POLITECNICO DI TORINO

Master's Degree in Automotive Engineering

Scientific adoption of virtual reality tools for ergonomic validation and design of a self-configurable seating-buck

Advisor:

Prof. Andrea Tonoli

Candidate:

Vincenzo Belmonte

Academic year 2017-2018

“Al ragazzino al secondo piano che canta, ride e stona.
Perché vada lontano,
fa’ che gli sia dolce anche la pioggia nelle scarpe,
anche la solitudine”

CONTENTS

Introduction

The present work has been carried out at the "concept development department" at Italdesign Giugiaro S.p.A in Moncalieri (Turin).
Aim of the project is to apply the latest virtual reality technologies to the standard process used for the ergonomic validations.
In order to get the final task, it was necessary to follow two parallel paths. The first is mainly related to the design and realization of a self-configurable seating-buck that allows to represent all vehicle configurations in terms of cabin compartment dimensions and driving position. Such system acts as a link between the real world and the virtual one allowing to the user a physical basis for the ergonomics validation with the use of standard components for the main elements that define the driver accommodation, as the seats, the steering wheel and the pedals.
The second one provides preliminary tests in order to evaluate the accuracy and the reliability of some virtual reality tools obtaining encouraging results but also highlighting the limits of this technology at least for consumer grade sensors.
Since the treated subject deals with the ergonomic and design parameters affecting the vehicle accommodation, the first chapters give a brief overview of the main theoretical concepts and the regulations that govern the design of a human oriented cabin compartment able to fully comply with safety and ergonomic requirements.
Moreover, it was considered appropriate to describe how the ergonomic validation process it is performed nowadays and the role that physical models play during this essential phase of the project of a new vehicle.

1 Vehicle Seating Accommodation

1.1 Ergonomics and Comfort Fundamentals

With the term *Comfort* is intended a feeling perceived by the user, in a working environment or in other specific service conditions and is aimed to the definition of the perceived level of well-being.

In the Automotive field, it is mandatory to guarantee to the passengers a high comfort level. Since the vehicle is designed to carry occupants and goods and it can also become, as in several cases, a working environment, it is necessary to properly define some parameters and take care of different details in order to reach the desired target. Beside the simple feeling perceived by the passenger it is important to take in mind also the safety aspects. It is clear nowadays that the comfort plays a key role both for the active and the passive safety. It is obvious, indeed, that a driver acting in an uncomfortably situation will be less focused on driving, increasing the risk of crashes. [1]

Regarding the passenger vehicle, different theories hold that among the factors that affect the on-board comfort, the main is the seat, that should allow several adjustments according to the anthropometrics of each passenger, providing an important sustain. Modern vehicle seats are complex systems and their comfort level deals with several aspects making the necessity to study the problem with a multidimensional approach. Such approach will include, of course, the vehicle packaging characteristics (height of the seat, steering wheel positioning, pedals positioning, space for knee and legs), design aspects (stiffness of the foams, geometry, breathability), but also social aspects such as the brand, the style and the culture of the customer. [1]

Figure 1.1 Ergonomics - Human Centred Design [2]

The term ergonomics derives from the ancient Greek "ergon" (work) and "nomos" (law): according to the IEA (International Ergonomics Association), ergonomics is the science that deals with the interaction between the elements of a system and the function for which they are designed, in order to improve the user satisfaction and the overall performances of the system. [2]

The Italian Society of Ergonomics (SIE) states that the object of the ergonomics is the human activity in relation with environmental, instrumental, and organizational conditions in which such activity is performed. The purpose is the adaptation of such conditions to the human beings, with respect to their characteristics.

Born with the aim to study and to enforce during the design a series of regulations that safeguard the lives of the users and increases the efficiency and the reliability of the Human-machine systems, the ergonomics enlarged its own field of application to satisfy an always increasing demand of safety and well-being.

In the last years the ergonomics is fed by the acquisition of scientific and technological development that allow to improve the quality in everyday life.

The ergonomics can be divided into three main branches:

- Physic Ergonomics: posture, vibrations, working loads;
- Sensorial Ergonomics: Concentrated senses (Sight, touch, hearing, smell) and distributed senses (thermal, kinaesthetic);
- Cognitive Ergonomics: Perception, cognitive action, decision.

Regarding the automotive field, in the past, the ergonomics was interpreted only after the vehicle realization, to understand the matching with the needs of the customer. Nowadays, instead, it strongly influences the design process in order to promote the development from the customer point of view. A vehicle must be, as well as functional also people-oriented. [3]

1.2 Anthropometric Data

1.2.1 Human Body Variability and Statistic Description

Anthropometrics is the science that measure the human body in its totality or in its components: in other words, the anthropometrics deals with criteria aimed to express the shape, the dimensions and the composition of the human body. Ergonomics uses the anthropometric knowledges regarding with the relation of the people with the environment in which it operates. [4]

The measurements of human body dimensions are crucial during the design of products and working environments; since the characteristics of an environment and the location of components and different controls in it are determined by the potential users and on their preferences, it is fundamental to design such environment considering the different body dimensions and the necessary movements to interact with it.

The wide range of body dimensions and anthropometric data characterizing each individual, in the specific case each vehicle passenger, influences the perceived comfort. [1]

In order to represent the human variability and describe it in statistical terms, the percentile concept is used: The percentile represents the number of people in percentage that for a given anthropometric dimension have that value lower or at least equal. For example, the height corresponding to the $95th$ percentile is the height that is not exceeded by 95% of the population considered in the study.

Since in the main applications it is necessary to predict a variation of a particular characteristic taken in exam, such variability can be generally described by a Gaussian distribution.

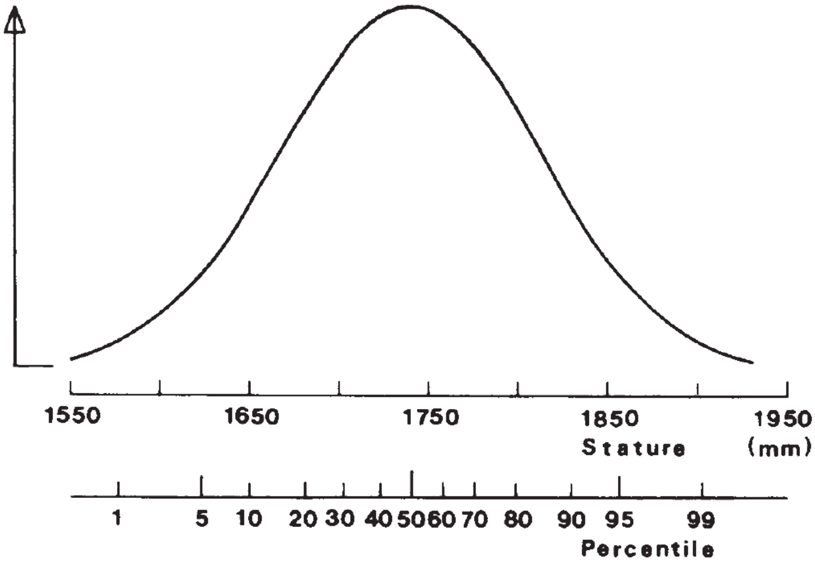


Figure 1.2: Example of gaussian distribution regarding British male adult height (1984) [4]

In the figure above, used as example, the horizontal axis represents the values of the considered quantity, while the vertical axis represents the frequency with which is expected to find a person characterized by a given value of such dimension. The distribution is symmetric with respect the mean value, that will also correspond to the maximum of the probability. Regarding this distribution it is possible to state that the 50% of the population (50%ile) is smaller than the average value; [4]

However, it is important to take into account that anthropometric characteristics are strongly influenced by different aspects such as the age, the gender but also geographic and ethnic contexts. This is an aspect that must be considered especially nowadays in a more and more worldwide oriented market.

1.2.2 Static and Dynamic Anthropometrics

Other important definitions useful to the understanding of the treated argument are those of static and dynamic anthropometrics.

The Static Anthropometrics concerns the human structure dimensions, generally by means of a specific measurement taken between specific anatomic points in known posture established by regulations and standards. Some examples are the height, the height of the eyes or of the elbow in upright posture, limbs lengths, shoulder width.

The Dynamic Anthropometrics, on the others side, includes reachability measurements and area of freedom that allow to a subject a certain degree of freedom aimed to adopt a "natural" posture and to perform a determined task.

1.3 Hints on Biomechanics

1.3.1 Physiological Aspect

The sensation of comfort in a vehicle is mainly influenced by several subjective parameters such as the sense of safety, the state of health and the psycho-physical well-being. For this reason, it is very hard to carry out comfort measurements that can be considered as universal accepted. The driving position can be considered belonging to the family of the so called static posture, and this strongly affects the comfort feeling. During that period the driver should be able to preserve the ability to act on all the commands and to rotate his head without efforts.
Nowadays the perceived discomfort is mainly related to keeping the posture and not to the need to operate the commands acting on them with anomalous operations of the body segments and relative joints. [5]

1.3.2 Static and Dynamic Muscular Activity: optimization of muscular strength

It is possible to distinguish between static and dynamic muscular activity: the static condition is generated by the contraction of a muscle to oppose to a movement or to a load. In this condition the length of the muscle remains constant and there are no movements in the body segments involved in the activity. During a dynamic activity, instead, the length of the muscles changes and the body segments involved in the activity moves.
In order to use the muscular strength in the most efficient way, body junctions must lie in "neutral" position: in this way muscles and ligaments that cross the body are in the lowest possible tension level allowing to exert the maximum force.
Raised arms postures, rotated wrists, bent neck or head, are some examples of posture in which body joints are not in a neutral position.
In general, besides, it is suggested to limit the duration in time of each muscular effort and to alternate posture and movements to prevent fatigue and musculoskeletal damages.

1.3.3 Postural Dimensions

Relevant dimension in postural terms, that allow to evaluate the postural stability of an individual, estimate loads, moments on joints, fatigue and rest necessity, are:

- Angles between segments
- Body masses distribution
- Loads applied to the environment
- Duration and effects of posture retention

Some postural examples are reported in the figure below.
Static posture are body positions adopted for an extended period, while the uncomfortable are those that need constant movements and changes.
The sitting, both in a work environment and referred to vehicle passengers, is considered as a static position. Among different driving positions, some are considered better than other since they reduce the fatigue causing musculoskeletal problems, that, as said above, often involve pain mainly in the backbone zone, in the neck and the shoulders. [1]

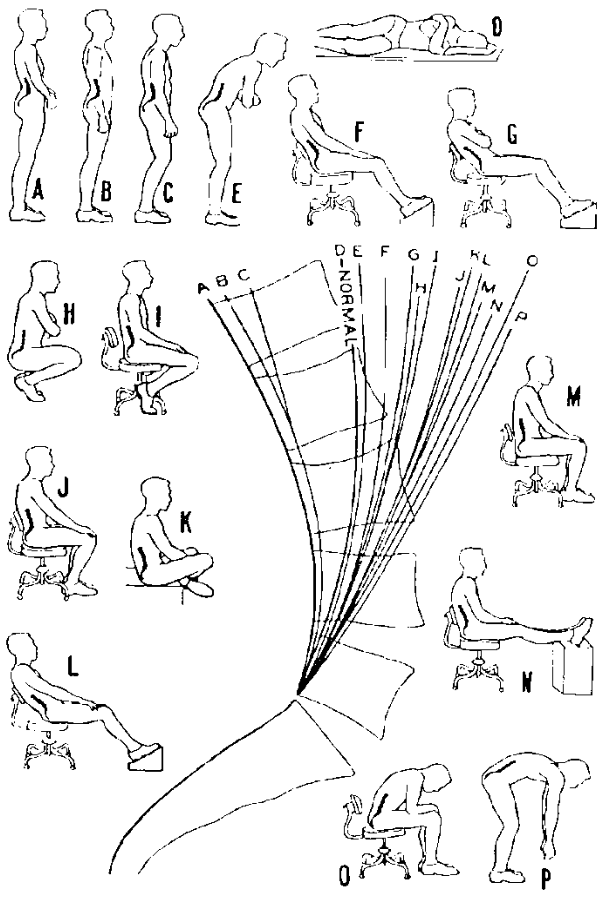


Figure 1.4 Postural examples [5]

1.3.4 Fundamentals of Ergonomics Design

According to the given hints of posture and biomechanics, it is possible to define the main aspects that must be taken into account during ergonomics design:

- Controls and their functions must be designed, and positioned in order to be compatible with:

- Body segments physiological and movements characteristics used for the actuation.
- Requirements of speed, precision and effort
- Possibility to avoid human errors and/or minimize relative effects

- The type, the design and the layout of the controls must correspond to its relative control aim;
- Controls must be designed and positioned to minimize risks that could affect the user safety and health, taking into account all possible accident situations and their frequencies.
- The stroke and the actuation loads must be chosen according to the nature of the task and to the physiological nature of the users and have to be based on anthropometrics characteristics.
- The function of each control must be easily identified and recognized from adjacent commands.
- Some specific controls must be protected in order to avoid accidental actuation.
- When possible, it is appropriate to reduce the number of controls, may be embedding in the same one different tasks.

1.4 Hints of Vehicle Accommodation

1.4.1 Comfort of the Driving Position

The term accommodation defines the position occupied by a passenger in a vehicle. In particular with position is intended to the position assumed by the driver holding the steering wheel on its centreline and with feet placed over the pedals in the rest position. The comfort of the driving posture is influenced by the extent of static muscular contractions involved on the steering wheel, from the stretching and the contraction of the fleshy parts surrounding the articulations, as well as from the compression derived from the seating contact zone. Important aspects are given by the sustain of the lumbar zone and from the hip inclination to avoid abdomen compression.

Regarding the comfort for rear passengers instead, this is mainly characterized by the higher possible level of unloading of possible muscular activities. Important need is the higher possible level of active mobility for all articulations, up to the opportunity to completely modify the body position.
At the same time, it is necessary a certain level of sustain in order to limit the passive mobility during lateral and longitudinal vehicle accelerations.

The vehicle comfort concept is of course related to the type of the vehicle, that unfortunately cannot be realized following to a pre-fixed scheme but to the kind of its destination of use. The main typologies of vehicles utilizations refer to the following conditions of use:

- Urban use: In such conditions it is requested a focused driving but for short periods and could exist the possibility of several inlet and outlet from the vehicle. Privileged aspects are external visibility, freedom of movements especially of torso and limbs, easy manoeuvrability of commands (intended as optimization of efforts), ease of access.
- Mid-long distances use: In this case the vehicle is often used in highways or extra-urban contest. The driving position is more relaxed and there are more possibilities in the modifications of the posture.
- Sport driving: The peculiarity of a sporty vehicle is a lower mass centre determining a distended position of the limbs; are requested fast actuation of the commands and high level of sustain of the body against lateral and longitudinal accelerations. [3]

1.4.2 Design of Driving Position: ergonomics assumptions

The main aspects, considered during the design of the driving position are: direct and indirect visibility (front and rear), seats adjustments, inclinations and positioning of the steering wheel, dispositions of pedals and other commands such as gear lever and hand brake.
Of course, the visibility is the main source of informations coming from the road when a user drives a vehicle. Generally speaking the direct visibility through the windscreen must respect some rules essentially regarding the field of view developed downwards and upwards starting from the point of view. The driver must be able to notice road changes other vehicles, signals and general obstacles but at the same time it is necessary to easily pay attention to the signals placed in high positions such as traffic lights and reduce the perception of confinement caused by the cabin.
As already said the seat plays a fundamental role in the described problem. It must ensure to any user (independently to the anthropometrics) a comfortable positioning, a correct reachability of the various commands, a sufficient external visibility, for this reason it must be provided by adjustments to ensure such functions. [3]

The steering wheel must be positioned in order to ensure the higher possible comfort level to the upper limbs of the users. The upper part of the steering wheel has to be reached without detachment of the shoulders from the backrest of the seat; nevertheless, it is necessary to avoid interferences between the elbow with the backrest and armrests during the taking in the lower part.
For this reason, the choice of the inclination of the plane tangent to the steering wheel rim must be chosen as compromise between two possible alternatives: a vertical orientation allows fast actuation but does not provide an optimal loads application; with a horizontal steering wheel, instead, the muscular effort is reduced but the speed of actuation is penalized.

Moreover, the steering wheel positioning also influences the instrument visibility and of the engine hood. Its lower part cannot interfere with user's legs during the actuation of the pedals. [3]

Regarding the pedals and their reachability, it is another fundamental parameter for the driving set-up and it is strongly influenced by the packaging of the vehicle.
The pedals must be designed and positioned in order to allow the maintenance of the angles between the legs segments inside the comfort ranges, so as the actuations of the commands must be ensured for all the users.

Concerning what described above the main requirements that a driving position must have to fulfil its functions are:

- Corporal aspect: The driving set-up must ensure a correct external visibility and of the cockpit. It must allow a comfortable positioning of the various body segments and allow the reachability of the commands
- Physiological aspect: The weight of the driver must be sustained in order to relief it without affect the musculature. The torso weight should be sustained by the backrest, thing that would require a consistent backward inclination. Nevertheless, an excessive backward inclination could cause too high levels of fatigue on the cervical articulation. For this reason, it is necessary to find a compromise to satisfy the two contrasting aspects. Another important aspect is the avoidance of anomalous hip angle that should promote a natural curvature of the backbone.
- Morphological aspect: Pressures generated on the driver legs must be opportunely controlled in order to be decreasing from the buttock centre towards the outer thigh. Must be absolutely avoided the slowing of the blood circulation due to too soft foams and the heat developed between the seat and the body must be reduced as much as possible.
- Structural Aspect: Vibrations coming from the road and passing through the body vehicle and its components must be reduced and opportunely controlled. In the end the seat itself must have good mechanical characteristics to sustain the body in case of crash. [3]

1.4.3 People in Vehicle Positioning: Preferences and Personal Habits.

The choice of the driving position in a vehicle strongly varies from one person to another. This depends on individual needs of each passenger that during the accommodation has as first aim to find a comfortable position for the different parts of the body. As consequence this selection strongly depends on the anthropometric characteristic, on preferences and on personal habits that could also bring to an anomalous usage different from the one planned during the design. However, it is obvious that the driver must be able to actuate simultaneously pedals, steering wheel and all primary controls. According to Sundström**,** any user tends to have one or two preferred positions, that usually holds most of the time. [1]

Unfortunately, according to what described up to now, it is very difficult to design an ideal driving position able to satisfy all needs.

The so called dynamic seat should be at the basis of the design of a seat. A fixed seating position at the end results harmful for the body. The ideal position is a variable one that encourages, by means of a well-designed seat, a variety of posture.

