M. Sc. Engineering Design

Automobile Front-End Structure: Modularity and Product Platform

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Abstract

This paper has as its main objective to develop and apply modularity and platform concepts on an automobile front end structure designed to outperform the Peugeot 406 Coupe.
Supported by different existing structures benchmark and main innovation sources research focused on modularization and platforms a new type of structure will be studied and developed.

1. Introduction

“To sustain sales growth and market position, manufacturers absolutely must have strategies for developing products to meet customer needs innovatively without driving up costs, sacrificing quality, or delaying product delivery” [1].

One of the ways to attain these objectives is through the use of modules and the creation of a platform based product family. The front end of an automobile structure presents a set of characteristics that allow the use these concepts, although their application requires deep changes in current automobile structures philosophy.

Here, will be presented an analysis of different types of structures, materials and its implications to better explain the adopted innovation strategy and help understand automobile structures innovation main drivers. This analysis was based on automobile repair shops and stands benchmark, on Internet, papers and patent research.

In this context, we seek to create an innovation strategy for the automobile front-end frame structure development based on modularization concepts and platform products, in order to outperform the Peugeot 406 Coupe’s current one.
2. Product Definition

During the history of the automobile its structure has suffered a great number of changes. These are due to technological developments, to organizational changes and new social concerns, emphasizing the new material and production technologies development, new production philosophies (ex: *just in time*) and the growing concern on ecology and safety.

2.1 Structure Types

2.1.1 Chassis / Body-on-frame

The chassis was the most common type of structure used on the earliest cars of the 1900’s. Mounting a separate body to a rigid frame, which supports the drivetrain was the original method of building automobiles, and its use continues to this day. The original frames were made of wood (commonly ash), but steel ladder frames became common in the 1930s.

![Automobile with a Body-on-Frame structure. Isuzu [23]](image)

However, the automobile increased complexity allied to the new weight reduction demands, made this type of structure unviable. Most small passenger vehicles switched to unibody construction in the 1960s, leaving just trucks and large cars using conventional frames. Notable long running examples in the UK have been the Land Rover ‘Defender’ and the ‘Discovery’ series. Body-on-frame remains the preferred construction method for heavy-duty vehicles, especially those which are intended to carry and pull heavy loads.

Due to components complexity increase, this type of Body Structure has stopped being used. However, and connected to the *drive by wire* and *fuel cells*, this type structure is starting to reappear, but with a deep redesign.
The chassis structure type (skateboard structure) contains the powertrain and mechanical components, while the body is a separate structure. There are no mechanical links between the body and chassis. This makes it easy to produce the rolling chassis in large quantities separate from the bodies, and place an almost limitless number of different body styles on top of a common structure.

2.1.2 Monocoque (Unibody)

Monocoque or Unibody is a construction technique that uses the external skin of an object to support some or most of the load on the structure. This is as opposed to using an internal framework that is then covered with a non-load-bearing skin. Monocoque construction was first widely used in aircraft, starting in the 1930s, and is the predominant automobile construction technology today.

The first automotive application of the monocoque technique was 1923’s Lancia Lambda. Citroën built the first mass-produced monocoque vehicle in 1934, the innovative Traction Avant. The popular Volkswagen Beetle also used a semi-monocoque body (its frame required the body for support) in 1938.

Unibody is a specific type of a Monocoque structure that was developed in the post-war period. The Ford Consul introduced an evolution of the monocoque chassis, called unit body or unibody. In this system, separate body panels are still used but are bolted to a monocoque body-shell. Unibody is defined as a structural skin where outer panels are welded together early in production, contributing to the overall structural integrity of the vehicle.
Unibody construction is now the dominant technique in automobiles, around 95% of current automotive production world-wide uses the welded steel monocoque as the conventional form of body construction. It has provided an efficient and cost-effective means of volume production since the 1950’s.

### 2.1.3 Space Frame

Originally developed for performance cars such as Maserati in the early 1950’s, the Space Frame structure body panels are attached on an extruded metal structure, offering greater flexibility in terms of production assembly and in the choice of materials. Current space frames can be constructed from either aluminium or steel extrusions and can readily take advantage of technology such as composite panels and high-strength adhesive bonding.

