at Politecnico di Milano University since 2008, to develop projects realized by students for their theses at the end of their educational programme. This process has evolved over the years, moving from the direct transposition of the maquette into a presentation model to the conversion of the maquette into a three-dimensional digital model that then yields the presentation model.
The objective of this work is therefore to compare four different protocols so as to understand how to best preserve the design intent, as expressed through the drawing and studio maquette, in the presentation model of car concept designs.

Fig. 1. Description of the four protocols used during the ten editions of the Master's programme (graphic elaboration by Flora Gaetani).



To do so, the approaches and protocols used during the final steps of the ten editions of the Master course were analysed, with particular focus on the role of revising the project during the phases to define the concept and final model. The reviews were made considering sketches and renders in relation to the various phases of completing the physical model. The presence or absence of the above-mentioned design reviews within the process was also detected and always compared with the faithfulness to the design intent.
This faithfulness was observed while considering the geometric correspondence (style of the main surfaces, their convexity or concavity, position, shape, and character lines [3]) and their visual correspondence (maintaining the division between glass surfaces and body, paint colour with respect to the CMF project [4]).
In the ten editions of the Master's programme, the protocols were modified to refine the quality of the final presentation model and, despite the emergence of critical aspects, a much higher level of quality was achieved compared to the first protocols used. Not only that, the high quality required ensured that the projects also acquired a higher level of detail compared to the first years. The greater quality of the presentation model therefore led to a better definition of the project itself.

State of art

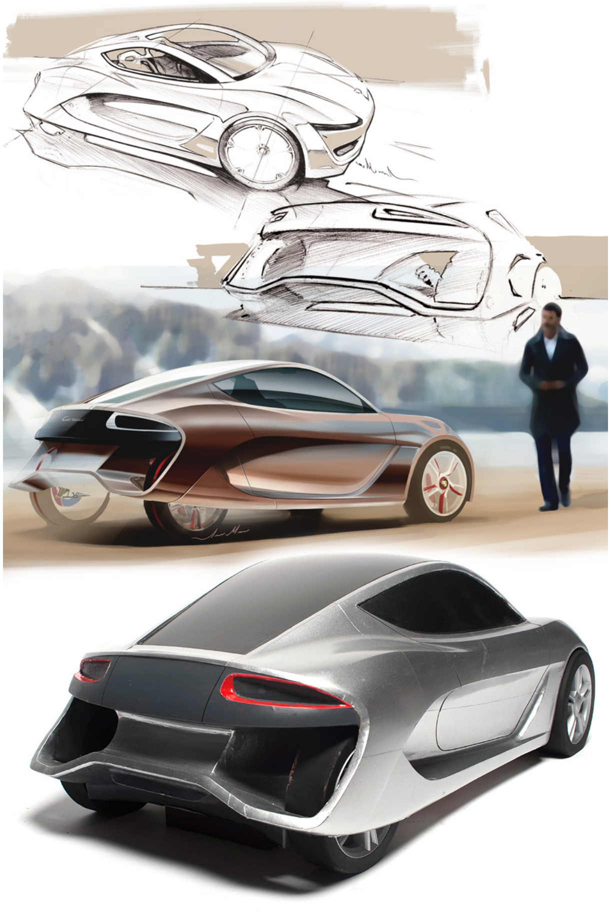
The teaching project underlying the Master's programme that we have investigated entails replicating what occurs in design centres at companies involved in car design, although only partially and with corrective actions aimed at favouring the correct preparation.
Historically, projects for vehicles have been developed on the dual tracks of drawings and the creation of physical models in progressively larger scales (from 1:10 to 1:5 to 1:1), without noticeable differences in the process from company to company [Bernobich, Chirone 1982, pp. 23, 24].
Today, the vehicle design process is considered by car manufacturing companies as just one phase in the entire project design and production cycle, in which its specific aspects shine through clearly. For this reason, small and large differences can be identified based on the size of the company, its history, the product characteristics, the profile of the target customer, and often also the management guiding it in a given period of time.