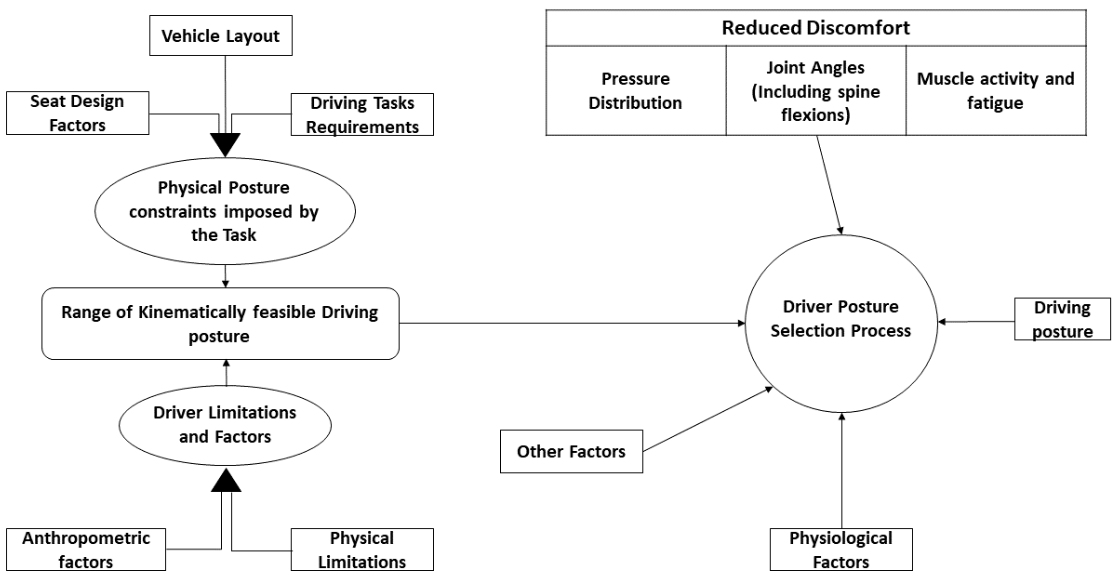


Figure 1.5: Block-diagram of the driving position selection [6]

The design of the passenger compartment, together with the one of the commands, of the seats and of the various possible adjustments, represent a set of kinematic constrains for the posture; moreover, the anthropometric factors and physical limits of the user interact with such constrains imposed by the vehicle structure during the determination of the potential driving positions. During the seating process also play significant role psychological factors.

A non-ergonomic design of the compartment brings the users to assume inappropriate postures bringing to physical problems; therefore, even if the driver uses to change its position to relieve an uncomfortable situation, at the end will result in another incorrect posture that will bring to other problems.

1.4.4 Procedure for Vehicle Seating Accommodation

Knowing at this point that does not exists an ideal accommodation positioning and that each user will follow a different procedure during this choice, it is however necessary to consider a series of rules that allow to reach a positioning that guarantees to increase the level of comfort and the control of the vehicle itself.

To get this task it is necessary to keep the shoulders perfectly in contact with the seat backrest and stretch the arms to reach the upper part of the steering wheel with the wrists. The backrest inclination must lie in a range between 18°÷25° with respect to the vertical axis.
Hands should be positioned in a “9:15 position” on the steering wheel inserting the thumbs in the dedicated housing. This hand opposition with respect to the vertical axis of the steering wheel allows a better control of the vehicle ensuring a higher sensibility of the adherence limits.
The seat must be positioned in order to reach the complete stroke of the pedals; The longitudinal adjustment must be set to obtain an angle around 120° between the upper and the lower part of the legs.
Ultimately it is necessary to regulate the fastening point of the seat belt, the headrest and the rear mirrors. These are some advices that allows to adopt a driving posture aimed to the increase of safety and comfort of the users.

1.5 Driving Pose Prediction

1.5.1 GCIE and Society of Automotive Engineers (SAE international)

The prediction of the driving position is fundamental for the design of the vehicle: Commands positioning, display, restrain systems, visibility verifications and the in general the design of the whole vehicle body, depends on the understanding of how the user will accommodate.
Since it is necessary that each car manufacturer deeply knows competitors’ vehicles, European automotive companies decided to exchange some real data in order to avoid costly operations and giving rise to the GCIE – Global Cars Manufacturers Information Exchange group.
The GCIE List (an example is reported in the figure below) allows the exchange of CAD files regarding the package of the vehicle with all standardized dimensions. Of course, this opportunity strongly facilitates the design process of a new vehicle. [7]

GCIE Procedure Part 3 - Rel 2006

Manufacturer :
Model name : - - - -
Model Year :
Body type :
Rear End :

\# of seats : 2
\# of doors : 2
Market : Europe
Engine displace[nt] : 3.0l
Tire/Rim Size Front : 225/45 R17
Tire/Rim Size Rear : 225/45 R17
Fuel Tank capacity : 55

Code -2003	M	Code	Mass	INTERIOR DIMENSIONS – LENGTH DIMENSIONS	Unit	Value	Comment
L13		L13		BRAKE PEDAL - KNEE CLEARANCE	mm		
L17		L17-1		MAXIMUM SEAT TRAVEL-FRONT	mm		
neu		L17-2		MAXIMUM SEAT TRAVEL-SECOND	mm		
neu		L17-3		MAXIMUM SEAT TRAVEL-THIRD	mm		
L18		L18		FOOT ENTRANCE CLEARANCE - FRONT	mm		
L19		L19		FOOT ENTRANCE CLEARANCE - SECOND	mm		
L23		L23-1		SGRP TO FOREMOST DESIGN H-POINT - FRONT	mm		
neu		L23-2		SGRP TO FOREMOST DESIGN H-POINT -SECOND	mm		
neu		L23-3		SGRP TO FOREMOST DESIGN H-POINT - THIRD	mm		
L26	2	L26	1	STEERING WHEEL TO CENTER OF FRONT WHEEL	mm		
L28		L28-1		LOWEST & REARMOST H-POINT TO HIGHEST & FOREMOST H-POINT - FRONT	mm		
L33		L33-1		SGRP TO HIGHEST AND FOREMOST DESIGN H-POINT	mm		
L34		L34		EFFECTIVE LEGROOM - FRONT	mm		
L48		L48-2		KNEE CLEARANCE - SECOND	mm		
L87		L48-3		KNEE CLEARANCE - THIRD	mm		
L50		L50-1		SGRP COUPLE DISTANCE - FRONT TO SECOND	mm		
L85		L50-2		SGRP COUPLE DISTANCE - SECOND TO THIRD	mm		
L51		L51-2		EFFECTIVE LEGROOM - SECOND	mm		
L86		L51-3		EFFECTIVE LEGROOM - THIRD	mm		
L52		L52		BRAKE PEDAL TO ACCELERATOR PEDAL	mm		
L53		L53		SGRP TO HEEL - FRONT	mm		
				WIDTH DIMENSIONS	Unit	Value	Comment
W3		W3-1		SHOULDER ROOM - FRONT	mm		
W4		W3-2		SHOULDER ROOM - SECOND	mm		
W85		W3-3		SHOULDER ROOM - THIRD	mm		

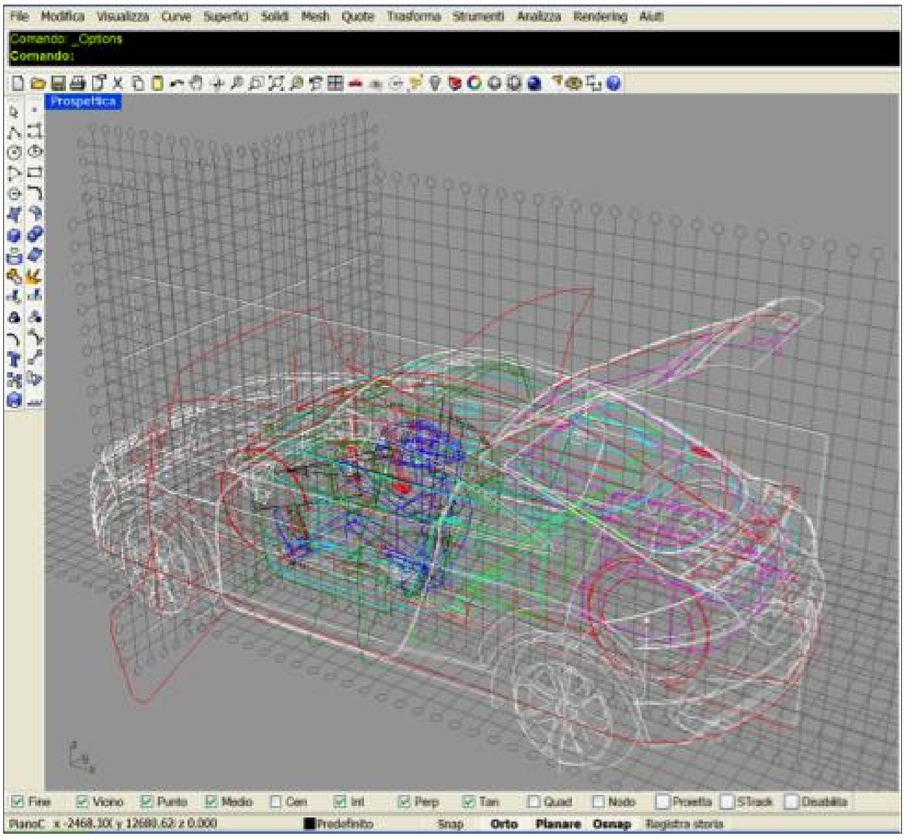


Figure 1.6: GCIE LIST – Data exchange example. [7]

The dimensional identification consists of a code[1] characterized by a number and a letter. For example, the value H30 is referred to the vertical distance between the H point and the vehicle floor. All dimensions are defined as normal with respect to the reference system (ISO 4130) except for the ground level dimensions, defined with a loaded vehicle with a given mass. [7]

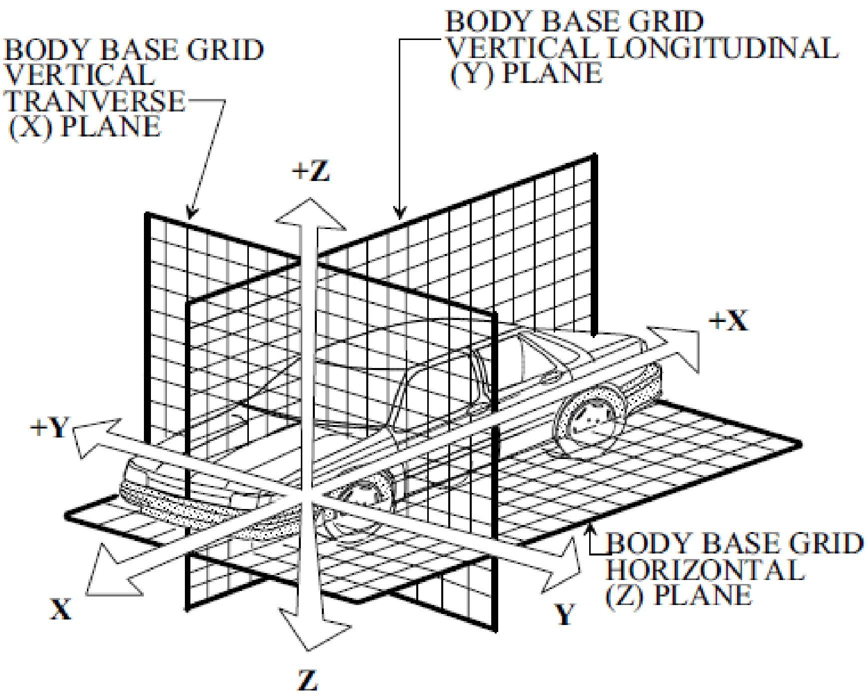


Figure 1.7: Reference system (Ref. DIN ISO 4130) [7]

Most of the dimensions reported in the GCIE, are taken from the SAE technical standards (Society of Automotive Engineers).
Even if in the automotive field each car manufacturer has its own procedures during the vehicle design and the ergonomics validations, the SAE practices represent an important basis. [8]
In the table 1.1 are reported the main SAE practices used for the internal package of a vehicle, while in the figure 1.7 are depicted the instruments defined in the above-mentioned practices. [8]

[1] The letters L, W, H, A, D, V, indicates respectively the length, the weight, the height, the angle, the diameter and the volume; numbers from 1 to 99 are used for internal dimensions, from 100 up to 199 for the external dimensions, from 200 to 299 for luggage compartment dimensions and from 300 to 599 for the *UCV (Utility Cargo Vans) vehicles.*

STANDARD	TITLE	DATE
J182	*Motor Vehicle Fiducial Marks and Three-Dimensional Reference System*	15/07/2015 *Revised*
J287	*Driver Hand Control Reach*	11/03/2016 *Revised*
J826	*Devices for Use in Defining and Measuring Vehicle Seating Accommodation*	10/11/2015 *Revised*
J941	*Motor Vehicle Driver's Eye Locations*	16/03/2010 *Revised*
J1052	*Motor Vehicle Driver and Passenger Head Position*	30/09/2010 *Revised*
J1100	*Motor Vehicle Dimensions*	20/11/2009 *Revised*
J1516	*Accommodation Tool Reference Point for Class B Vehicles*	27/10/2011 *Revised*
J1517	*Driver Selected Seat Position for Class B Vehicles – Seat Track Length and SgRP*	27/10/2011 *Revised*
J4002	*H-Point Machine (HPM-II) Specification and Procedure for H-point Determination – Auditing Vehicle Seats*	19/01/2010 *Revised*
J4003	*H-Point Machine (HPM-II) Procedure for H-point Determination – Benchmarking Vehicle Seats*	21/10/2008 *Revised*
J4004	*Positioning the H-Point Design Tool – Seating Reference Point and Seat Track Length*	29/08/2008 *Revised*

Table 1.1: Suggested SAE standards for the interior vehicle design

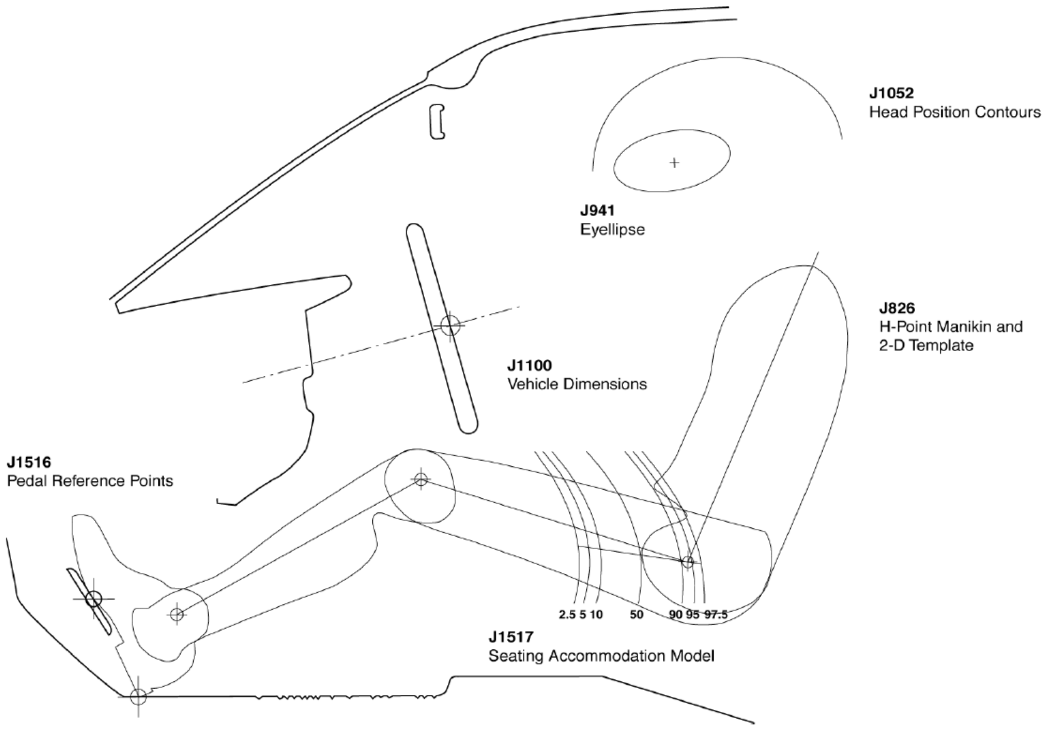


Figure 1.8: Accommodation instruments defined in the SAE standard [8]

1.5.2 H-Point Definition

Each vehicle varies according to the segment, the shape, the car manufacturer and other several factors. For this reason, it is necessary to have at its disposal an instrument, that independently on the vehicle layout, is able to simulate the presence of a human inside the vehicle in order to get some standard measurements. The used instrument is the SAE manikin, in particular the most used is the SAE 95%ile. Its aim is to set a standard in order that each car manufacturer has an unambiguous reference.
The SAE standard J1100 - Motor vehicle dimensions – sets a series of standard measurements and procedures regarding the motor vehicles. One fundamental specific is the H-point (hip-point) and is used as reference to define not only the driver positioning, but also other key dimensions[2]. [9]

[2] Some dimensions examples, defined starting from the H-Point, and aimed to the definition of the packaging strategy are: entrance height (H11), Seat belt height (H25), effective head room front (H61), leg room (L33), shoulder room (W3), elbow room (W31), hip room (W5), knee room (L62), thigh room (H13). [9]

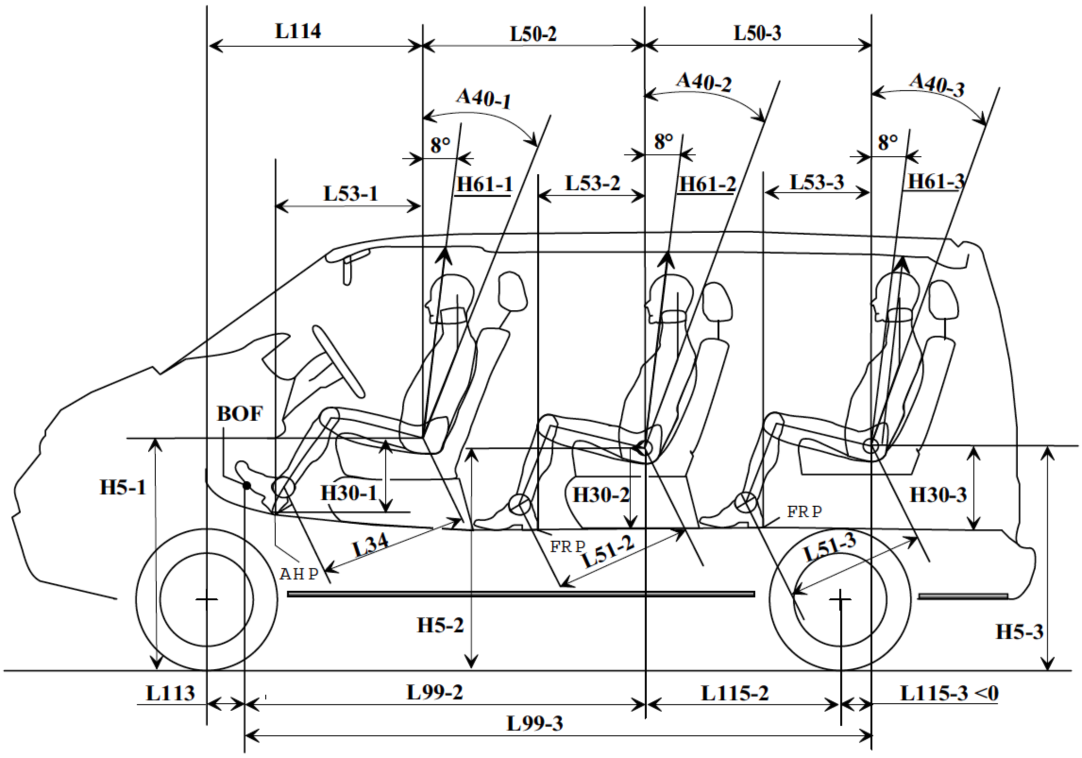


Figure 1.9: Main vehicle dimensions dimensions [7]

In general, the H-point represents the articulation point between the torso and the upper legs, i.e. the relative seating hip position.
During the vehicle design, the H point has several and complex variables that must be taken into account such as the roof height, the aerodynamics, the visibility, the safety and the inlet and outlet vehicle facility.
Four types of devices can be adopted in order to define the H-point:

- The H-Point Machine (HPM) and the 2D model defined by the SAE standard J826;
- The most recent H-Point Machine (HPM-II) defined in the SAE standard J4002;
- The design instrument H-Point Design Tool (HPD) defined in the SAE standard J4004.