### 2.2 Materials used

#### 2.2.1 Steel Alloys

Steel is the most predominant material in a vehicle, in average it constitutes more than 60% of the weight of the automobile. This strong application in the industry automobile is dewed to the capacity of the steel industry to present new solutions and have chain of
steady and reliable suppliers. The great disadvantage of its use is its high density, reason for which is constantly threatened. New applications of the steel, as steel foam, high resistance and low carbon alloys, as well as components optimization through the conception, have kept the high competitiveness of this material in the automobile industry.

2.2.2 Aluminium Alloys

Automobile production made out of aluminium alloys is still relatively small and few are the models that completely present an aluminium structure, such as the Honda NSX, Jaguar XJ, Audi A8 and Audi A2. Although a large scale of certain structural elements is produced in aluminium, an entire model is still unusual. Aluminium presents, relatively to the steel, as disadvantages the fact of being more expensive as well as the difficulty of assembly and repairing due to weak weldability. However the perspective of an increasing use of Aluminium in the automobiles have harnessed the development of more advanced techniques of stamping, as well as the development of alternative technologies as hydroforming. The use of Aluminium in automobiles in alternative to Steel can reduce the weight of these up to 30%, being its application main advantage.

2.2.3 Carbon Fibre

The 1st composite structure appeared in 1981 on the McLaren MP4-1.

![Figure 5 – Carbon Fibre structure. Porsche Carrera GT [25]](image)

In spite of the high structural quality of carbon fibre, it’s not often used due to its cost and low production rate. Even if material costs are reduced, there are still problems. One is that most automotive applications of CFP involve the time-consuming process of hand-positioning every layer of fibre and then placing the resulting resin-impregnated parts in an autoclave for a lengthy bonding process, resulting in a cycle time of several hours.

3. Component Identification

Here is a brief description of Peugeot 406 Coupé frame structure. It presents a unibody type structure constituted of steel stamped parts.
The 81 parts that constitute the car are stamped and assembled by resistance welding and MigMag welding. The automobile has to provide engine, suspension, steering, battery, radiator and bumper support, wheel space and guarantee frontal crashes protection.

4. Modularization and platforms

4.1 Modularization

These last few years modularization concepts have been widely applied in industry all around. However each type of industry and its region has its own modularization concepts.

Modularization can be divided into three main groups (Takeishi and Fujimoto 2001 [2]):

1. Product architecture modularization
2. Production modularization
3. Inter-firm systems modularization (based on outsourcing)

Product modularization relates to the creation of direct relations between components and its functions. A component becomes modular as the relation between itself and the function it performs becomes unidirectional. Meaning that a component can be totally modular if it relates to, and only to itself a certain function. So that a component can be modular it still needs simplified and standardized interfaces.

As figure 7 shows, in product modularization each component relates to a function and each sub-component relates to a sub-function. With this methodology and in order to change a function or sub-function it’s only needed to develop one new component and not the entire product as it happens with fully integrated products.
In process modularization (figure 7) the product is divided into several components (modules). Each module is produced in its own assembly line. Afterwards the several parts are assembled in the main line. This type of approach allows better components handling as a higher quality control. On a traditional approach the parts (or small modules) are assembled in a sequential way on the main assembly line.

In inter-firm system modularization (figure 9) usually the bigger modules assembly made through outsourcing. These modules are then assembled on the automakers main
assembly lines. Inter-firm system modularization is not only performed at the production level but also at the component conception and assumes the existence of a process modularization.

From the three present modularization types, product, process and inter-firm system, product modularization will be analysed in greater detail due to its major influence on the new front-end structure development.

For product modularity to exist its necessary the fulfilment of two criteria (Muffatto and Roveda [3]):

- A one-to-one mapping from functional elements to the physical components of the product
- Presence of non-specific interfaces between components
Meaning that is necessary for the components (modules) to have a well defined function. To change a certain function one only needs to modify the respective component or to modify a component it’s only needed to modify its respective function staying the rest unaltered. This is due to the existence of independence between several components and the performance of several functions.

The figure below shows the difficulty/complexity of modularization related to product structure.