Literature on the process of transportation design is scarce, especially when compared to the enormous number of books on the characteristics of cars and prototypes [Krzywinski, Wölfel 2012, p. 269]. However, a specific common thread can be found in the project design process for road vehicles [5].
The design process always begins with a collection of ideas, the most typical expressive form of which is found through preliminary drawings. A selection of these is made to identify the most interesting and promising in terms of coherence with the project specifications. This also relates to the so-called 'package', that is, the set of geometric limits bounding the new project [6]. The drawings should therefore be reconsidered and refined to respect these limits so that the initial idea dictated by pure creativity may be effectively developed in industry.
Different types of drawings are associated with different phases of the design process. Of these, ideation sketches are used at the beginning of the process [Tovey, Porter, Newman 2003, p. 137]. The scientific value of drawing within the design process, whether in architecture or design, is that it is the main tool used to study the laws governing the formal structure of the project and to study the expression of the design idea, whose evolution and continuous rethinking was described by Bouchard and Aoussat as a progressive reconfiguration of a problem towards a solution. The design process consists in reducing the abstraction of the designer's mental representation through the use of different successive levels of representation that increasingly integrate the constraints [Bouchard, Aoussat 2003; Bouchard, Aoussat, Duchamp 2006].
Within the wider world of the project, in both design and architecture, the issue was already addressed by Giovanni Klaus Koenig when he wrote that "When something is designed, in the precise moment in which it is designed, it exists only in the architect's mind and precisely due to its complexity it must be studied, criticized, reprocessed, investigated, possibly transformed, reduced, or expanded before it is executed materially" [Koenig 1962, pp. 8, 9]. This was also looked at again more recently by Mario Bellini when he stated that "the creative idea takes shape […] through a conceptual flow that starting from the mind reaches the hand, transforming itself into expression on a sheet of paper" [Bellini 2019, p. 9].
Once the reference drawings have been defined, these should be able to communicate the author's design intent clearly and uniquely. In fact, the steps immediately following this see a shift from the primarily two-dimensional techniques of drawing to the three-dimensional techniques of modelling, aimed at ensuring full understanding of the effective perception of a large object conceived with articulated, complex surfaces in the three-dimensional space. The best projects identified from the drawings are then produced as physical models in clay [7], first in 1:4 scale and then in real scale, and as virtual models.
This process, from the drawing to the model, occurs in the company along parallel paths managed by dedicated personnel called "clay modellers" and "digital modellers" [8]. In the educational aspect of the Master course examined in this work, the choice was made to consider clay modelling as preparatory to digital modelling because it allows for a greater spatial understanding of complex shapes. This understanding is helped by the possibility of using touch in addition to sight and by avoiding the mediation of the computer screen, where the framework of perspective projection is put forth again, although usable in a different way. This leads to a misalignment of the two models in time, with the possibility of losing the perfect coincidence between physical and virtual models. This possible loss,

Fig. 2. Model and sketch to describe the Alfa Romeo Ascari, Ed. 1 (Luca F. Bovo and Iosef Fanizza, graphic elaboration by I. Fanizza).

however, is irrelevant from the educational point of view since the process to develop the final project of the Master course ends with the realization of these two models.
The way in which these two models are used in the presentation of the projects has varied over the years. This change was analysed here to understand the advantages and disadvantages of the different solutions adopted with respect to their ability to maintain consistency between the presentation model exhibited and the design intents narrated through the drawings.

Fig. 3. Sketch, render, and model with wrap film of Porsche Caracal, Ed. 4 (Adnan Al Maleh, Juan D. Cadena, Denis Pasquini, graphic elaboration by drawings by A. Al Maleh).