While the HPM and the HPM-II are physical devices used during real test mainly aimed to the auditing and the benchmarking, the HPD is a CAD instrument used during the vehicle design to set the H-point positioning in the relative package. [10]

The SAE manikin (figure 1.9) can be used to carry out a real H-point measurement, to understand if the vehicle actually is able to respect the starting design. In other words, starting from the initial project design, a vehicle representative model (ergo-model) is created, and considering a certain number of tolerances that could affect the measurements (such as the seats deformation) the real H-point is measured. This data is compared with the one declared during the design process and not always such procedure allows to reach a condition in which the two values coincide. Therefore, it is present a procedure to evaluate the H-point on the vehicle, in order to verify also the data declared from other car manufacturers.

Figure 1.10: H-Point measurement device. (from Johnson Controls)

In the SAE standard J1100 four definitions of H-point are presented:

- *H-point*: It is the centre of rotation between the torso and the thigh in the 2D and 3D devices used in the definition and measurement of vehicle seats accommodation. [7]
  In other words, the H-point is the point (in the HPM, HPM-II or HPD) positioned at the centre of the assembly between back pan and cushion pan (backrest and cushion panel), in the centreline of the device. When the device is opportunely positioned in the designated seating positioning inside the vehicle, the H-point position can be used as reference point of the vehicle. Unless otherwise specified, this is the H-point definition procedure used in the standard SAE J1100. [10]

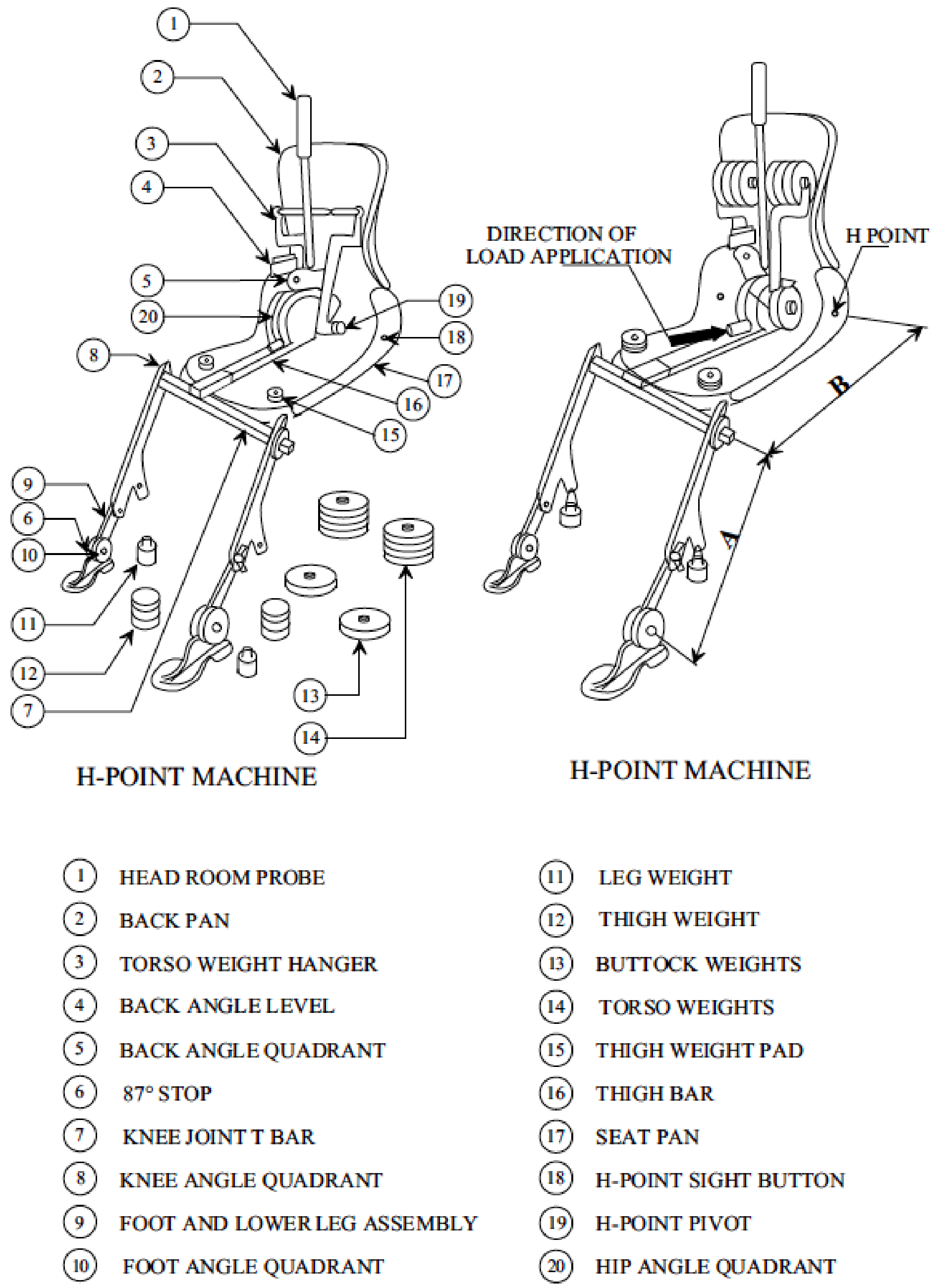
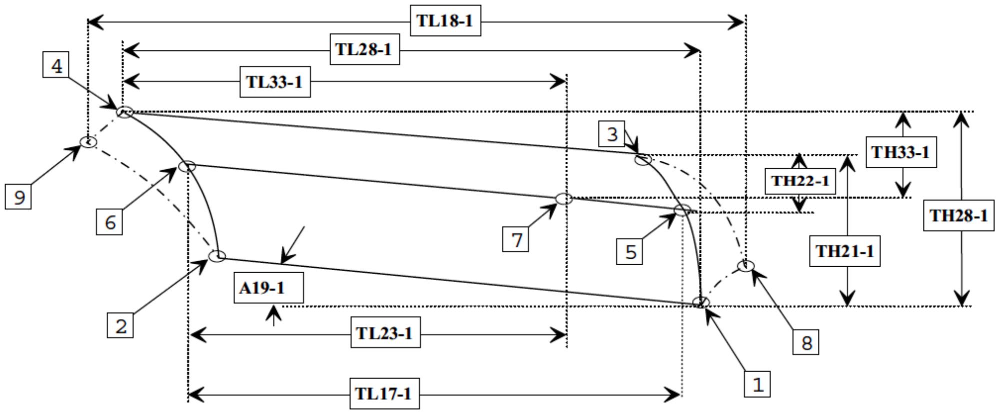


Figure 1.11: 3D H-point Machine [7]

- *Design H-point*: It is the H-point defined during the design phase using appropriate procedures and a 2D model device. If the seat is defined it can be regulated, so the trajectory of the design H-point in the overall adjustment stroke must be represented. This sets the so-called *travel path*[3] or seat travel box and can be described with respect to the reference system. [7]

[3] With the term *H-Point Travel Path (or seat Travel Path)* is intended all H-Point positions given by the complete series of seat adjustments.

The SAE standard J1100 defines the *design H-point* as a position of the H-point which coordinates are determined in the CAD using the H-Pont design tool or by means of a 2D model of the seat, with the seat positioned in any position in the adjustment range. [10]



POINTS ON SEAT TRACK
1 RLP Rearmost - Lowest H - Point.
2 FLP Foremost - Lowest H - Point.
3 RHP Rearmost - Highest H - Point.
4 FHP Foremost - Highest H - Point.
5 RDH Rearmost - Design H - Point.
6 FDH Foremost - Design H - Point.
7 SgRP Seating Reference Point.
8 RAP Rearmost - Achievable H - Point.
9 FAP Foremost - Achievable H - Point.

Figure 1.12: Seat travel box [7]

- SgRP (Seating Reference Point): It is a unique and specific H-point defined by the manufacturer as seat project reference point for a given accommodation position that
- Sets the rearmost designed normal driving position or the driving position among those provided, that takes into account all possible adjustments;
- Simulates the hinge position between human torso and thigh;
- The position is determined by the X, Y and Z coordinates;
- Is the reference point used to arrange the 2D model (with 95%ile leg) according to the SAE standard J826 or the HPD described in the SAE standard J4004. [7]

Although adjustable seats will have several *design H-point* inside their travel path, there is only one SgRP for each seat/seat position. Il Seating Reference Point is established in the first design process phase; It is used for the positioning of various design instruments, for the definition of some of vehicle dimensions and it is regulated by different national and international standards and rules. [10]

For the SgRP definition in the HPM (SAE J826) standards SAE J1516/J1517 are used, while for the definition of the SgRP in the HPM-II (SAE J4002/J4003), the SAE standard J4004 is used. [10]

The above-mentioned definitions are indicated in the SAE standard J1100; however, for the sake of simplicity, theoretical H-point (design) and real H-point (measured on real vehicles) definitions are often used.

1.5.3 Driving Position Simulation Tools: Virtual and Physical Techniques

The measurement tools listed above, useful for the evaluation of the H-point position, are described in the following in detail with reference to the positioning and measurement procedures; Among the vehicle accommodation methodologies two representations can be used: Physical and virtual techniques (table 1.2). such representations are used in several applications during the vehicle design and the safety evaluation that require precise data regarding the passenger posture and positioning.

ESTIMATION METHODOLOGIES

VIRTUAL TECHNIQUES	PHYSICAL TECHNIQUES
➢ **Standard:** • ***2D H-Point Template*** **[SAE J826]** • ***H-Point Design Tool*** **[J4004]**	➢ Standard: • *H-Point Machine (HPM)* **[SAE J826 → J1516/J1517]** • *H-Point Machine II (HPM-II)* **[SAE J4002/J4003 → J4004]**
➢ **Anomalies, preference and personal habits**	➢ clinic measurements: • Lab Test (*seating buck*) • On road test (Static and Dynamic) • Customer complaints

Table 1.2: Methods for the driving accommodation positioning estimation

The implementation of virtual simulation models for the vehicle accommodation during the design process is something related to important investments in terms of time and costs, but in long-term can strongly accelerate the process and make it less expensive for the company. [9]

For the theoretical (virtual) H-point representation two standard tools can be used: The *2D H-Point Template* of the SAE standard J826 and the CAD tool *H-Point Design* described in the standard SAE J4004.
The 2D model of the SAE standard J826 – Devices for Use in Defining and Measuring Vehicle Seating Accommodation- is realized to represent a male profile wearing shoes corresponding to the inclined seating profile H-Point. (figure 1.12). The segments of

torso, thigh, leg and shoes are provided by a locking of the articulation joints in order to fix the angular relationship between them. It is also included a reference bracket for the evaluation of torso inclination with respect to the vertical axis. [11]

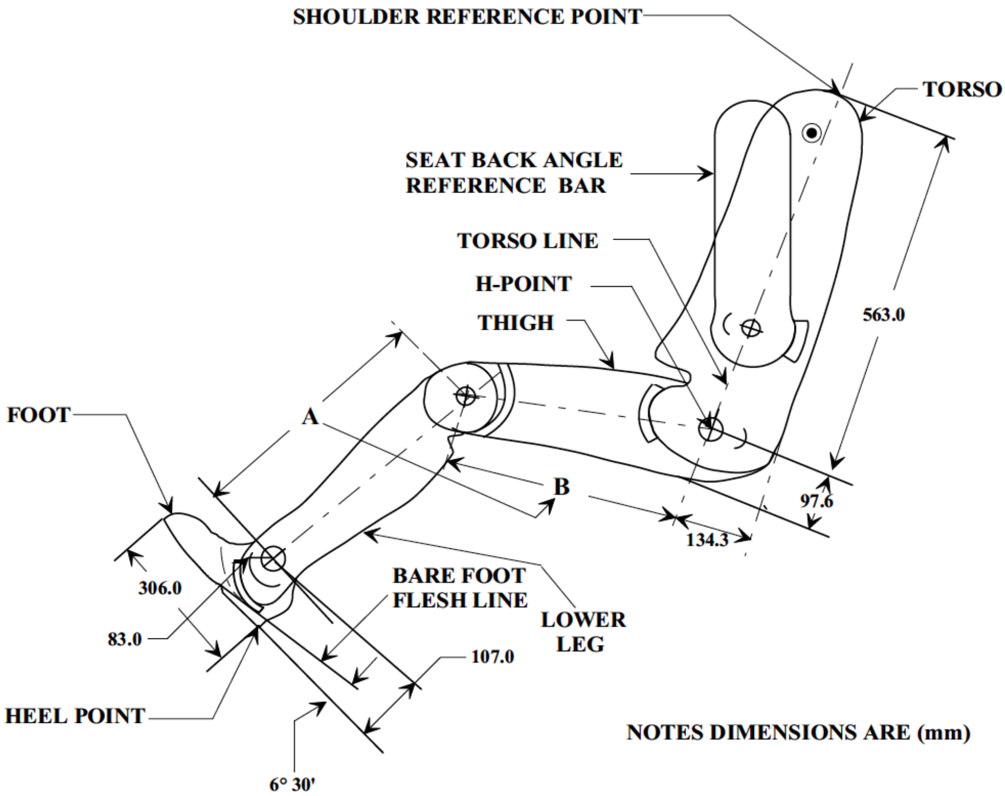


Figure 1.13: H-Point Template [11]

This model allows to visualize the available cabin space and an early accommodation in the first phases of the process of a new vehicle development, essentially for the purpose of comparison with the data obtained with the use of the *H-Point Machine.*

The *H-Point template* has well defined shape of the shoe in order to highlight some important points. Such points are essentially the BOF[4] (ball Of Foot) that falls 203mm from the HOS (Heel of Shoe). In the SAE manikins defined in the SAE standard J4002 (HPM-II) and in the SAE standard J4004 (HPD) has the shoe with the flat bottom. [11]

[4] The Ball Of Foot (BOF) is a point lying on the tangent of the sole in a side view, located at 203mm from the heel point (HOS). Regarding the Y coordinate the BOF is at the centre of the shoe. The BOFRP is the point representing the ball of foot location on the shoe plane when the H-point machine shoe is set to a specified shoe plane angle, the bottom of shoe is in contact with the undepressed accelerator pedal, the ball of foot is aligned with the lateral centreline of the undepressed accelerator pedal in rear view, and the heel of shoe is at the depressed floor covering. (Figure 1.14). [10]

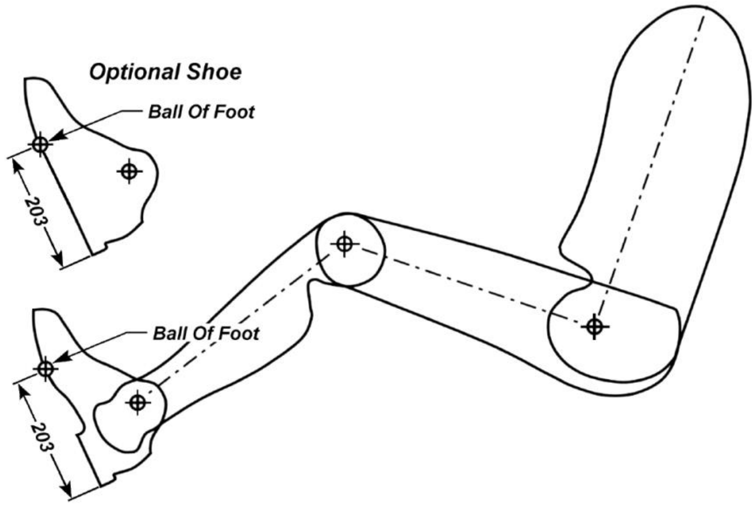


Figure 1.14: H-Point Template – CAD version [11]

Thanks to the CAD it is possible:

- To amend in an immediate way, simple and without costs;
- Realize Structural verifications;
- To simulate test (*for example crash test*);
- To study the interaction with the human being. (This is possible by using virtual manikins or, as in this study, by means Virtual Reality tools that allows to connect a person with the CAD of the vehicle) [12]

Regarding the positioning of a specified SgRP and torso angle, The SAE standard J826 recommends setting the H-point of the CAD model on the SgRP with the specified torso angle using the value specified by the car manufacturer or by using the standard SAE J4004 or J1516/1517. For the positioning of a
non-specified SgRP and torso angle instead, the SAE standard J826 suggests the installation of the *H-Point Machine 3D* to determine the seat travel path e to use the standard SAE J1100, J4003/J4004 to determine the BOF, *Accelerator Heel Point* (AHP), *Shoe Plane Angle* (SPA)*,* SgRP and torso angle.

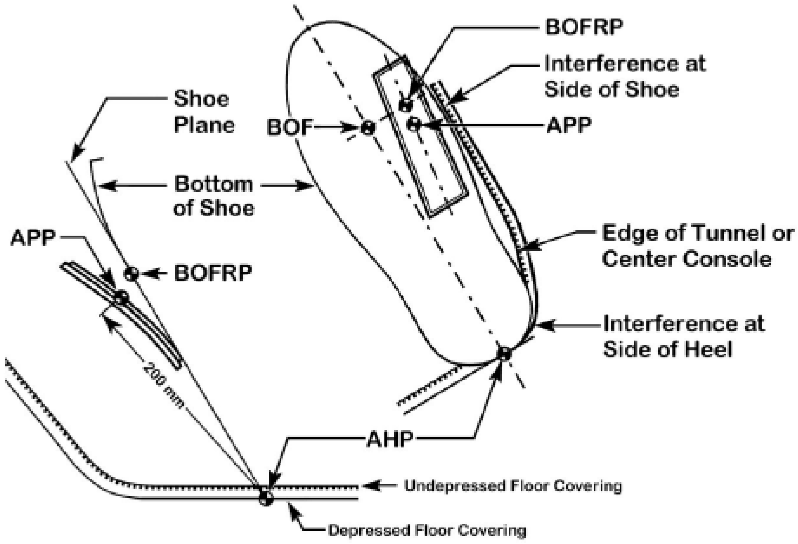


Figure 1.15: BOF, BOFRP, AHP, Shoe Plan [10]

The other standard instrument belonging to the virtual techniques in defining and measurement of vehicle seating accommodation is the *H-Point Design* described into the standard SAE J4004 – *Positioning the H-Point Design Tool: Seating reference point and Seat Track Length*- that describes how to position the HPD, how to establish the SgRP and the other reference points used during the driver seat positioning and the one of the passenger. The use of the HPD together with the HPM-II, is described into the standard SAE J4003, while the SAE J4004 standard defines a new methodology for the positioning of the driver seat rails based on studies and statistical model performed at UTRI *(University of Michigan Transportation Research Institute)*. [13]

The *H-Point Design (*figure 1.15) is a CAD instrument used during the design phase to establish the so called VOP (*Vehicle Occupant Package*), in particular to define the key reference points inside the vehicle (including (SgRP and AHP) that are used in order to set and measure several aspects of the vehicle compartment.