**Figure 10 – Modularization complexity related to product structure [source: 3]**

Product modularity can be divided in several types and forms (Heikkila and Kaski 2005 [4]):

1- Component-sharing modularity
2- Component- swapping modularity
3- Cut-to fit modularity
4- Mix modularity
5- Bus modularity
6- Sectional modularity

In component-sharing modularity (figure 11a) products are designed around a common component. Ex: cellular phones.
In component-swapping modularity (figure 11b) there is the possibility to select option within the standard product. There is a list of modules that can be added to the base product. Ex: personal computers.

In cut-to-fit modularity (figure 11c) there is the possibility to change the dimensions of certain modules before combining it with another module. Ex: glasses.

In mix modularity (figure 11d) the modules lose their identity after combined. Ex: Ink cans obtained through mixers from the base colours.

In bus modularity (figure 11e) the modules can be added in line to an existing base. Ex: Track lighting.

In sectional modularity (figure 11f) the modules fit each other, but in a unique way. Ex: Lego.

Modular products production has as main advantage to allow more flexible products, more adapted to customer needs, less response time to market changes and a smaller components number to a product family.
4.2 Platforms

The thinking behind the platform strategies is quite straightforward, although the concept is quite elastic. In essence, platform strategies are a form of carry-over whereby components from one product are used on another in a more comprehensive and structured manner.

A product platform is a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed and produced (Muffatto and Roveda, 1999 [5]).

Platform strategies take several forms. The main versions are:

- The platform is used to provide models of a similar basic size and layout for two or more separate brands held within one group. This is the ‘classic’ form of the multi-brand platform. An example is the VW Lupo and the SEAT Arosa.

- The platform is used to provide several variants of the same basic model. One of the most successful of the recent attempts at this strategy has been Renault with its Megane models.

- The platform is used to provide niche models. Examples here include the Ford Puma (derived from the Fiesta), the Audi TT (derived from the VW Group A platform), and the Opel Tigra (derived from the Nova).
• The platform is of such a design that by adding or subtracting sections, it is used to provide models in more than one size segment. For example, the Ford Fiesta is a B segment platform. Ford created the Ka from this platform, but the smaller Ka is categorized as a ‘sub-B’ segment car.

• The platform is used to support multiple manufacturing locations and globalization strategies [6]. The Fiat Palio is a good example of this use of platforms with a car designed for emerging markets around the world and built in several locations.

Product families development through platforms has major benefits in cost reduction, quality enhancement, variety increase and higher strategic management flexibility.

“World Products” production, with each region’s particularity, it allows the use of platforms to a high number of products. This makes it possible to reduce costs through the use of scale economy. Product reliability and quality is amplified due to the already tested platform products production. Platform production also allows an external variety increase (on the market) with an internal variety decrease. This implies a family type product development resulting in reduced development times for new products allowing greater external variety. The flexibility increase makes it possible to launch new products more rapidly, answering faster with fewer costs to market variations.
The two above mentioned concepts, modularization and product platforms, are closely connected often being confused. Modularization is sometimes considered a type of platform, or the opposite, platforms being considered a type of modularisation.

One way to separate these two concepts is the number of products in question. Modularization relates to the possibility of easily changing one product function through the change of some of its components and product platform relates to the resource sharing between a product family.

5. Modularization and Platforms in the automobile industry

For the global automotive industry, platforms are the panacea of the 1990s, the perfect way to combine economies of scale, globalisation, multi-branding, and rapid rates of new product introduction. Recent mergers and acquisitions have reinforced the strategy of building brand portfolios, which have been further underlined by vehicle manufacturers considering the revival of moribund brands such as Riley (BMW-Rover), Auto-Union (Audi) and Maybach (Mercedes).

An automobile platform is a shared set of components common to a number of different automobiles. Many vendors refer to this as a vehicle architecture. Originally, a platform was a literally shared chassis from a previously-engineered vehicle, as in the case for the Volkswagen Beetle frame under the Volkswagen Karmann Ghia. The first generic platform to be shared among a number of vehicles was the Ford Fox platform of the 1970s. In the 1980s, Chrysler's K-cars all wore a badge with the letter, "K", to indicate their shared platform.