Methodology

The aim of this work was to determine the best way to maintain the design intent in the models when presenting the concept of an automobile in reduced scale.
As mentioned in the introduction, this objective was addressed by analysing the design results within the Specialized Master course in Transportation & Automobile Design at Politecnico di Milano. Observations of the dynamics during design rewies were made during the first ten editions of the programme, along with an analysis of the final work with respect to the iconographic material produced by the students (analogue and digital renders) that best expressed their original design intent.
Over the years, four protocols were used (fig. 1) to develop the final presentation models. The first three protocols were used in multiple years so that the results obtained were not influenced by contingent factors. The last protocol was implemented only in the tenth edition of the Master's programme; the COVID-19 pandemic prevented the completion of the physical models in the eleventh edition.
The elements common to all protocols are the clay maquette, the iconographic set, and the presentation model. The input model was always a clay studio maquette in 1:4 scale developed by the students during the Car Design Studio as part of the Master's programme; the iconographic set was always aimed at describing the phases of project, design intent, and final result.
Protocol one was used in the first and second years. The clay maquette developed by the students was sharpened by a professional clay modeller. This model was put on showcase.
Protocol two was used from the third to the sixth years. After the clay maquette was sharpened, the model was finished with wrapping or paint. This model, equipped with details such as glass surfaces and doors cuts, was put on showcase.
During protocol three, used from the seventh to the ninth years, refinement of the clay maquette was followed by surveying with a full-filled surface 3D scanner [Guidi, Russo, Beraldin 2010]. The scan thus obtained was aligned, optimized, and smoothed, and the polygonal model obtained

was sent to the milling machine. At this point, the physical model was finished and painted. The model, equipped with details such as doors cuts and graphics, was then put on showcase.
Finally, protocol four was used in the tenth year. Following refinement of the clay maquette, the model was surveyed with a full-filled surface 3D scanner. The scan thus obtained was aligned, optimized, and smoothed. At this point, the polygonal model was re-modelled with surface modelling software. The digital model thus obtained was sent to the milling machine, finished, and painted. The model, equipped with details such as doors cuts and graphics, was put on showcase.
The chosen methodology was made possible by the extensive observation of the procedures conducted by the teachers during the final phases of the Master's programme. The teachers chosen to support the students during the course of studies all have extensive professional experience in the field of car design and varied background. This ensured that the students would be confronted with different points of view, just as occurs within automobile style centres. Another similarity with the professional world was the structure of the Studio itself, which has changed continuously over the years and been refined to divide the various project responsibilities between both the professors and students. The areas are divided into: meta-design, exterior design, interior design, colour & trim, and presentation techniques. Everything was coordinated by a person in charge (a figure similar to a project manager in the professional world) and by the director of the Master's programme.
Just as it is necessary to consider the natural changes in the educational structure that have occurred in the editions of the Master, it is also clear how the human aspect was important throughout the phases of the research project, both in evaluating the final results and in assessing and modifying the intermediate steps. This human variable was expressed and generated its greatest importance during the design review, ensuring that the design intent was maintained.