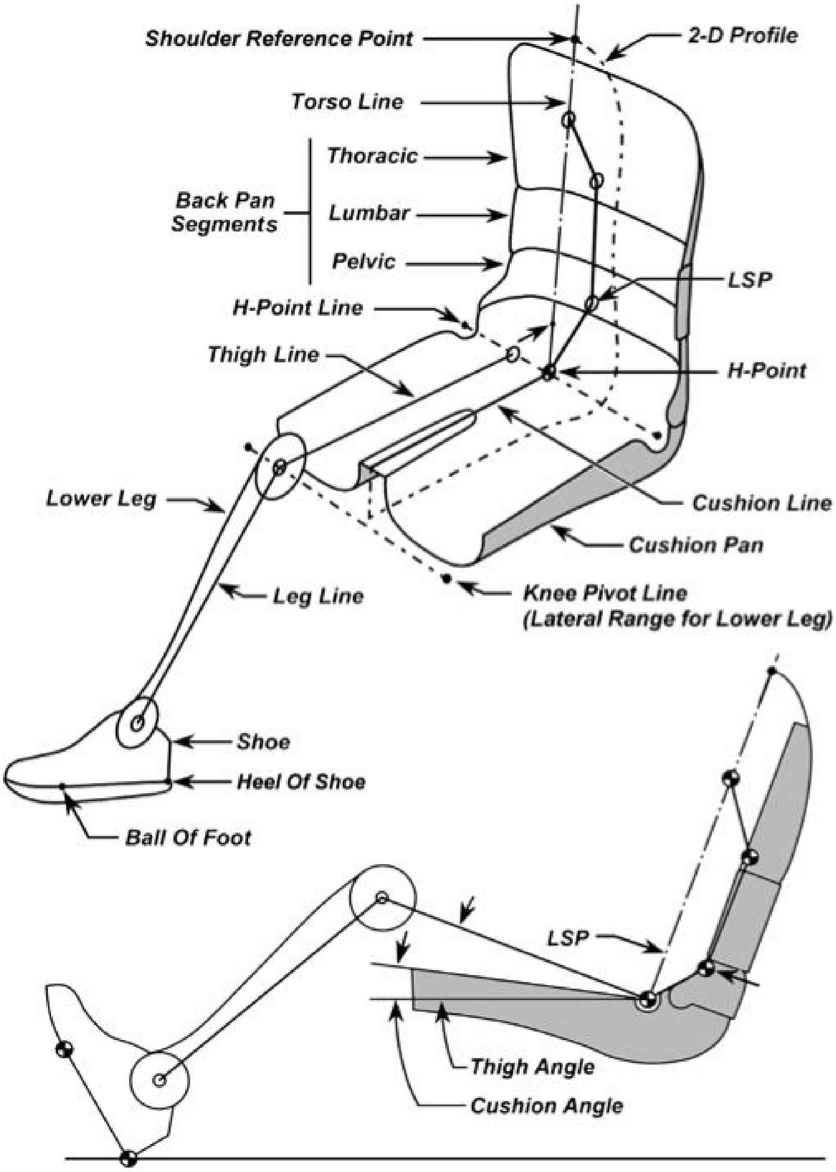


Figure 1.16: H-Point Design Tool (HPD) [13]

The manikin described by this standard is different with respect to the SAE J826 that has a non-articulated torso, does not provide a measurement of the LSP *(Lumbar Support Prominence)* and has a shoe sole with a standard profile characterized by a small heel, different with respect to the shoe of the manikin relative to the SAE J4004 that has a footwear with flat bottom profile.

The HPD instrument can be used in CAD as part of the benchmarking process in the following ways:

- It is usually used to determine the driver SgRP and the H-point travel path;
- It is often used for the thigh and leg positioning in order to evaluate the seating vehicle package;
- It can be used for the footwear positioning. [14]

Among the physical techniques, those that allow to carry out measurements in practice, the standard SAE instruments are the 3D HPM (SAE J286) and the HPM-II (SAE J4002/J4003).
The H-point machine (SAE J826) has been developed at the end of the 1950 (when the necessity to simulate the on-board occupants during the design phase) using relatively soft seats, with a very poor lumbar support. It is characterized by four parts (thigh, leg, foot and torso) with adjustable legs segments.
The cushion pan and the back pan (representing respectively the human thighs and torso) reproduce a male adult profile (figure 1.16); The two panels, made by reinforced plastic and metal, are joined together in the hip (H-Point). A graduated scale is linked to the H point in order to measure the available space for the head into the compartment; a torso angle quadrant allows to evaluate the torso inclination. The thigh bar, fixed to the cushion pan, sets the center line between the thighs and makes as basis for the hip angle quadrant; the lower legs segments are adjustable and are fastened together with the T-bar representing the knee articulation. The knee angle quadrants are positioned at the boundaries of the T-bar. The lower parts of the legs segments provide the feet assembly joints that are calibrated to carry out the angular measurements. In order to easily set the 10%ile, 50%ile and the 95%ile of an adult male some stops are provided.
Two spirit levels allow to check the manikin orientation and to simulate the 77kg weight (50%ile weight of an adult male) some ballasts can be installed on the torso, thighs and legs. [11]

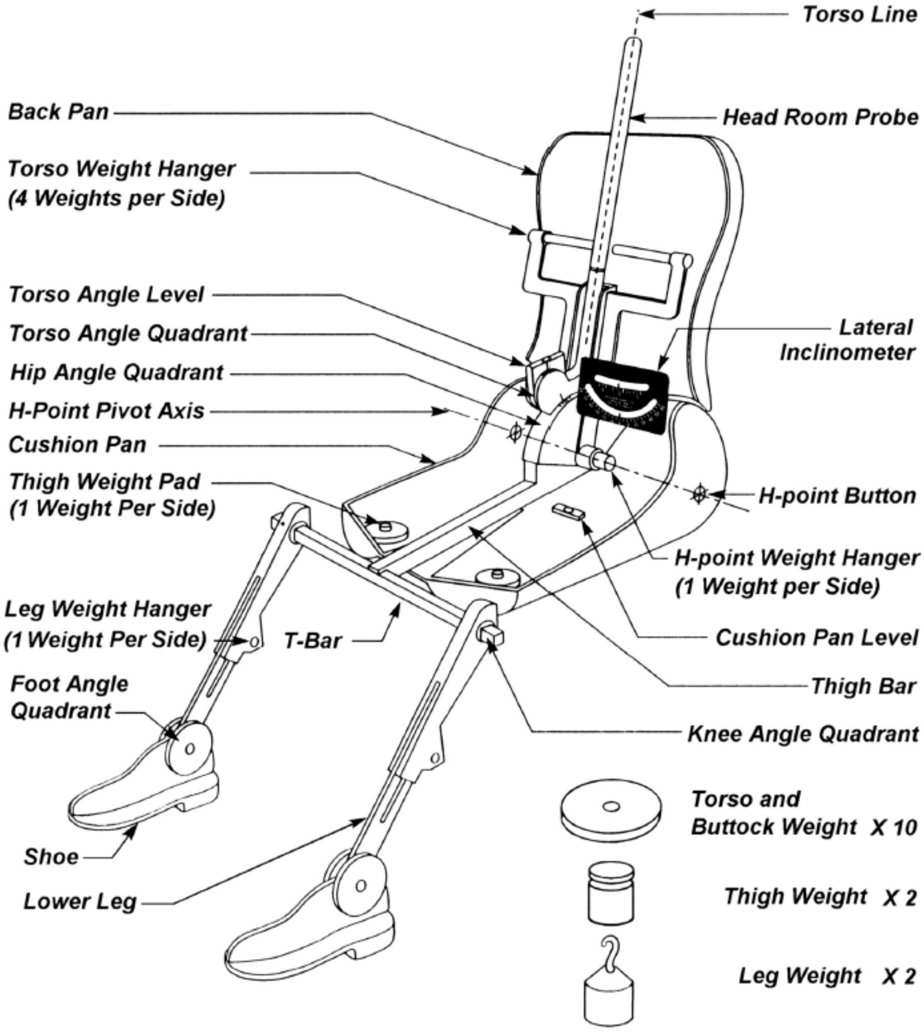


Figure1.17: H-Point Machine - SAE J826 [11]

Even if the HPM has been used for more than 30 years, its limits on modern seats and in a virtual simulation environment design process showed the necessity of a new tool.

In the 1993, The SAE *Design Devices Committee* convened a work group in order to bring improvements to the manikin. UMTRI *Biosciences Division* and *Biomechanical Design Laboratory of the Michigan State University College of Engineering* researchers described the ASPECT program (Automotive Seat and Package Evaluation and Comparison Tools), that brought to the creation of a series of new tools for the vehicle and seats design, among which also a restatement of the H- point manikin and new statistical models aimed to the user's accommodation prevision. The following table lists the new instruments and the relative SAE Standards. [8]

Instrument/Model	SAE Standard
UMTRI Seating Accommodation Model (SA	J1517
UMTRI Eyellipse Model	J941
Head Contours	J1052
ASPECT Manikin	J826
Pedal Reference Point	J1516
SgRP Definition	J1100
Human Body Reference Forms	*
ASPECT Posture Prediction	*
Application Guidelines for Human Model	*

**** No current SAE recommended practice.***

Table 1.3: New tools for the interior vehicle design and packaging [8]

The *Seating Accommodation Model* UMTRI (SAM) is function of the seat height (H30), of the longitudinal distance between the centre of the steering wheel and the AHP (L6), of the inclination angle of the seat cushion (L27), on the type of transmission but also on the human anthropometrics. For this reason, SAM allows to predict the seat positions for any driver height.

The new manikin derived from the ASPECT program (figure 1.17), with respect to the HPM of the SAE standard J826, is provided by an articulated lumbar backbone that allows to measure the lumbar support relief, it is able to evaluate an H-point measurement that is directly related to the H-point measurement of the H-point J286, and simultaneously measures L27 and L40 (Backrest inclination). The new manikin provides lighter legs that can be then installed without affecting the H-point positioning and allowing the evaluation of the knee and hip angles.

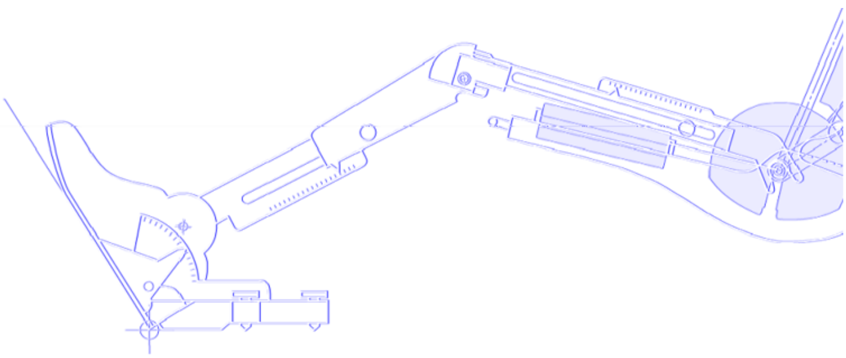


Figure 1.18: Figure 1.17: ASPECT Manikin [8]

In order to evaluate and validate the new tool, the obtained measurements by using an ASPECT manikin positioned in 11[5] different seats and in different package configurations have been compared with the same obtained with a SAE J826 manikin. This comparison highlights as the H-point measured with the ASPECT manikin results in a lower and a further back position with the respect to the H-point measured by the HPM. This is due because the lumbar support tends to push the SAE manikin forward. In the figure 1.18 are depicted the data coming from each seat: the centre point in the graph indicates the coincidence between the two measurements.
It is important to notice that the results obtained with the ASPECT manikin are strongly grouped together. This means a higher repeatability.

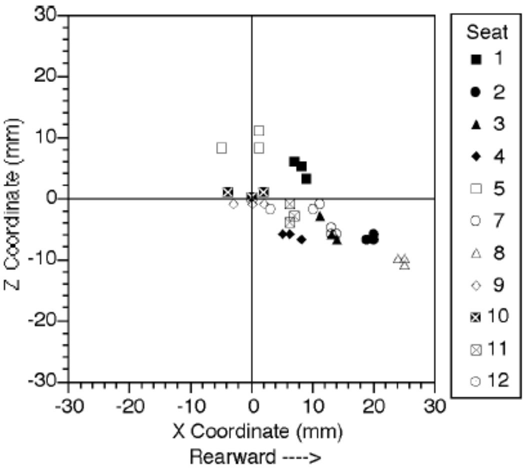


Figure1.19: H-Point ASPECT Manikin with respect to the H-Point SAE J826 for 3 tests on 11 seats. [15]

The figure 1.19 shows the horizontal deviation between the two H-points tracked according to the ASPECT lumbar support, that can be calculated (in mm) using a linear regression that combines the ASPECT H-Point and the *Lumbar Support Prominence* (LSP) of the seat (equation 1.1): [15]

$$\text{ASPECT HPt(X)} - \text{J826HPt(X)} = 1.14\text{LSP} - 4.3 \quad (1.1)$$

If LSP=0 the two H-points coincide.

[5] The legend in figure 1.18 shows 12 seats. One of these has been neglected by the analysis since it belongs to another class of vehicles.

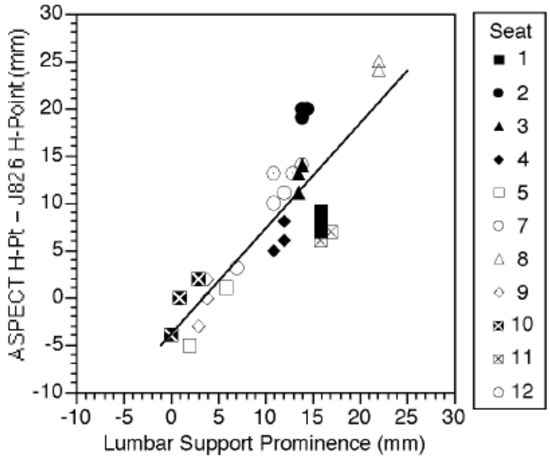


Figure 1.20: Horizontal Offset between H-Point ASPECT and the SAE J826 as function of the LSP [15]

Finally, the figure 1.20 compares the torso angle of the ASPECT manikin with the one of the SAE J826: setting as input the average inclination preferred by people and obtained during an in-vehicle test, the results show a more vertical inclination of the ASPECT with respect to the SAE J826. [15]

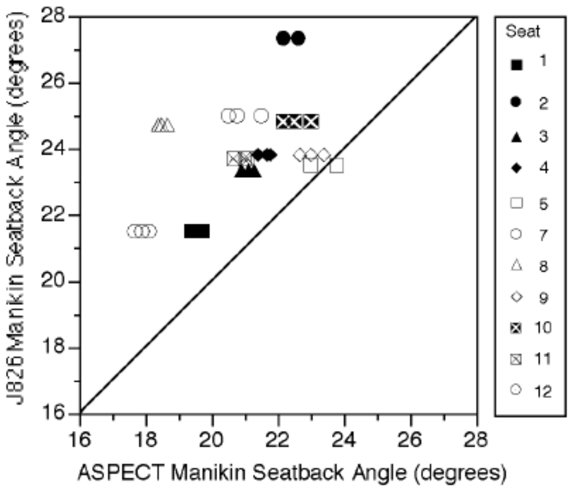


Figure 1.21: Comparison between The ASPECT manikin and the SAE J286 one of the Backrest Inclination for three tests on 11 seats [15]

The results of such analysis evidence how by using two different measurement tools on the physic ambient, the obtained results are different. For this reason, at the beginning of the 2000's, has been developed a new machine for the H-point determination and the relative measurement procedure in order to substitute the standard J286 with the SAE standard J4002 – *H-Point Machine (HPM-II) Specification and Procedure for H-point Determination: Auditing Vehicle Seats* – that seeks to solve some limits of the previous model. [9]

With respect to the HPM J826, the HPM-II with the articulated torso had the advantage to reach a higher repeatability, ease of use, additional functions and measurement capabilities; The constituting elements that make-up the manikin (such as legs, shoes, back pan and cushion pan) are all separated parts and this strongly improve the ease of assembly. [16]

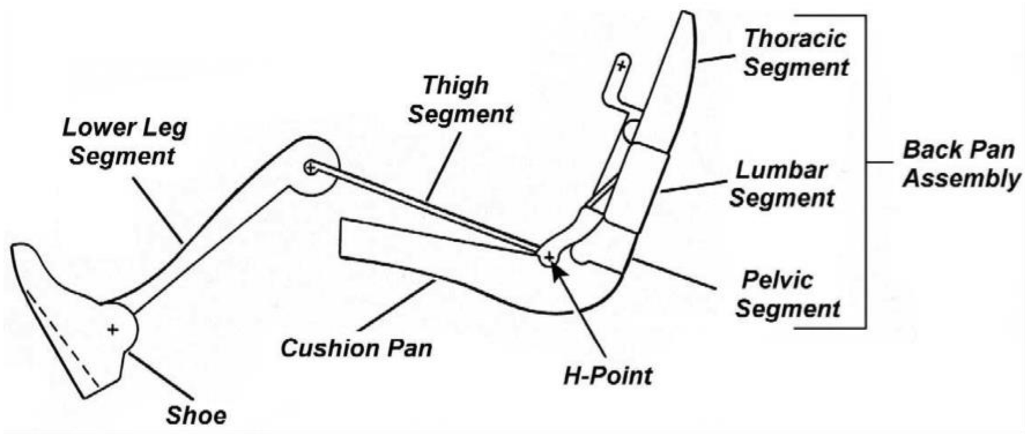


Figure 1.22: New HPM-II components [16]

The new procedure aimed to the definition of the position of the H-point is based on the installation of the HPM-II without the legs; The use of the legs is optional, and this represents an important advantage of the HPM-II. Different improvements have been made also for the shoe element and for its positioning inside the vehicle; moreover, the cushion angle can be measured independently from the thigh one. The articulation of the back pan allows an easier fitting of the HPM-II into the bucket seats beside to furnish the new value of the LSP (figure 1.22). [16]

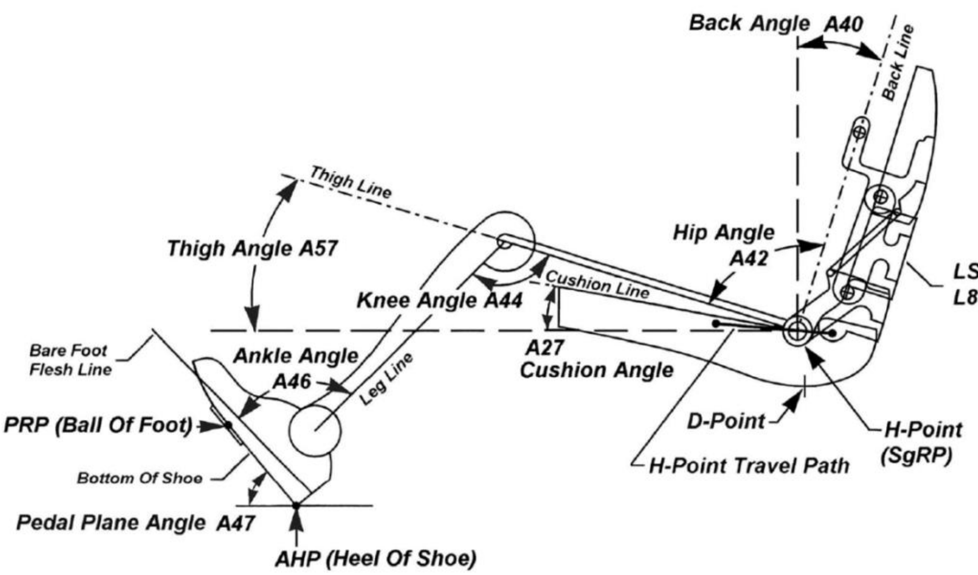


Figure 1.23: Reference points, reference lines and postural angles [16]

As previously indicated, the SAE standard J1100 recommends the use of the SAE standard J1516/J1517 for the determination of the SgRP in the HPM (SAE J826), and the SAE J4004 for the SgRP in the HPM-II.
The latest versions of the SAE standards J1516 (2011) -Accommodation Tool Reference Point for *B Class vehicles*- and SAE J1517. Driver Selected Seat Position for *B Class vehicles*: *Seat Track Length and SgRP* – are intended to *B Class vehicle*s (track and buses); however, are still applied previous versions of such standards (1990) for *A Class vehicle* (passenger cars and light trucks) for the estimation of the vehicle seating positioning, based on a second-degree equation, since the procedure is more detailed with respect recommended by the SAE standard J4004.