Today, platform sharing is much less noticeable. Vehicle architectures consist of "under the skin" components only, and shared platforms can show up in unusual places like the Nissan FM platform-mates Nissan 350Z sports car and Infiniti FX SUV. Volkswagen A platform-mates like the Audi TT and Volkswagen Golf also share much of their mechanical components but seem entirely different. Ford Motor Company has had much success building many well differentiated vehicles from many marques off the same platforms.

In general terms, the cost-savings delivered by platform strategies can be exploited in many ways. The vehicle manufacturers can offer ‘more car for the money’, with higher levels of equipment, better materials, etc. This is clearly the case with the VW Golf for example which has won praise for raising the standard of the segment in which it sells.

Indeed, if the recent performance of the VW Group is considered, it is apparent that platform strategies have been very successful in terms of increasing total sales volumes and relative market share [7]. Between 1997 and 1998, VW Group sales in Western
Europe grew by 17.8% to 2,189,000 units, sales for Skoda grew an impressive 41.2%. In addition, profitability at VW Group has increased.

It is important to acknowledge that differentiation between the various brands in a multi-brand structure is achieved in a variety of ways not just in terms of the product appearance and performance. Niche models derived from platforms, and only economic because of the volumes achieved on the platform, can be used to enhance brand values across the model range. The marketing dimension of platform strategies further involves issues such as franchised dealership network characteristics, service, finance and other packages, advertising and sponsorship. All of these may be used to enhance brand differentiation. In this sense, the Audi ‘ownership’ experience is distinctly different than the Skoda experience.

However, the vehicle manufacturers face two key issues with respect to multi-brand marketing of platforms: brand integrity and internal competition. Brand values are an emotive issue both for the vehicle manufacturers and for consumers. There can be little doubt that in the automotive industry, ‘brand equity’ is absolutely vital for competitive differentiation. In this respect, sales and marketing staff may be caught between the desire for newer and better models which platforms offer, and the desire to ensure that the core customer base is not alienated by features which are anathema to the traditions of the brand. Niche models which aspire ‘sporting’ values, but are derived from more humble high-volume cars, may lack the dynamic qualities that consumers expect and have a negative impact on the perceived values of the brand.

The problem of brand integrity can only be exacerbated in situations where separate vehicle manufacturers share product [8]. This is often the case when one manufacturer alone cannot generate sufficient sales volumes to justify the investment cost required for a model. Current examples include the Ford Galaxy, VW Sharan, and SEAT Alhambra MPVs, all produced at Setubal in a plant jointly owned by Ford and VW. In these cases, the vehicle manufacturers may sustain product differentiation and go beyond ‘badge engineering’ by offering their own engines and transmissions, as well as minor trim differences. However, it is clearly more difficult for any manufacturer to develop coherent brand separation and product differentiation marketing strategies when it does not have control over all the brands.

The second major threat is that the incremental sales generated by creating a new model from an existing platform is that sales may be taken from existing models within the brand(s) controlled by a manufacturer. Thus, for example, a prospective VW Golf buyer may choose a SEAT Toledo, an Audi A6 buyer may choose a VW Passat. Where differentiation between models is not perceived as substantive, consumers may consider that the premium brand model is no better than the cheaper ‘mass’ product. Most vehicle manufacturers have experienced declining customer loyalty over time. There is a danger that platform strategies will simply encourage further brand switching by consumers.
6. Others Innovation drivers

Modularization and product platform are definitively innovation factors in the automobile industry. There are, however, other very important factors that were analysed during the front-end structure development. These factors appear due to social, economical and environmental changes, such as customer’s awareness and growing automotive industry competitiveness. Follows a brief description of these factors.

6.1 Cost efficiency

Due to the above mentioned high automotive industry competitiveness, the production cost is a very important factor when producing an automobile, and therefore cost is one of the main innovation drivers. Globalization and increasing information access have made the final consumer more demanding. The automobile industry has to keep improving the production quality, car reliability and also present a competitive price. The cost efficiency concerns are present in the entire product life cycle, from raw-material acquisition to automobile recycling.

6.2 Safety

In the automobile industry, safety is an innovation driver of high importance. Strongly stimulated by the development of information technologies, safety has become a fundamental innovation driver, pressuring the automobile industry to apply efforts in this area. Legislation stopped being the only aim to fulfil. The attainment of high scores in Car Assessment Programs, as for example the EuroNCAP or the USNCAP, has become a competitive factor heavily used by the automobile industry. Being the capacity to absorb energy during a crash one of the frame structure main functions, safety has been one of the more important innovation drivers.