The first years of experimentation

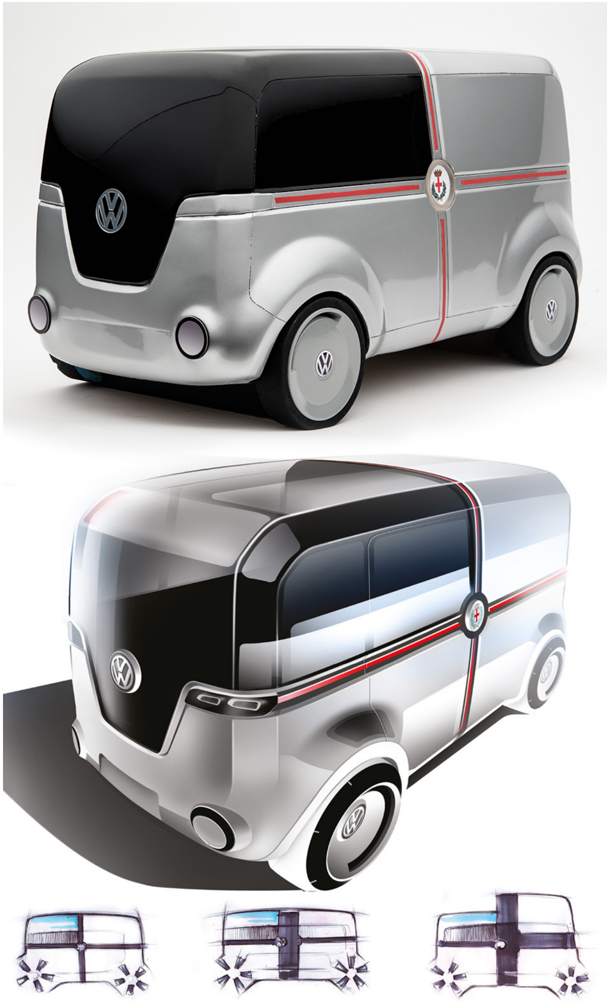
The description of the results follows the same division of the protocols in order to clarify the evolution of the entire project.

In the first protocol, used during the first and second editions of the Master's programme, the models exhibited remained in clay in 1:4 scale and were finished only from the formal, not the visual, point of view. The material used is optically diffusive and therefore does not exalt the shape details of the surfaces. The models exhibited consequently highlighted the non-definitive nature of the project. The tactile perception and visualization of the surface style was left to the supporting iconographic material (sketches and renders). The faithfulness to the design intent was rather good because the entire process occurred with continuous contact between teachers and students, but leaving the tactile perception to just the two-dimensional material was restrictive with regard to the expressive quality of the final result (fig. 2).
The second protocol was used in the next four editions. The finishing of the clay model was done externally by professional clay modellers. This led to some discrepancies and inaccuracies in the final models with respect to the design intent. From subsequent analysis with the professors, this discrepancy was revealed to be due to the poor definition of some of the models prepared by students,

Fig. 4. Model with wrap film displayed for the ten years of the Master's programme, Porsche Medhelan, Ed. 4 (Mario Antonioli, Matteo Tamini, Vander Zanutto).

which necessitated independent choices on behalf of the external professional.
The objective of this protocol was to lend greater tactile definition to the models by applying wrapping or paint.

Fig. 5. Painted clay model, render, and sketch of VW QB, Ed. 3 (Jonathan Bauccio, Josip Cupin, Ahmed Zayed Radwan, drawings by A. Zayed Radwan).



These two techniques, while falling within the same protocol, had different formal and visual characteristics.
Wrapping is a technique that is now widespread in the application of advertising graphics on car bodies. A similar tool is used in automobile style centres to cover clay style models in whole or in part so that the surfaces have optical qualities similar to painted car bodies [9]. Wrap film is an extremely thin film of cellulose resin [10]. This material has the ability to faithfully follow the surfaces on which it is applied, whether characterized by simple curvature (such as the sides) or complex curvature (such as the front). Its cling capacity highlights inaccuracies and discontinuities. In the professional world, it is used precisely to correct defects when modelling surfaces. In presenting the projects, it was shown to be a quick tool but with an inadequate visual yield. It is therefore good for intermediate work, but ineffective in presentation (figs. 3, 4).
The paint has a greater thickness, and an underlying layer is also added to isolate the clay from the paint. The final result led to an optimal visual effect, completely faithful to the paint on a normal car body. While nearly negligible on real-scale models, the greater thickness of this treatment on reduced-scale models could lead to geometric discrepancies due to a general increase in the fillet radii. In the model shown in figure (fig. 5), it is clear how the perception of some corners at the rear is reduced with respect to the reference drawings.
In addition, with both surface finishes, wrapping and painting, the models degraded quickly over time. This was due, in the first case, to the low resistance to abrasion and pressure and, in the second case, to the different heat resistances of the materials (clay and paint), which led to cracks in the paint (fig. 6).