The standard recommended procedure for the prediction about the seat positioning, aimed to the determination of the rail lengths and the vehicle accommodation, is referred to the study - *Driver selected seat position model* - (1984). Such study is aimed to the prediction of the position distribution of a population composed by American drivers (half male and half female), and are used seven regression equations, one for each of the seven percentiles (2,5%ile, 5%ile, 10%ile, 50%ile, 90%ile, 95%ile and 97,5%ile); in particular, the longitudinal distance between the H-point and accelerator pedal is evaluated for each percentile using a second order equation that is function of the seat height (H30). In the following the seven equations are indicated (1.2÷1.8) and determine the accommodation curves of the seven drivers depicted the figure 1.23 as function of a single package variable, the seat height H30: [13]

$$x_{97.5} = 936.6 + 0.613879z - 0.00186247z^2 \quad (1.2)$$

$$x_{95} = 913.7 + 0.672316z - 0.00195530z^2 \quad (1.3)$$

$$x_{90} = 885.0 + 0.735374z - 0.00201650z^2 \quad (1.4)$$

$$x_{50} = 793.7 + 0.903387z - 0.00225518z^2 \quad (1.5)$$

$$x_{10} = 715.9 + 0.968793z - 0.00228674z^2 \quad (1.6)$$

$$x_5 = 692.6 + 0.981427z - 0.00226230z^2 \quad (1.7)$$

$$x_{2.5} = 687.1 + 0.895336z - 0.00210494z^2 \quad (1.8)$$

Where x_i is the longitudinal position [mm] of the H-point of the i-th percentile with respect to the accelerator pedal, while z is the vertical distance [mm] between the H-point and the heel (H30).

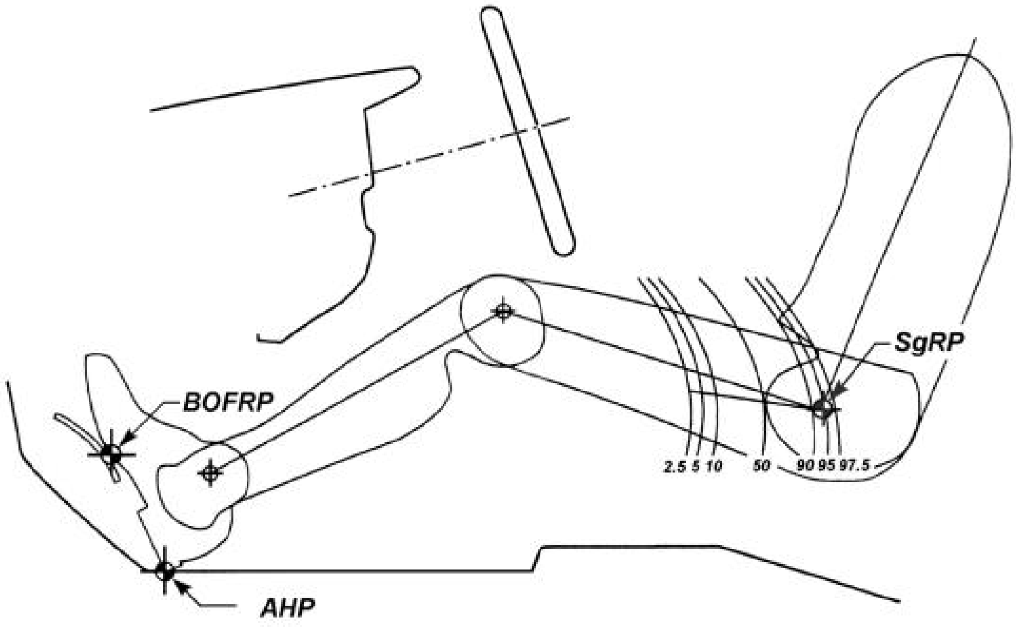


Figure 1.24: Driving position selection Model SAE J1517 [13]

Applying the procedures described in the SAE standard that define the curves that indicate where the manikin is accommodated (given as inputs the travel box, the curve of the accelerator pedal and the vehicle floor) and intercept that curves with the nominal line of the ravel box, it is possible to obtain the H-point of the manikin SAE 95%ile.

The weak point of the methodology described in the SAE standard J1517 for the HPM J286 positioning is that it does not estimate the positioning along the Z coordinate: all points lying on the nominal line of the travel box are considered adapt for the vehicle accommodation.

As anticipated, although the *H-Point Machine* J286 is older with respect to the HPM-II J4002/J4003, it is still used for the estimation of the vehicle accommodation for their higher accuracy with respect to the procedure of the HMP-II described in the SAE standard J4004 and shortly explained in the following.

The SAE standard J4004, for the determination of the dimension and the positioning of the seat travel box in order to accommodate a high percentage of population, indicates a procedure for the measurement of the H point that is function not only of the H30 dimension, but also of the stature, the type of transmission, of the longitudinal distance between the steering wheel centre and BOF (L6) and of the cushion inclination (A27), as depicted in the figure 1.24: [13]

$$x = 16.8 + 0.433(stature\ in\ mm) - 0.24(H30) - 2.19(A27) + 0.41(L6) - 18.2t$$

Where t indicates the type of transmission: t=1 for manual transmission and t=0 for automatic transmission.

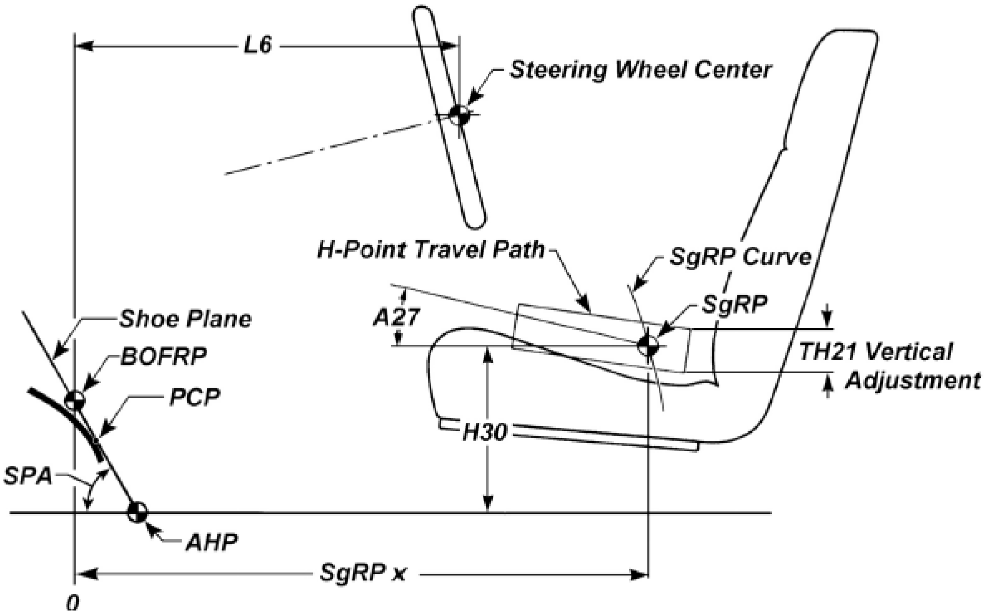


Figure 1.25: Dimensions for the evaluation of the driving position [13]

The longitudinal position of the steering wheel is a fundamental factor of the comfort and of the driver posture: examining a population sample and carrying out a statistical analysis of the results has been proved that the longitudinal position of the steering wheel is affected by the height of the seat and of the driver. [17]

In the following figures the blue, red and dashed curves represent respectively three different probabilities of steering wheel positioning evaluation from the user's point of view, in particular:

- Red Line: Considered correct position;
- Blue Line: Too far Steering wheel;
- Dashed Line: Too close steering wheel.

The figure 1.25 highlights that, fixed H30 and driver height, the higher percentage of "correct" evaluation (around the 70%) is obtained for a value L6=550mm; on the other side varying the height of the driver (figure 1.26) the effect is relatively small: the main effects are in the categories "too close" and "too far". For example, with a value H30=270mm, a value L6=550mm is probably considered as "too close" for the smaller user with respect with the taller ones.
Finally, varying H30 the percentage of evaluation as "correct" is approximately the same up to the value H30=325 mm, where the red curve shows a noticeable fall. Figure 1.27

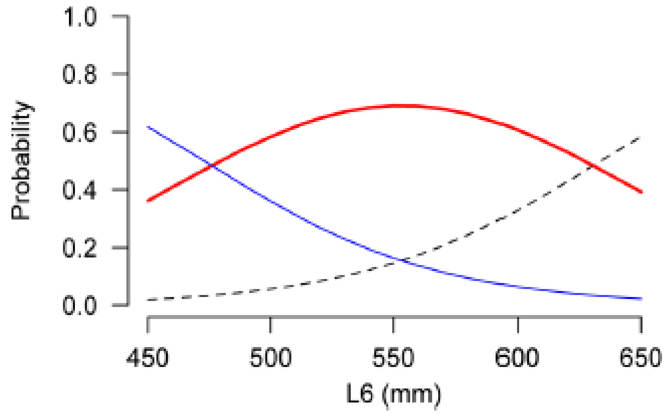


Figure 1.26: Effects of L6 on the evaluation of steering positioning for height=1750 mm and H30=270 mm [17]

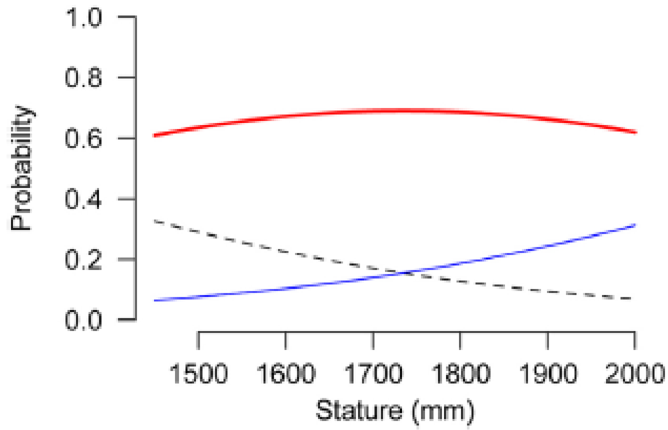


Figure 1.27: Height effects on the evaluation of the steering positioning for L6=550 mm and H30= 270 mm [17]

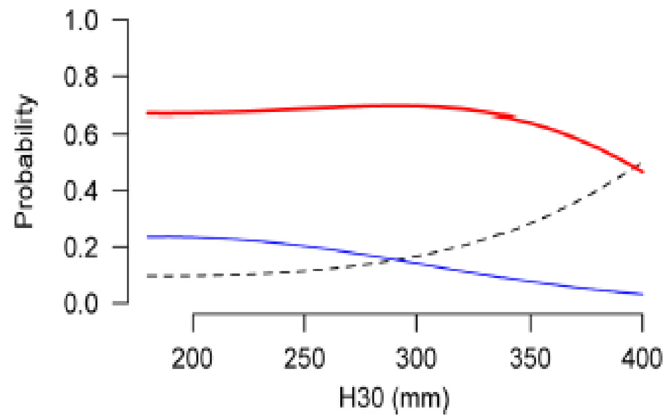


Figure 1.28: Effects of H30 on the evaluation of the steering positioning for L6=550 mm and Height=1750mm [17]

From the analysis of these graphs it is possible to conclude that in general, changing the anthropometrics of the user (mainly changing the height), the curve tends to be flat, for this reason it is reasonable to fix the steering wheel position. This conclusion justifies the choice in continuing to use the second-degree equation that is function only of the H30 of the standard SAE J1517 for the estimation of the vehicle accommodation. This because the SAE standard J4004 (that has as principal aim the one of the definition of the travel box taking into account the steering wheel positioning) does not allow to reproduce in a satisfactory way the position of the American drivers, also because often the users does not consider, or consider it later, the steering wheel positioning during the in-vehicle accommodation.

Closing the regulatory aspect related to the estimation methodologies for the vehicle accommodation, it is important to identify also other physical and virtual techniques besides the SAE standards. In particular among the physics techniques it is possible to consider the so-called *clinic measurements*[6], i.e. tests that allow to examine the choice of the accommodation position of a population sample, and to make a parallel with the prediction of the anomalies, preferences and persona habits (belonging to the virtual techniques).

1.5.4 Seats Architecture

The H-point is a seat key parameter and its position must be controlled to guarantee the seat quality and satisfy the customer expectations. Ensure the correct match between the theoretical H-Point (design measurement) and the real one (physical measurement) it is, due to the tolerances, a challenging task that requires the co-working of different actors that take part to its definition. One of the reason of this difference is given by the constructive tolerances of the seats.

The seat is one of the main components in a vehicle and the expectations of the customer regarding the seating comfort are always increasing; among the automotive seats producers the seat has always been a challenge having three design tasks that must be simultaneously satisfied: The comfort, the ergonomics and the safety. [18]

Automotive seats have different aims, as first the positioning of the driver to allow the reachability of all the instruments and commands and to furnish an adequate field of view to use the vehicle in the safer way possible. In order to guarantee safety and comfort, it is appropriate to design an adjustable seat at least in the longitudinal direction, height and backrest inclination. Moreover, can be included other functionalities such as air-bags and climatic regulations.

[6] *Clinic Measurements can be carried out both in Lab or on road. Lab tests consist into the setting-up of a test-bench, and, being a static test does not guarantee the correct reproduction of the reality. The reason of such Lab tests is mainly due to the lower costs with respect to on road test. Also calls from customers belong to clinic measurements. Once the vehicle is on the market some customers complaints that must be taken into account and evaluated in order to amend the vehicle.*

Generally speaking, the majority of the seats can be described as composed by a frame, a cushion, a backrest and a headrest. The cushion and the backrest are composed by various stiffness foams, electric components, springs, trims. The basis allows the fastening of the seat to the vehicle floor and guarantees the relative adjustments. [9]

Figure 1.29: Main seat components [9]

Urethane foam is usually used as filling material of the cushion and the backrest. Usually it is obtained by cold giving the possibility to obtain complex shapes, stiffness and a good aesthetical impact. During the accommodation the foams deform under the driver weight moving the H-point. This aspect must be considered during the design phase. Regarding the seat cover, it can be of several types that differ from the other for stiffness and aesthetical aspect. It is important to consider also the difference between a fabric covered seat with respect to a leather one: the second being a stiffer material will maintain a higher H-point.

2 Physical Models in Body Vehicle Design Process

Although is common thought that nowadays vehicles are uniquely realized by the aid of computers, physical models still represent an actual phase of the process that allows to reach a satisfactory level of tactile and visual perception. The realization of such models is still related to the craftsmen abilities in modelling dedicated materials in order to perfectly reproduce the desired result.
Of course, this process is highly expensive both in terms of costs and time.

2.1 Product Evolution Process

In order to better understand the effects of the physical models in a vehicle development process and in particular where they are distributed along the time line, it is appropriate to give an overview about the Product Evolution Process (PEP).
The PEP, also defined as the *time-to-market process,* summarizes all activities for design and testing of the product as well as the set-up of production processes required for the manufacturing of the product.
Each Car Manufacturer has its own secret procedure to correctly manage its projects. Despite this there are common patterns that defining an industry-wide accepted structure of vehicle development.
A PEP model is characterized by several milestones precisely fitted during the time line that identify distinct phases with the relative deliverables[7]. [19]

2.1.1 Phases of the PEP

When a new vehicle project starts, the first task is the deployment of a product strategy. This essentially means to define which type of car the company wants to insert into the market and at what time this must happens. A time parallel phase to the product-strategy is the so-called *pre-development*. This process deals with components, technologies and innovative ideas and their feasibility on technical and economical point of view for the application to the production processes.
In general, these two phases do not directly belong to the actual project-phase even if they are continuously updated during the whole vehicle project. For this reason, they are often referred as "*pre-development phase*" or "*strategy phase*".

[7] In the project management field a deliverable is a tangible or intangible good or service produced as a result of a project that is intended to be delivered to a customer (either internal or external).

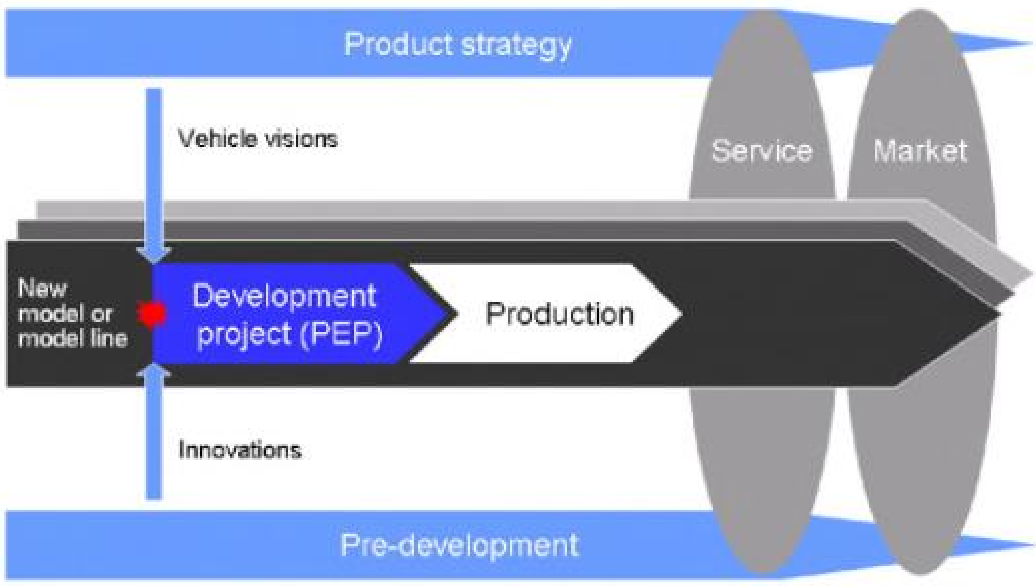


Figure 2.1: Process framework of vehicle development process [19]

The PEP is generally divided into four main phases:

- Target Definition;
- Design Validation;
- New Product Development;
- Maturation & Ramp-Up;

At this point to better understand the distribution of such phases and where the realization of physical models is inserted inside a product evolution process, an indicative PEP is reported in figure 2.2:

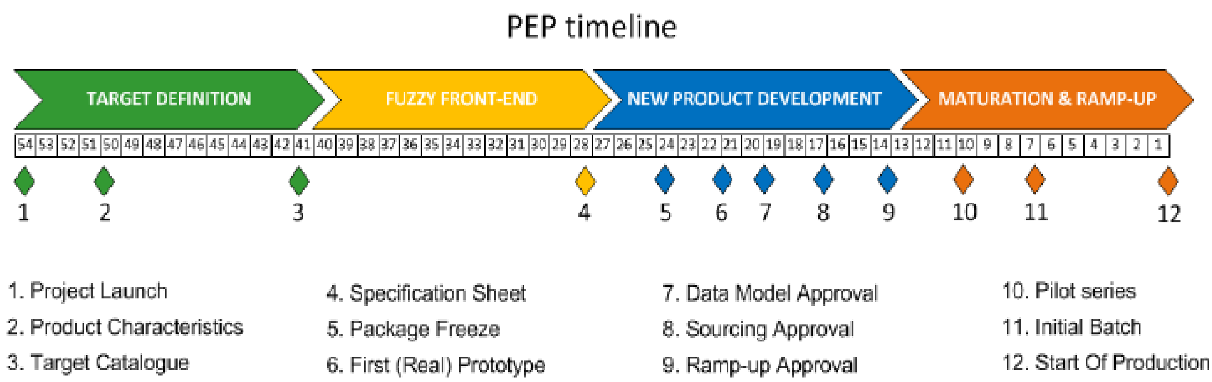


Figure 2.2: Example of a Product Evolution Process timeline with relative milestones [19]

Looking at the figure 2.2 It is possible to notice the timeline division characterized by decreasing weeks going from the idea of the product up to the start of production. Moreover, a series of indicative milestones with the relative deliverables is reported.
The phase of interest in the studied case, in which one or more physical models are realized in order to perform the validation of the requested parameters, is the Fuzzy Front-End one, during which the design and the product validation is performed.