6.3 Environmental impact

The producer responsibility for the product related environmental damage in its entire life cycle allied to growing awareness of environmental problems forced a change on automobile industries environmental strategies. The Kyoto agreement, but mainly the end-of-life vehicle management directive forced the automobile industry to focus on other areas such as engine performance, vehicle weight reduction and recyclable raw material utilization.
7. Product Development

Based in the above mentioned innovation drivers a new structure for the Peugeot 406 Coupe was developed. In this paper only the modularization and product platform driver will be analysed, the remainder drivers analysis can be found in [9].

Peugeot 406 Coupe presents a unibody structure build of stamped steel sheets and plates.

![Figure 14 – Peugeot 406 Coupe front-end frame structure](source: Authors)

This type of platform, Unibody, represents an innovation in terms of platform production when compared to the Monocoque one’s. As also referred in chapter 2, in a monocoque type structure the outer shell plates support the main loads and are part of the automobile structure (figure 15).

![Figure 15- Chassis Monocoque, as chapas exteriores fazem parte da estruturas](source: Authors)

In a unibody structure the outer shell plates are not structural. Their only function is to cover the inner structure (part of structure that supports the loads) and to give the automobile its outer form (figure 16).
This type of structure allows a platform production as the structure can be shared among different models only being necessary to change the outer panels. The structure being an interior part, non visible, can be shared between models and brands without the loss of brand or models characteristics/identity. It has, however, limitations. The outer panels are limited by the structure geometry hence the application to different models is somewhat inhibitive. Unlike the application to different brands, same market segment.

The application of a type of structure to different models has lead to a loss of identity of some brands because although it is an interior component it strongly influences the outer ones that define the brand and model identity/characteristics.

With the objective of eliminating this influences and allow the use of the same structure in very different models a Spaceframe type structure was developed.

It was developed considering 406’s dimensions and mechanical components volume.
A spaceframe type structure gives the outer panels geometry a great deal of freedom (hood, side panels and bumper) (figure 19) unlike the current structure of the Peugeot 406 Coupe.

The developed structure can easily be modular and a platform product. It can be Component-sharing modular or Cut-to-fit modular as the outer panels can be developed around a common structure creating a model with different characteristics (ex: standard and sport version). On the other hand a quick redimensioning of the structure bars allows its use in other similar models (ex: station wagon version).

However this type of structure greatest advantage relies on the possibility to be used in platforms (different brands and models) without losing their basic characteristics or identity. This due to the fact that a Spaceframe structure is an open structure type build from tubes that did not constrained the outer form. The outer panels can have different
forms and characteristics, only being necessary to guarantee the connection points between the outer panels and the different brands and models common structure.

For models that a dimensional change is necessary, a spaceframe structure has a lead advantage over the Uniboby one as it suffices to redimension some tubes instead of the whole geometry.

Figure 20 – Unibody and Spaceframe structure meshes.

8. Conclusion

From this paper it can be verified that different types of modularity and product platform exist and that their distinction is not easy nor consensual. Some authors define modularity as a product platform type. Based on the performed analysis one can conclude in a consensual way that the modularity and product platform distinction resides on component quantity. Modularization corresponds to the possibility to easily change functions of one product through the change of its respective components and product platform corresponds to the resource sharing within a product family.

As for the analysed structures it was verified that the most currently used structures in the automobile industry, one of which the Peugeot 406 Coupe, presents several limitations in platform and modularization production. This type of structure, Unibody, strongly constrains the outer components geometry leading to non brand or model differentiation.

The developed Spaceframe structure has clear advantages in terms of modularity and platforms application. Due to the fact it is an open tubular structure it allows the use of different outer panels material as plastic, steel, aluminium, etc. This can be achieved for different brands and models without any loss of identity/characteristics.
The inherent higher cost of this type of structure is compensated with higher benefit/cost relation. On the other hand, the development of new technologies as bonding and hydroforming, associated with the accumulation of knowledge from aluminium stamping, is responsible for decreasing the manufacturing cost of aluminium structures.

9. References


10. Additional Sources