Towards faithfulness to the design intent

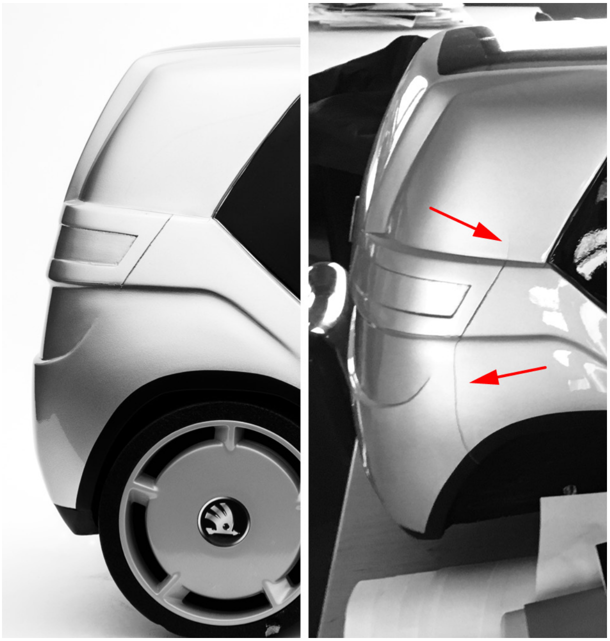
To remedy the degradation of the models yet maintain the visual quality of the paint, painted milled models began to be created in the third protocol, starting with a 3D scan of the clay model.
Therefore, starting in the seventh edition, the scan was inserted after finishing the clay maquette. The process to acquire and render a polygonal model suitable for milling entailed the classic phases of acquisition, alignment and cleaning, merging, and editing [Guidi, Russo, Beraldin 2010]. As can be seen in figure (fig. 7), the character lines of the

car door have practically disappeared in the final model, denoting a critical point in maintaining the design intent.
An analysis of the entire process shows that the most critical phase is editing, in which smoothing of the surfaces often coincided with simplification, leading to an excessive attenuation of some details. In this phase, the designers' review and control operations were less frequent due to the entire process being carried out externally.
The process was optimized starting from the eighth edition of the Master's programme: the clay model created by the students was only half modelled, relying on the intrinsic symmetry of cars. This greatly simplified the physical modelling process and ensured that the students concentrated more on defining the project.
In the last protocol used in the tenth edition of the Master, the polygonal mesh obtained from the scan of the clay studio maquette served as the reference for building a digital model based on NURBS-type polynomial parametric equations. This step was critical within the protocol because, without adequate intervention on behalf of the teachers (project manager) and students (car designer), the design intent changed notably. In fact, the operators' approach to the reconstruction was based only on the numerical variance between the NURBS surfaces and the scan. This meant that the reconstruction was quantitatively consistent with the overall acceptable tolerance of the total dimension of the model, but was inadequate upon qualitative inspection. With regard to the geometric faithfulness to the design intent, this translated into a comparison of character lines where they were not present in the original model, thereby changing the project.
These defects were corrected before painting thanks to a fruitful, intense collaboration between modellers and teachers. These corrections are clear from the photos (fig. 8), evidencing the position and trend of the character lines on the sides. The final result was therefore satisfactory, despite some differences that were not possible to fix (fig. 9).