2.2 The ICT Revolution in the Automotive field

Reducing costs and improving time-to-market without affecting the quality of the final product have always been a primary target of the Automotive Industry. On the same side the need of developing and producing new car models to increase the gamma of vehicles offered by each Car Manufacturer in a more and more efficiently way, has spread technology innovation to other sector of manufacturing. Surely a high influence in this term has been given by what is defined as the ICT Revolution[8]. Before the introduction of computers, the design of a vehicle was mainly based on experience of the engineers and on empirical considerations, while mathematical analysis was used just for few critical components.
The consecutive step was essentially the realization of several prototypes by which all considerations and tests were made, applying the needed modifications. When a satisfactory target was reached the mass-production was started.
After the twentieth century, thanks to the development and the introduction of computers and in particular their ability to reproduce mathematical models, it was possible to deeply change this slow and complex approach.
Although first applications, especially related to Finite Element Method (FEM), were applied for aerospace applications, it didn't take too much time to exploit a such approach also in the automotive field. [20]
It is well known that nowadays this revolution brought to a profuse application of the computers aid in the vehicle design process allowing to obtain various output that can serve different departments that collaborate to reach the same target: The realization of a product able to completely satisfy the largest number of customers possible by maintaining an affordable effort in terms of time and costs for the company.
This approach allows nowadays to obtain reliable and validated mathematical models aimed to the reproduction of virtual prototypes, Finite Elements analysis simulations, assembly simulations, Aerodynamics simulations but also visual representations for aesthetical purposes.
It is important however to underline that this path is not free from drawbacks. The enormous amount of data, indeed, that must be managed by a company in order to get the desired task, requires a dedicated approach for the management of the whole information processes and resources regarding the whole lifecycle of the product.

[8] With term ICT (Information and Communication Technologies) Revolution is intended as the summary of the accumulation of new technologies regarding electronics and computer, and of their impact in process and exchange the informations.

At this time such revolution is considered not complete yet and it will continue to change the automotive world.
Surely the virtual reality will represent one of the main actors in this process thanks to its ability to reproduce a level of details and an immersive experience comparable to what is nowadays obtainable only from the physical prototypes.

2.3 Hints on Body Vehicle design-process

Referring only to the car body design process, that is the one of interest for the studied case, should be clarified how this process is carried out in an automotive company and the role that computers play in the definition of the virtual models.
First, it is important to take in mind that, differently from other car subsystems, the body design covers not only technical aspects but also aesthetic characteristics that represent one of the leading factors in the commercial success of a car.
With the term *Body-Vehicle* is intended (conventional definition for a steel-body) an assembly of thin-wall metal sheets joined together in order to obtain the primary frame of the vehicle. More precisely this definition characterizes what is defined as *Vehicle Body in White*. The addition of movable parts (eg. doors, engine hood and tail gate or trunk lid), external components (bumpers, windshield, windows, weather strips, griller, spoilers lamps) and interior trim (dashboard, seats, trim panels and general coverings) determine the whole *Body-Vehicle*.

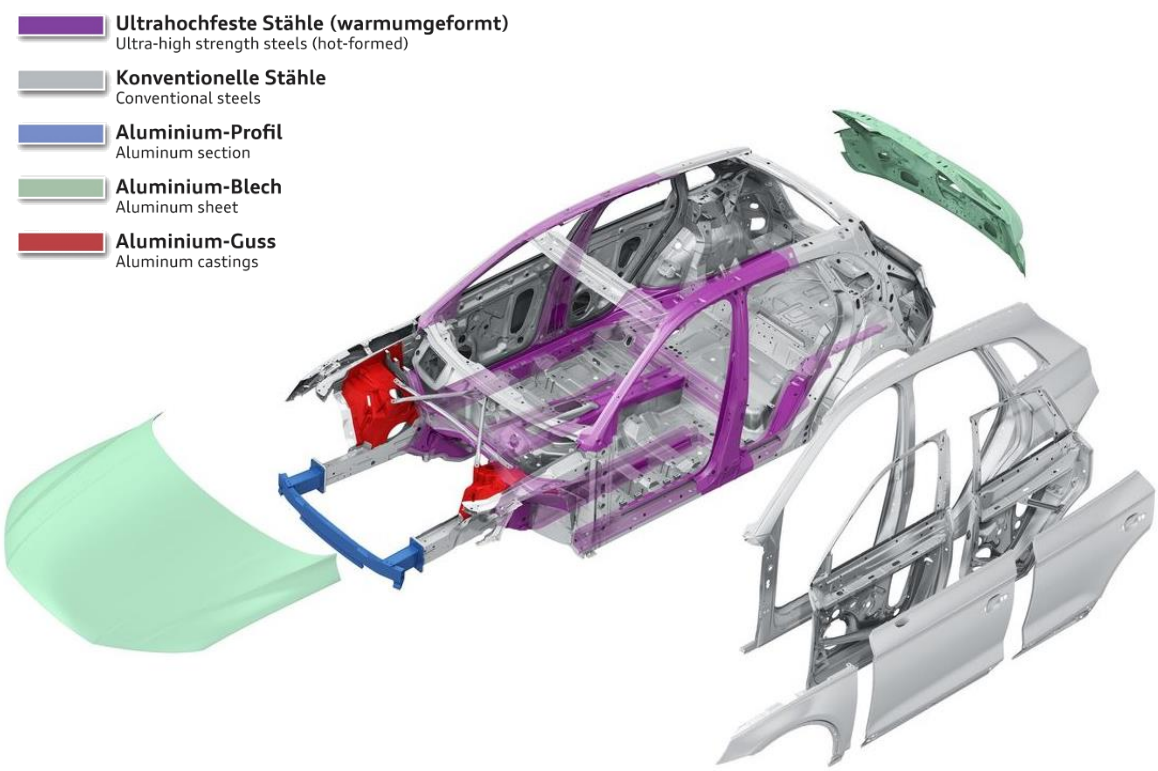


Figure 2.3: Audi Q5 Body. (From Audi MediaCenter)

The body design must achieve in general, several tasks that can be considered to be of primary importance.
These tasks are:

- Aesthetics: to provide a pleasing overall appearance and surface quality;
- Structural: to support the weight of the transported passengers and loads as well as withstanding mechanical stresses from multiple sources;
- Ergonomic and roominess: to supply easy access and adequate room for the driver, passengers and transported goods.
- Safety: to ensure integrity of passenger compartment in the case of crash, while absorbing the impact energy as well as to reduce injuries to vulnerable road users in case of collision;
- Aerodynamics: to minimize drag due to air impact and control the air flow effects on vehicle stability;
- Insulation: to minimize noise, vibration and thermal radiation;
- Visibility: to provide the highest possible day and night visibility;

Moreover, the body must satisfy other important requirements such as: high reliability, low cost, high recyclability. [21]

During the body design process the drawings should be available early enough with respect to the start of production in order to enable all related activities to be performed. Actually, the body engineering must be performed in parallel with the style development. The large use of computers during the process allows nowadays to reach an overall development time of about 24 months from the style model to the start of production.
The applications regularly used are:

- Computer Aided Styling (CAS);
- Computer Aided Drafting (CAD);
- Computer Aided Manufacturing (CAM);
- Digital Mock-Up (DMU). [20]

Another important characteristic provided by the use of computers in the vehicle development process is, beside the reduction of timing for drawings and the implementation of modifications, to keep all operations and steps in an organized database that guarantees a fast and reliable set of informations always available during and after the process.
Going deeper in detail the described work is mainly related to the *concept development phase* in which the cooperation of engineers, marketing experts and stylists, defines a product specification by examining alternative solutions in parallel. This concept specifications must satisfy customer’s expectations achieving also economical and technical feasibility.

During the time that goes from the concept definition to the product definition many activities are performed in parallel such as planning, engineering, style definition, planning and development of the assembling processes, economical evaluation, in addition to the manufacturing of prototypes.
Such activities are performed in parallel and this is possible thanks to the use of design tools in particular of CAS, CAD and CAM, that allows rapid modifications and the reuse of models based on the know-how deriving from previous projects.

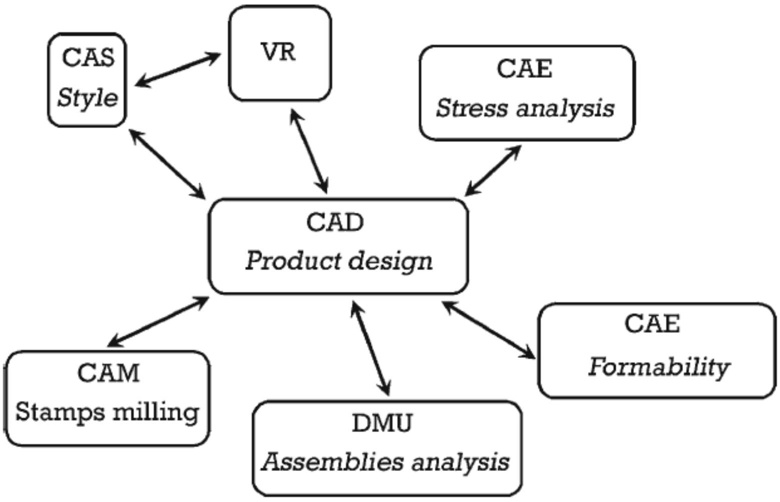


Figure 2.4: Links between product development activities and dedicated informatic tools [20]

Starting from the style department, it applies CAS tools to improve the style architect productivity and to create an output in terms of mathematical surface style model that can be directly used by engineers for consequent analysis. This step starts immediately after the development of a new model. In this phase a set of specifications aimed to the early definition of the model are given. These informations are essentially:

- The type of car in terms of car segment and expected production volumes;
- Main exterior and interior dimensions;
- Engine and gear-box layout;
- The so-called Carry-Over parts that can be re-used with a low level of modifications from a previous project;
- The manufacturing and assembling technologies that can be used;

Such informations allow to the style department to carry out a preliminary sketch of the car starting the body style and structure development.
Among the style development two phases can be identified:

- Form generation;
- Mathematical model generation.

During the first phase the designers and the engineers must cooperate to define the shape of the product. The cooperation is necessary in order to convert the graphical elements deriving from the style into a technological feasible object by the work of engineers.

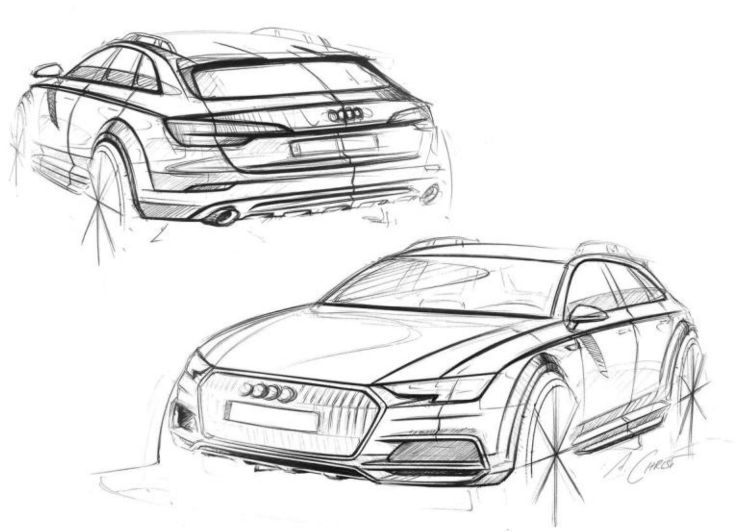


Figure 2.5: Design sketch for style definition (From Audi MediaCenter)

The lines of the initial sketches are then converted into spatial coordinate surfaces that are used as input for the CAD system to enable the addition of other details (Figure 2.6). Usually during this engineering phase several modifications are applied reinterpreting the initial shape. The final output of the process is a mathematical CAD model that provides the effective evaluation of the car exterior and interior shapes as depicted in figure 2.7. The term mathematical derives from the fact that its surface geometry is represented by continuous mathematical functions.

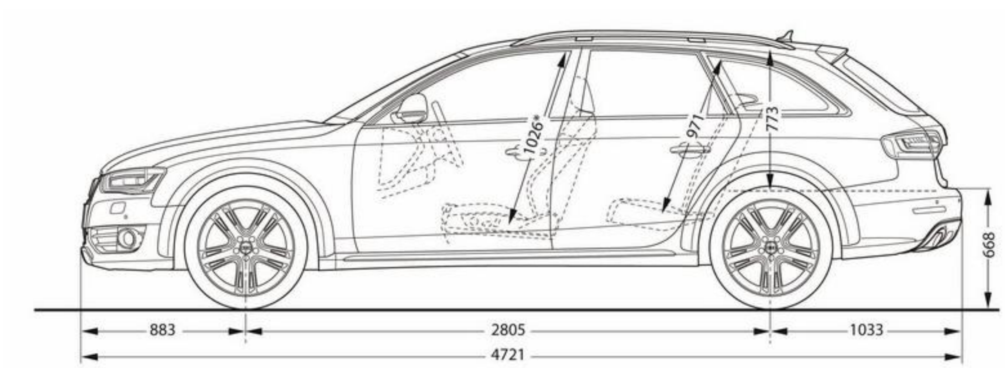


Figure 2.6: Transformation of the sketch into coordinate lines (on the XZ and YZ planes) (From Audi Media Center)

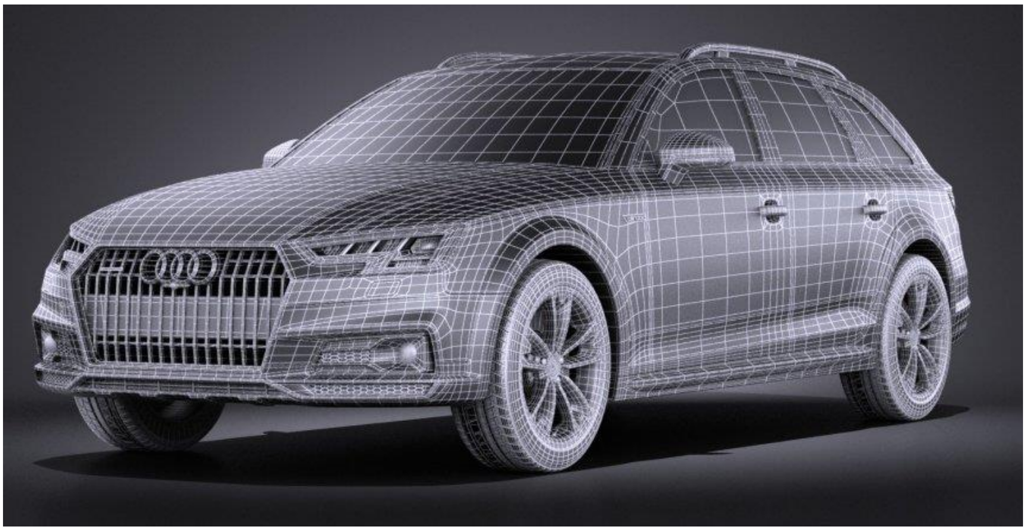


Figure 2.7: Three-dimensional rendering of the final product (From Audi MediaCenter)

Although high level virtual representations have been reached by means of today's technologies, the realization of full scale physical model is the only way to offer a direct view and a sense of touch missed in the conventional CAD.

2.3 Physical Models

Computer tools introduced in the vehicle development process brought a significant improvement in terms of cost and time reduction with respect to the traditional methods, but the realization of physical models still represents a fundamental phase of the project. Full scale objects allow to offer a realistic and direct viewing of the developing vehicle that is often not perceived using the CAD, moreover they are still in use to confirm and validate the decisions taken in the virtual environment.

Such models are used through the entire vehicle development both for aesthetical and technical evaluations. In general, in the early stage of the process coarse models are realized starting from the informations given by interior and exterior surfaces coming from the CAD mathematics and some master sections[9].

These starting data usually bring to a first rough-shaped object, but as the process progresses more detailed models are built with a strong increase of costs.

Physical models are usually made starting from a block of synthetic material obtained by mixture of wood sawdust and epoxy resin milled by computer numerical control machines that takes as input the CAD/CAS mathematical surfaces.

The goal of such models is not always univocal and during the vehicle development process different objects are realized for different purposes. In general, it is possible to

[9] With term master section is intended a set of body sections cut at specific vehicle locations which describe the necessary informations for a vehicle structure design.

define two families of models: those realized for style purposes and those for engineering validations.
Regarding models for style purposes it is possible to identify:

- A dimensional Model: This 1:1 scale model is usually realized in an early stage of the process and its only aimed to the visualization of proportions, volumes and shapes of the body. For this reason, these coarse models are usually made by lighter and less expensive materials such as polystyrene. Thanks to its lower level of details and the use of a less valuable material this physical object provides the basis for the style evaluation and allows to apply modifications to the general shape of the vehicle.

- A Design Clay Model: 1:1 scale model aimed to the visualization and the evaluation of the style content of the vehicle body. The level of details with respect to the dimensional one increases, and it is usually made by clay. The use of Clay allows to add or remove or add some details thanks to its ductile tendency with the increase of the temperature.

- Design-Freeze Model: 1:1 scale model aimed to the final definition and freezing of the body style.

- Clinic Model: 1:1 scale model with a high-quality surfaces and detail resolution both regarding interior and exterior design. It is used in order to have Benchmarks comparisons and to obtain a feedback from possible customers. Its realization is carried out after the parallel engineering validations both in terms of ergonomics and feasibility point of view. The high level of details and of dedicated parts that must be realized in few components often by different technologies, strongly affect the costs and the time needed for its realization.

On the other hand, engineering purposes models are in general:

- Aerodynamics Model: This model gives the basis for a first aerodynamic analysis performed in a wind tunnel in order to evaluate how the vehicle shape interacts with the air flow simulating a running vehicle. Its scale dimension varies according to the type of analysis that must be performed and according to the wind tunnel dimension available during the design process.

- Ergonomic Model: 1:1 scale model for the physical representation of the first engineering data and packaging. These models are used for ergonomics evaluation and to evaluate roominess and accessibility. In order to offer a reliable basis for the ergonomics validations its precision should be around 1mm and must provide movable parts reproducing the real vehicle adjustment possibilities. Since they are only aimed to these kinds of evaluations are often partial, representing the driver compartment only.

- Design Check Model: 1:1 scale model for the analysis of technological feasibility and assembly simulation. It also allows to evaluate the gaps between movable parts and their kinematics paths. Therefore, it can be seen as the physical equivalent of a Digital Mock Up. [22]

It is important to take into account that the realization of physical models described above must not be considered as mandatory during the development of a new vehicle. Each one of these model covers a role that can be considered, according to the project, more or less important and so its realization could be avoided by the car manufacturer.
The work on clay models, for example, is very time and cost-intensive. Only few car manufacturers place so much value on 1:1 objects and refine them in such faithful detail.

Regarding to the previous brief description, this work focuses on models aimed to the ergonomic validations. Although high costs such objects represent the only feasible path for an effective ergonomic analysis since the ergonomic itself is something related to the human perception that the computer tools cannot fulfil.
The fourth chapter of this work describes the design of a seating-buck able to reproduce several vehicle layouts. The introduction of this device, together with a proper use of the virtual reality tools, can provide in the future a solid support for engineering analysis and style interiors evaluations removing the necessity of realize expensive clay models.

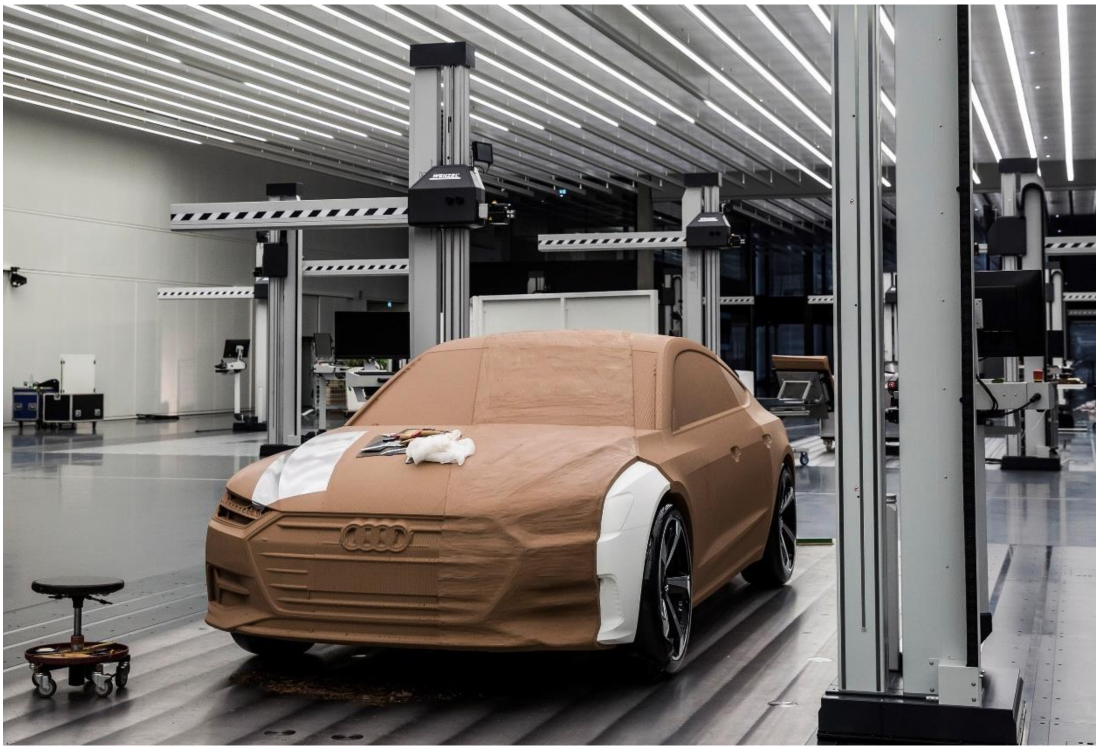


Figure 2.8 Clay Model building (From Audi MediaCenter)

3 Virtual Reality tools for Ergonomic Validations

It is becoming evident that several companies have undertaken the path towards a 4.0 Industry concept. The definition of a 4.0 industry deal with what is defined as the fourth industrial revolution that takes the automation of manufacturing processes to a new level by introducing customized and flexible mass production technologies. This step is mandatory to be competitive in the next future and automotive industry is not free from such deep change.
The Virtual Reality (VR), and in particular its application in the work environment, takes a relevant place to make this possible.

3.1 Hints on Virtual Reality Hardware

The term Virtual Reality is intended as a set of hardware and software aimed to the creation of a virtual environment that can be similar to the real world in order to create a lifelike experience.
Although the first concepts aimed to create an immersive experience trace back on the 60's, only in the last years great strides have be made, obtaining impressive results. This evolution is directly related to the development of new technologies both on the hardware and the software point of view. In particular the computational capacity of new computers able to process the big amount of data required for a correct functioning of a such complex system.
As always happen for the development of a modern technology it is first mandatory to define the more effective path to be followed in terms of economical return that is essentially related to the demand of that product on which invest on. Concerning the V.R. The Video Gaming market seems to be the best market to find and adequate demand that justify the effort both in terms of research and economic investment. Thanks to this evolution it is possible to purchase nowadays good performance devices for relative low prices, or at least easily affordable by a company that is intentioned in the investigation of V.R. application in its working environment.
Dealing with the application of the VR in the Automotive field, this technology allows to enhance the engineering design process and can considered as the most sophisticated tool to navigate and represent a detailed assembly. Early applications, indeed, deal with the visualization of the vehicle digital mock-up and with the style development process both for exterior and interiors, allowing the representation of a detailed model seen by a moving observer. Other successful applications obtained so far are the visualization of tests that represents a crashed vehicle body, a virtual stressed car or a virtual aerodynamics analysis. [20]
Besides the above mentioned uses of the VR applications on the vehicle process development, the new technological improvements allow nowadays to have more sophisticated and reliable devices that increase the range of applications of such technology for the engineering field. In particular this case study deals with equipments that allow, together with the visualization of a physical model aimed to ergonomic validations in a virtual environment, an affective interaction with it, giving to the user the

illusion of touching and manipulating the virtual object. Of course, the ultimate target is, despite an initial investment by the company, to reduce time and costs of the vehicle development process.

Going deeper into detail, to get a complete V.R. system able to represent a virtual working environment it is necessary to deal with a chain of different devices that properly work together to obtain the following features:

- High resolution stereoscopic view and give a full representation of the objects that fall in the semi-space containing the optical axis;
- Update the objects according to the point of view with a refreshing time lower than 10ms in order to avoid unacceptable lags;
- Full stereo sound output of both environment and object noise;
- Tactile and force feed-back, as function of object displacement.

Although it is not directly the topic of this work it is important to give a brief description of the main devices needed to create a V.R environment. [20]

3.1.1 VR Visualization Devices

Visualization devices can be divided into two families according to the way in which the virtual environment is displayed: direct vision or projection.
The first group includes:

- Head Mounted Displays (HMD);
- Binocular Omni-Orientation Monitors (BOOM).

The Head Mounted Display is a display device, worn on the head or as part of a helmet, that has a small display optic in front of one (monocular HMD) or each eye (binocular HMD) allowing an immersive experience. Tracking sensors mounted on the headset allow a real-time evaluation of the head position and orientation, giving the possibility to the computer to reproduce a consistent view.
Since the HMD is the chosen device for the application described in this thesis a deeper analysis is given in the following.

Regarding with the second group, the BOOM it is similar to a HMD device but in this case the user sees the virtual environment through two holes and explores the space by orienting a suspended box on an articulated arm. This device of course strongly affects the degree of freedoms of the users with respect to modern HMD that starts to exploit a wireless technology.
Belonging to this group a remarkable application is the CAVE (*Cave Automatic Virtual Environment*). It is a cubic room build up with screens, where users can freely move and interact with the virtual environment by acting on joysticks, haptic gloves or also real elements such as steering wheel, seats and pedals. [20]

The main advantages of this technology are:

- An ample field of view and high resolution
- Work environment accessible to more than one user
- More degree of freedom in user's movements with respect the BOOM technology.

Figure 3.1: CAVE with physical seating-buck as interaction with the virtual environment (From Porsche Newsroom)

Regarding the projection technology it is based on stereoscopic glasses used to see a semi-transparent screen giving to the user the perception of a 3D environment.
According to this brief description regarding the various visualization technologies, it is evident that thanks to the obtained development level of the modern devices the VR technology can be considered grown enough for applications that go beyond the simple visualization of 3D models allowing also an effective interaction with the virtual environment.
The project described in this work foresees the application of consumer grade HMD devices, together with the main physical objects that characterize the vehicle seating accommodation such as steering wheel, seats and pedals, fitted on a self-configurable seating buck. This provides the physical support for the ergonomic validation tests acting as a link between the real and the virtual world.
Such solution can be seen as a compromise between the CAVE and a pure VR navigation system putting together the main advantages of the two systems:

- The immersive experience given by the HMD;
- The freedom of movements guaranteed to the user in a CAVE.

3.1.2 Head Mounted Displays (HMD)

The Visor, is the hardware component that mainly influences the immersive experience. For this reason, its design is strongly influenced by important ergonomic aspects both in terms of wear ability and weight in order to satisfy the highest range of users. According to this criterion a series of adjustments are usually integrated in the most common V.R visors to better match with different user's anthropometric characteristics and guarantee them the best experience possible.
Therefore, a modern head mounted display should possess the following features:

- A proper shape to guarantee and easy and comfortable wear ability;
- Adjustable fastening belts;
- Adjustable Inter-pupillary distance;
- Adjustable lens distance;

Such characteristics play a very important role for a professional VR application in which the user may be forced to a long-lasting time usage of the tool.

Regarding the working principle of this visualization devices it is essentially based on a high-resolution screen with in front a couple of lens.
The lens deceives the user's eyes in order to give the impression to lie in a deep and width environment even if the screen it is set few centimeters above. Such effect could be simply obtained by spherical lens. The main drawback for spherical lens is the considerable weight and their thickness both aspects that enters in contrast with the idea to create the lighter and thinner visor as possible. To solve this problem, modern visors sets a couple of Fresnel Lens that despite a higher complexity allow to obtain the same result with a lighter and thinner solution.

Referring to the screen its performance and design characteristics are very important in order to obtain a convincing experience.
For the described study, the first tests were performed by using two commercial visors mainly designed for video gaming applications.

- *The Oculus Rift* by Oculus VR*;*
- *The HTC Vive* by HTC.

Both present two screens, one per eye, with a resolution (of each single screen) of 1080x1200 pixel with a sampling rate of 90Hz. As demonstrated in the following test for the binocular field of view evaluation, although such devices are mainly aimed to video gaming applications offer an acceptable accuracy and resolution also for professional applications. [23] [24]

Another important characteristic of the visor is its ability to precisely track all head movements to reproduce them in the virtual environment without perceptible lags. This

aspect is fundamental in order to give to the user the correct perception of view according to his head movements. For this scope a magnetometer measures the earth's magnetic field giving this information to the visor in order to allow to the software to determine in real time where is the North and so to ensure that the visor is correctly oriented.
Accelerometers present in the set allow to track the head movements with a good accuracy and to analyze the gravity direction.
to guarantee a more immersive experience a headphone set is integrated in the HMD.
As already said, the comfort perceived by the user is a fundamental parameter for the professional VR applications. The above-mentioned adjustments linked with the possibility to wear them with practically all types of glasses allow a wear ability that can be considered acceptable for testing applications. It is however important to take into account that also subjectivity can strongly influence this aspect. It is possible, indeed, to feel a "seasick" effect caused by different aspects that go from the design of the screens, the possible lags related to the tracking of the head, or simply depending on what is represented by the software.

3.1.3 Receiving and Emitting Sensors

In order to track the presence of the headset in the real environment a communication between the headset (and if present joysticks or other tracking devices) and a "base station" is needed.
This result can be obtained essentially following two different technologies: Infra-Red cameras or Infra-Red emitters. In the first approach, used for example by the Oculus Rift, an infra-red camera is able to track the infra-red lights present on the headset itself. The workstation on its side, acquires all needed informations applying them in order to properly represent in the virtual environment what has being watching.
The second solution, the one used by the HTC VIVE, uses a number (at least 2) of Infra-Red emitters positioned at the ends of the area that must be tracked. In this case the mentioned emitters rapidly trigger laser beams across the ambient in order to obtain the triangulation of the visor on which the receiving camera is set.
The technology behind the two devices is essentially the same but an inverted methodology is used. [23] [24]

3.1.4 Controllers and Trackers

The above-mentioned devices are usually provided together with a pair of controllers with 6 degrees of freedom (three displacements and three rotations) in order to reproduce the touching or the moving of the virtual objects.
Beside the precision and the reliability of the tracking that will be discussed beyond, the main limit of these kind of devices is simply represented by the fact that they keep the hands of the user occupied. While in a gaming situation this is not so limiting, in working application, and in particular in the studied case in which it is necessary to simulate the accommodation of a passenger in a vehicle, a such boundary is not acceptable.

The growing interest in applying the V.R technology also for working purposes, very far from the video games field, is bringing the evolution of the devices to a new level. Different companies, indeed, are developing dedicated tracking devices that in most cases are perfectly compatible with main commercial V.R. Systems. In particular strong efforts have been made in the direction of object tracking or in the hand free tracking. In the first case the main idea is to fix a dedicated device on any object that wants to be brought in the virtual environment.
Two notable examples, at least because of the possible adoption in this case study, are the VIVE Tracker and the Leap Motion.
The first is a device able to convert any physical object into a virtual one bringing it in the virtual environment. Based on the same technology as the HTC Vive and its controllers, the Vive Tracker calculates its position in a room based on infrared signals emitted from the base stations. Where these signals fall, it is tracked via an array of sensors on the device and converted into an equivalent virtual environment position. Such device can be also used as hand tracking system, but the drawback is the necessity to use a glove, reducing the feeling of freedom of the user.
An interesting application of such device can be also the body tracking. A precise and complete body tracking could allow the rapid realization of a virtual body for postural analysis. However, this device is on the market only since the end of the 2017 so no experimental tests have been carried out before this study.
Regarding the Leap Motion it is an infra-red based controller used to determine the position of the user hands in a limited space in real time.
A deeper analysis of such device is reported in the following description of the experimental tests carried out to evaluate its performances. [24]

3.2 Virtual Reality Software

The virtual representation of the vehicle body or of its interiors is related to the geometrical accuracy but also the to an accurate definition of colors, textures, light spots and their correct reflection on the surfaces. For texture is intended the repetition of an ornamental drawing on the surface. This allows to represent with high fidelity the interior trims of a vehicle considering the different possible configurations. As described below dedicated visualization software, nowadays implementable with virtual reality tools, allow to reach high defined 3-D models able to reproduce reflections according to different light spots positioned in the virtual environment but also all possible surface finishing. [20]
Regarding the present study this aspect represents an important improvement with respect to the ergo-model approach used nowadays. Although the physical models are only aimed to a physical validation, their level of accuracy and fidelity with respect to what will be the final product, is always increasing. This brings to a relevant increase of the cost needed for their realization and this negatively affect the vehicle process development. The possibility to substitute at least one of the clay-models with a virtual one, already defined also in terms of finishing for style purposes, allows to reach a high fidelity without affecting the costs.

Besides the aesthetical representation of the surfaces, importing from the existing CAD the studied model it is possible to take into account also the mathematical equations that characterizes the different components. This makes possible to reproduce and control in the virtual environment also the kinematics of movable components. This aspect will be obtained on the realized seating-buck tracking the displacements of the movable parts by using devices able to reproduce them in the in the Virtual environment as the Vive Tracker mentioned above.
The figure 3.3 shows the analysis carried out for two of the main software that provide the VR integration. In particular it has been considered the possibility of the two software to reproduce in VR some of the main ergonomic test performed on the physical model.

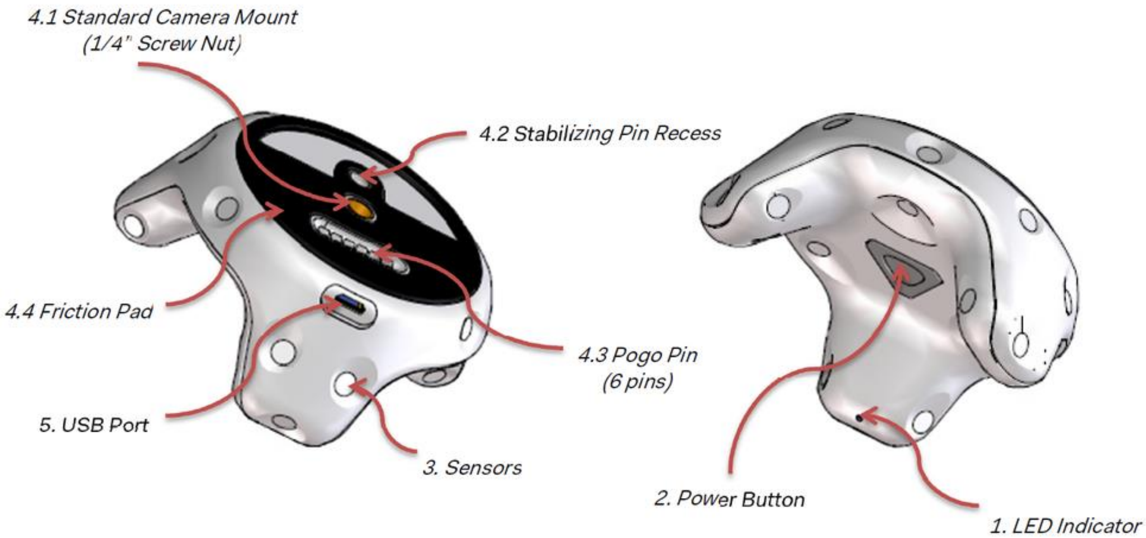


Figure 3.2 Vive Tracker with main features

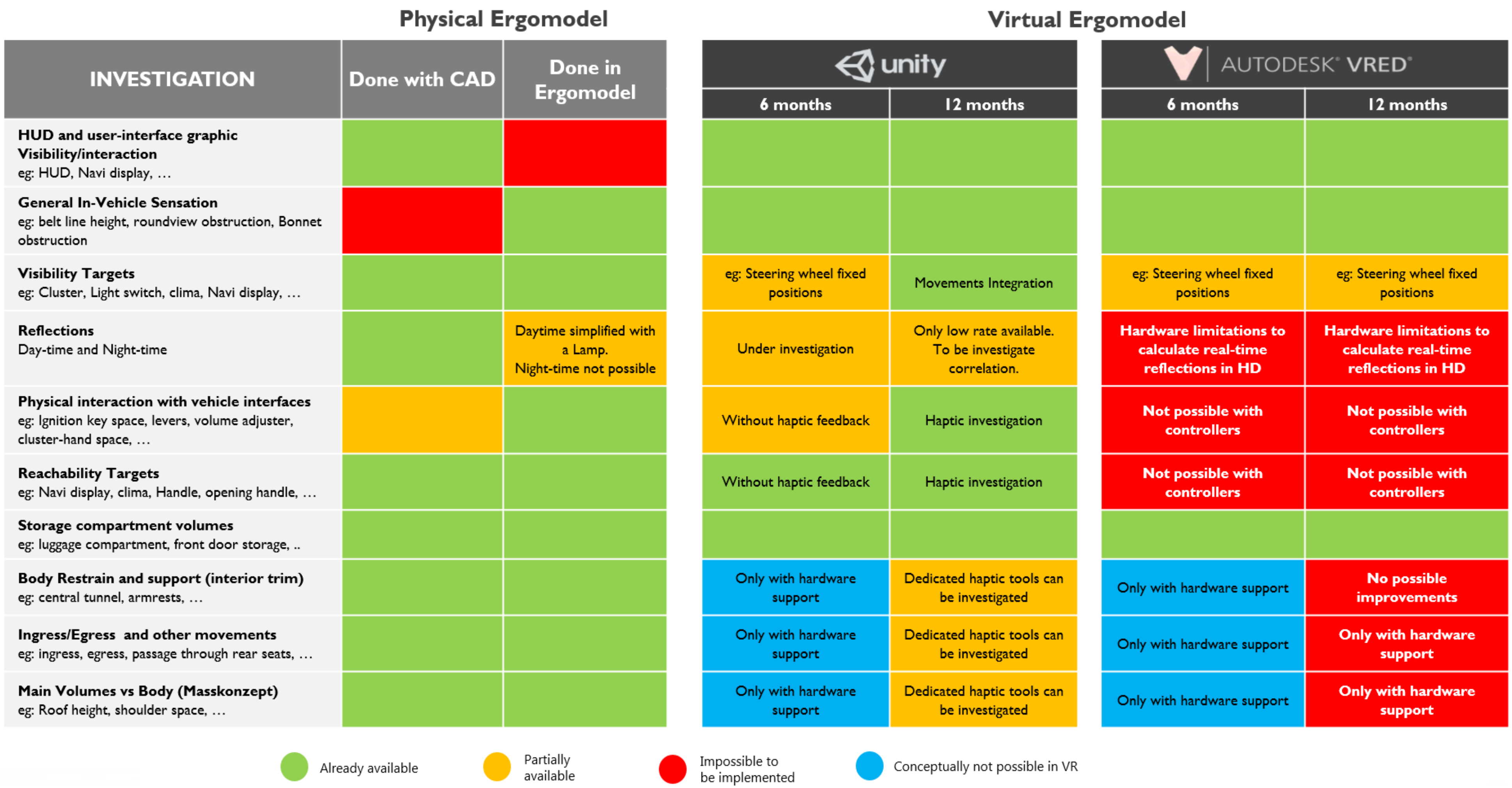


Figure 3.3: Autodesk VRED vs Unity comparison for main ergonomic test application [22]

This figure is the property of Italdesign Giugiaro S.p.A.