Observations on the protocols

Following this long process to analyse the protocols, a series of results stand out about the treatment of the concept maquettes and their transformation into presentation models.
The qualitative verification by the professors was always important and decisive and always involved consultation of the drawings and renders made by the students, in addition to verification on the clay model. On the other hand, the protocols became progressively more complex while the time dedicated to them remained unchanged.
The debate conducted over these years highlighted a series of guidelines within the scope of supporting the work in the final steps of the Master's programme to achieve the best balance between faithfulness to the design intent and visual quality.
First, it is known that the more formal maturity a project has, expressed in varied ways of representation such as sketches, renders, and clay models, the more the finishing touches on the presentation model will be faithful to the original design intent. When this does not occur, steps to define the presentation model are used as an additional moment in the design process, increasing the difference between the final model and the original design intent. It is

Fig. 6. Cracks on a painted clay model. The same model after some time.



therefore always necessary to clearly define the deadlines to avoid prolonging the "design timing" and indecision.
Problems involving the correctness of the shape always regard the definition of the surfaces in the project. Analysis of their semantic division [11] [Cheutet 2007] is an important tool in the review phases to highlight and share the surface and character lines trends.
Critical aspects leading to errors in the digital model were detected at two different times: when editing the polygonal model deriving from the three-dimensional scan, and during NURBS modelling. In the first case, an excessive rounding of the fillets was detected, leading to a reduction in the character lines. In the second case, an increase in discontinuity was detected, with the consequent creation of character lines where they did not exist.

Fig. 7. Milled model, sketch, and render of Audi Jewl.in, Ed. 9 (Gianluca Raciti, Giancarlo Temin, Esteban Wittinghan Q., graphic elaboration by by G. Raciti).

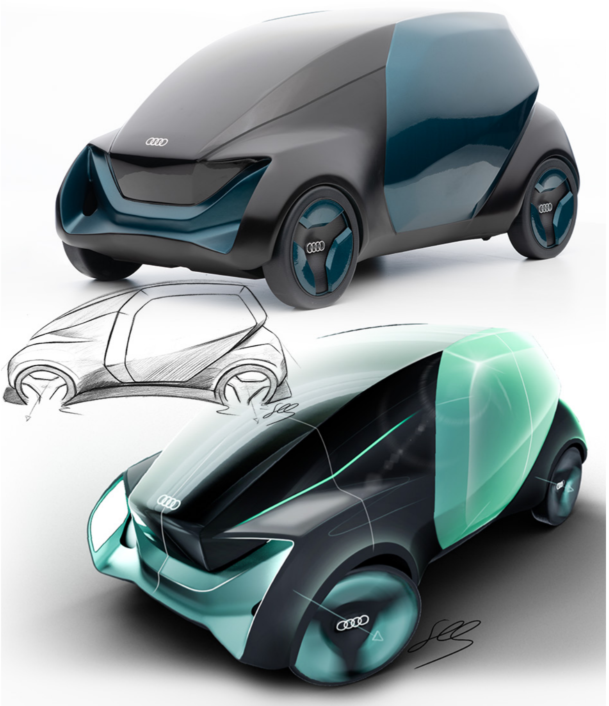
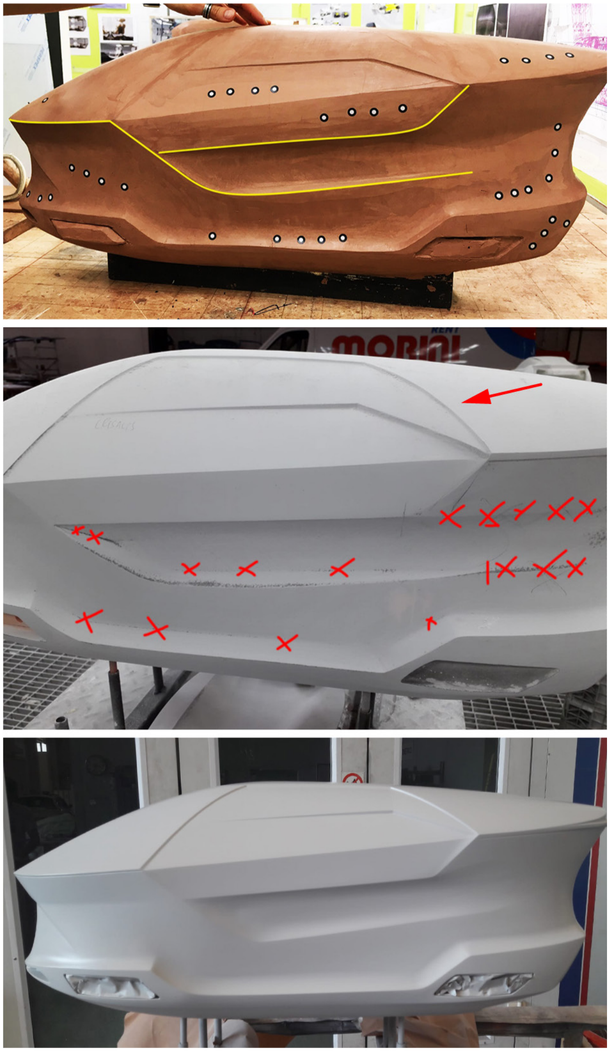


Fig. 8. Photos of the model revision phases. From the top: clay model, milled model to be corrected, and corrected version.



Conclusions

Among possible ideas for improvement, we can consider some tied to the process of creating the digital model and others tied to the means of using the iconographic material. Together with the design review, this material served as the most effective tool for guaranteeing faithfulness to the design intent.
With regard to the model, a possible solution would be to integrate the two modelling methods (NURBS and polygonal surface editing) in order to use the best of both approaches. The milled model should also be developed directly by the students, diversifying the approach among the various projects according to the level reached. In this sense, it may be useful to achieve a certain level of definition for the main surfaces in the clay model and then move on to a reference scan, followed by the definition of the project exclusively through digital modelling.

With regard to the iconographic material, it should always be present in support of every step, precisely to maintain the intent, also supporting the scans so that the operators do not rely solely on the quantitative assessments tied to them.
It is certainly necessary not to lose sight of the fact that we are always dealing with a design concept and not a definitive project, and that the time available to develop the presentation models is limited by teaching deadlines. Different representation tools say different things in the narrative of design activities, so they should not necessarily reach the same level of definition. What is important is to clarify the narrative and purpose of each tool.

Credits
The present paper is the result of research and results obtained by the authors together. However, the first and second sections and conclusions were written by Fausto Brevi; the other sections were written by Flora Gaetani.

Notes

[1] In some schools, the final model is in 1:1 scale, but students involvement is normally only marginal.

[2] The scales of the physical models do not follow the standard scales of representation in industrial technical drawing.

[3] Character lines are the lines determined by the intersection of the main surfaces defining the volumes of the car. These are edges that will not exist in reality because they will later be rounded, but they describe the "character" of the shape of a car and define the formal DNA of a brand.

[4] Colour Material & Finish. This is an area in the automotive world (also called Colour & Trim) dealing with the design of colours, materials, and surface finishes. Its epistemological origins lie in fashion design, with the adoption of its languages and tools.

[5] For the design process in companies, see The design process: <https://bit.ly/365dGmG> (Mercedes, accessed 2020, October 22); <https://bit.ly/37ahodV> (Jaguar, accessed 2020, October 23).

[6] These limits include the general dimensions, respect for obstructions due to the technological components, ergonomics, and legislative safety standards.

[7] The composition of car modelling clay material allows it to be spread out after heating and mould removing material.

Fig. 9. Render and model of Audi Crisalis, Ed. 10 (Filippo Batavia, Jean P. Bruni, Edoardo Trabattoni, Pietro Tranchellini, graphic elaboration by F. Batavia).

[8] 'Digital modellers' are sometimes also called 'surface modellers' or 'Alias modellers' after the name of the most common software used for this purpose.

[9] As a reference, see the site of Jaguar design process: <https://bit.ly/37ahodV> (accessed, 2020 October 23).

[10] Its composition and application are described on the distributor's website: <http://www.chavant.com> (accessed, 2020 October 24).

[11] Semantic division is the definition of primary and secondary surfaces, and also the position and radii of the fillets.

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