The first, *Autodesk VRED*, is a largely adopted software in the automotive field mainly aimed to the visualization of high-level renderings of the product and virtual prototypes. It is nowadays integrated with the Virtual Reality tools allowing the visualization of the product in a virtual environment once worn the visor. It is mainly thought and used just as a 3D visualizer not allowing some interactive actions with the represented model. Nevertheless, it remains the best choice when a final product or an assembly with high-level of details wants to be seen and explored in the virtual environment. [25]
An interesting alternative to Autodesk *VRED* is *Unity* by Unity Technologies. Unity is a gaming development platform that allows to reproduce 2D and 3D simulations supporting the main Virtual Reality Platforms. Another important characteristic is its open-source nature that allows to make, as described below, a first set of basic tests without the needed to acquire an expensive license.
The working environment can be divided in:

- Assets: all the resources that the created simulation uses. They can be 3D models, materials, textures audio and many others. The key aspect of such ambient is the possibility to convert into a Unity project the main used CAD formats such as STEP, IGES or STL. This means that once a product has been designed it can be easily converted into a Unity project and visualized by wearing the VR visors.

- Scenes: representing the ambient where to insert the assets and simulate the chosen scene. This allows to control and represents movements of each 3D object in the virtual environment reproducing in this way the real kinematics of the model. [26]

3.3 Test premise

UNITY has been chosen as platform for the tests described below. The used approach is based on the conversion of the CAD data needed for a given ergonomic analysis into the UNITY interface allowing the visualization in a VR environment. To obtain reliable results, as first step it was necessary to carry out some preparatory tests in order to understand if this conversion could negatively affect data coming from the CAD tools. Furthermore, it was mandatory to learn if consumer grade VR devices can represent an enough reliable instrument also in for professional applications. It is important to remember, indeed, that the VR devices used during the tests are consumer grade devices aimed for video gaming applications, while the application described in such work needs reliable and precise outputs to guarantee an effective instrument for an engineering validation.
For this reason, the two tests described in the following must be seen only as a first approach to a new and continuously changing technology.

3.4 Binocular Field of View Test

3.4.1 Visibility in The Automotive

To better understand the test described in the following it is necessary to furnish a rapid overview on the visibility and of some instruments used in the SAE standards regarding this field.

According to the SAE standard J1050 the human field of view can be separated into different regions. The one depending on one single eye is an area around 145 deg. and is delimited on one side by the nose, and on the other is nearly perpendicular to the sight line. The region where the fields of view of each single eye overlaps is defined as *binocular* and is about 110 deg. The ambinocular field of view derives from the sum of the field of view of each eye and extends about 180 deg. (Fig3.4) Such definitions refer to the case when the head and the eyes are held fixed and the subject is looking straight ahead. [5]

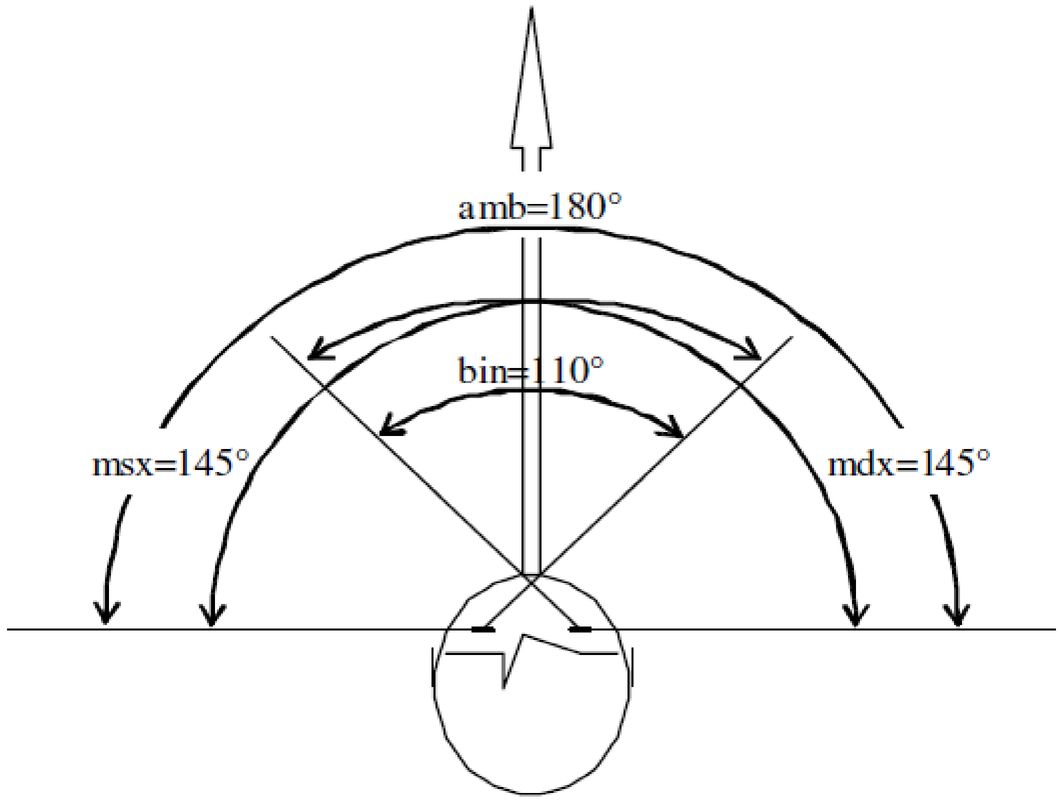


Figure 3.4: Definition of the different fields of view in accordance to SAE J1050a recommended practice. The assumption is that both the eyes and the head are fixed in a straight-ahead sight line. Apart from the objects along the *line of sight*, all the rest of the vision is of peripheral type. mdx: right eye monocular field of view; msx: left eye monocular field of view; bin: binocular field of view; amb: ambinocular field of view. [5]

The above descripted field of views generates a region in which the maximum visual acuity is obtained and another one known as peripheral view. The first is the most important for driving since it translates into a focused view as required for vehicles. The second one is used just to perceive the presence of obstacles and signs since the less accuracy does not allow a correct shape and distance evaluation.
Regarding the binocular field of view, it is important to take into account that it is the only region where a stereoscopic vision is guaranteed. The stereoscopic vision is fundamental for driving since it allows to appreciate the distance between the subject that is watching and the obstacles.

3.4.2 Eyellypse

The SAE standard J941 introduce the reference tool of the visibility analyses on board vehicles. Such tool is defined as eyellipse and is represented by two ellipses whose contour was obtained by a statistical analysis of the eyes locations for a given population. The two-dimensional eyellipses are representative of the 90th, 95th and 99th percentile distributions of the drivers' eye locations.
Referring to the figure of the 95th percentile eyellipse in side view, shows as the 95% of the eyes will lie below the line and the 5% above it.
The same consideration holds for a straight-line tangent to the lower edge of the eyellipse. So, it is important to remember that the eyellipse does not actually include the 95% of the eyes but each tangent has 95% of the eyes on one side and no matter if they are in the eyellipse or out of it.
The size of the eyellipses takes also into account the longitudinal seat travel and the backrest inclination. [5]

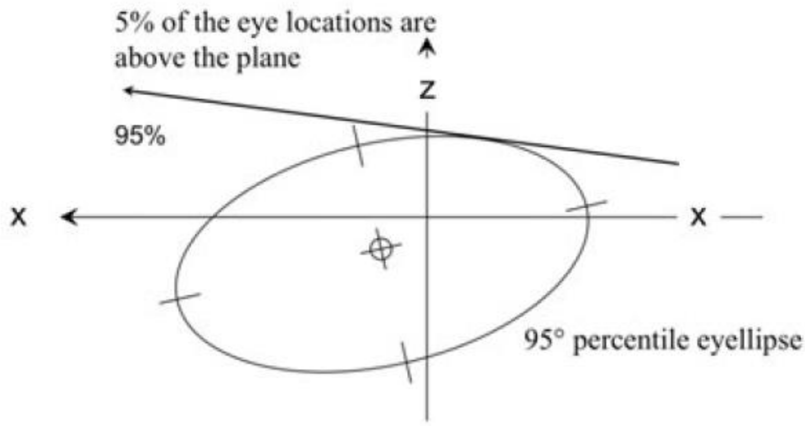


Figure 3.5: Eyellipse from SAE J941 [5]

3.4.3 Introduction to the Test

A first approach to the application of Virtual Reality Tools for the purpose described in this work, was an analysis about the accuracy in terms of field of view as perceived by a user that wears the HMD device.
The basic idea is that what is seen by the user in the visor should be consistent with the field of view reproduced in the modern virtual instrument (CAD) already used as first check of the ergonomics and visibility requirements. For such reason a test has been carried out in order to compare the two outputs in terms of binocular field of view. To better understand the followed procedure, it is necessary to briefly explain how this evaluation is performed today during the normal vehicle development process. As example for the test, has been considered the direct visibility evaluation of the cluster and how other vehicle elements (such as the steering wheel in this case) can negatively affect it.

The procedure can be divided into four phases:

- 2-D Approach
- Style Modifications
- 3-D Approach
- Ergo-Model Validation

The 2-D approach provides a representative section in the ZX plane of the cluster and of the steering wheel positioned in the space according to the first packaging considerations (figure 3.6). [27]

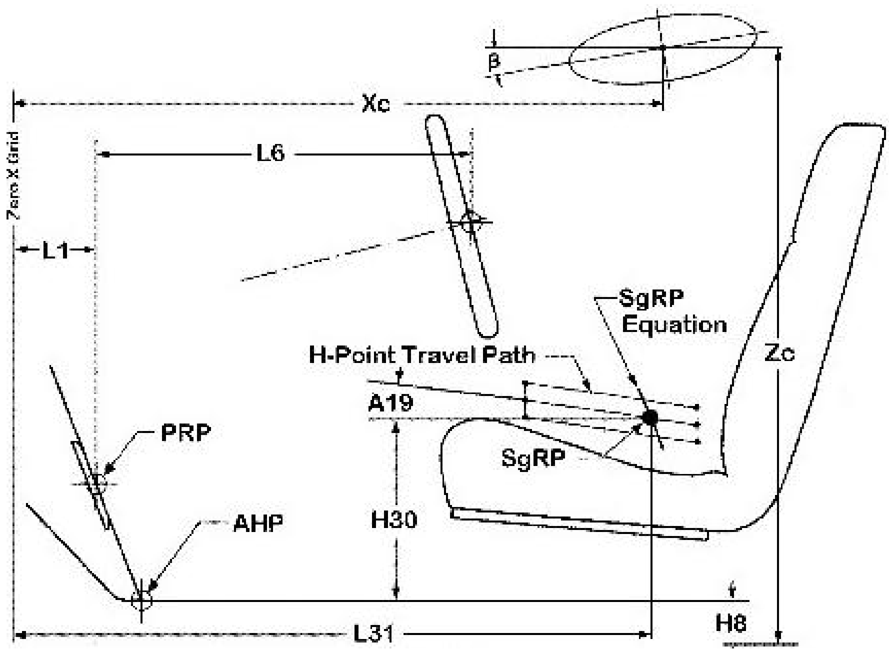


Figure 3.6: Eyellipse positioning in side-view packaging [5]

Moreover, such section includes the eyellipse of a given percentile for which the test must be performed. Starting from the eyellipse the binocular field of view as indicated in the figure 3.6 Is defined by a line at 45 deg. upwards and a line at 60 deg. downwards according to the SAE Standard J1050a. [28]
This procedure, defining the binocular field of view in the side view obtained only by the eye movements, allows a first positioning of the cluster taking into account the worst possible cases for the considered percentile.

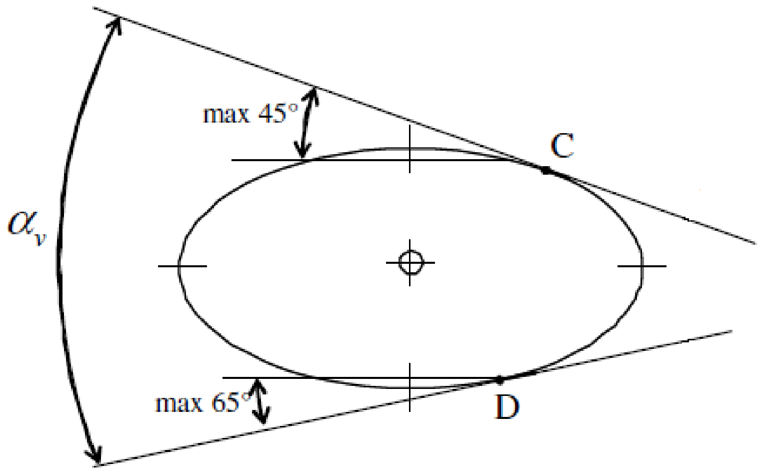


Figure 3.7: Binocular field of view according to the SAE standard J1050a [28]

The output in terms of positioning deriving from this first step is then given to the style department that operates the integration of the previously positioned cluster into a dashboard volume, including all aesthetical parts that will characterize that zone. In practice the aesthetical volumes of the dashboard module are determined completing the definition of the interiors configuration.
The implemented modifications, mainly driven by aesthetical considerations, impose the necessity to make a further check in terms of feasibility and prescription compliance.

At this point the first step is repeated, but in a 3-D environment. Different percentiles RAMSIS manikins are located in the investigated package. The CAD environment allows to set a virtual camera centred in the point of view of the virtual dummy reproducing a human binocular field of view. This step represents the key point of the whole mentioned process since precedes the ergo-model realization. It is important to take into account that an eventual modification at this level of the process requires an amount of effort in terms of time and costs that is negligible with the respect to corrections made on the physical object.
At the end an empiric evaluation on a physical ergo-model is performed. Once the interior design of the vehicle, both in terms of style and package, is mature enough a clay-model is realized to validate different parameters. In the described case, several testers of different size are accommodated on the model and the visibility of the cluster and consequently its positioning is validated.

3.4.4 Experimental Environment and Test

In order to evaluate the accuracy of the VR visor the output of the 3-D approach has been used as input for the test described in the following.
To obtain a consistent comparison between the standard procedure and the inquired one, it is crucial to make coincident the two points of view.
This condition is achieved by means of two auxiliary planes drawn in the CAD environment. Such parallel planes (Blue planes in the Figure 3.8) define a certain reference range in terms of X positioning and possible inclination of the user head. As soon as the first plane is intercepted by the user it means that the correct X coordinate has been reached. Starting from this position a certain head inclination range is allowed thanks to the two cylindrical surfaces between the planes. In other words, if the user does not see any blue zone in his field of view it will mean that also the correct head inclination has been reached.
To get the Z and Y correct orientations, a target must be aligned with the top right-hand corner of the black cross drawn on the cluster surface as depicted in figure 3.8. The numbers on the graduated scale help identifying the boundaries of the tester point of view.
At this point the image deriving from the 3-D approach of the same configuration and the one obtained by the Virtual Reality test are compared.

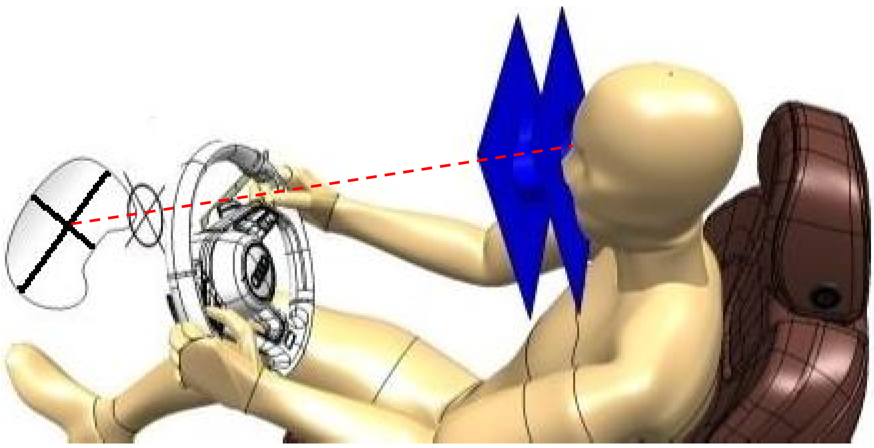


Figure 3.8: Experimental environment defined in CATIA V5. It is possible to notice the geometrical set composed by the two blue planes for a correct head positioning. [27]

3.4.5 Results

According to the figure 3.9 the deviation in the binocular field of view between the CAD analysis and the Virtual Reality results acceptable.
Looking at the dashed line it is possible to notice how the two fields of view differ from each other of a negligible quantity. The area enclosed by the steering wheel and the line is, indeed, comparable.
Among all performed test a deviation of maximum 2 mm has been highlighted.

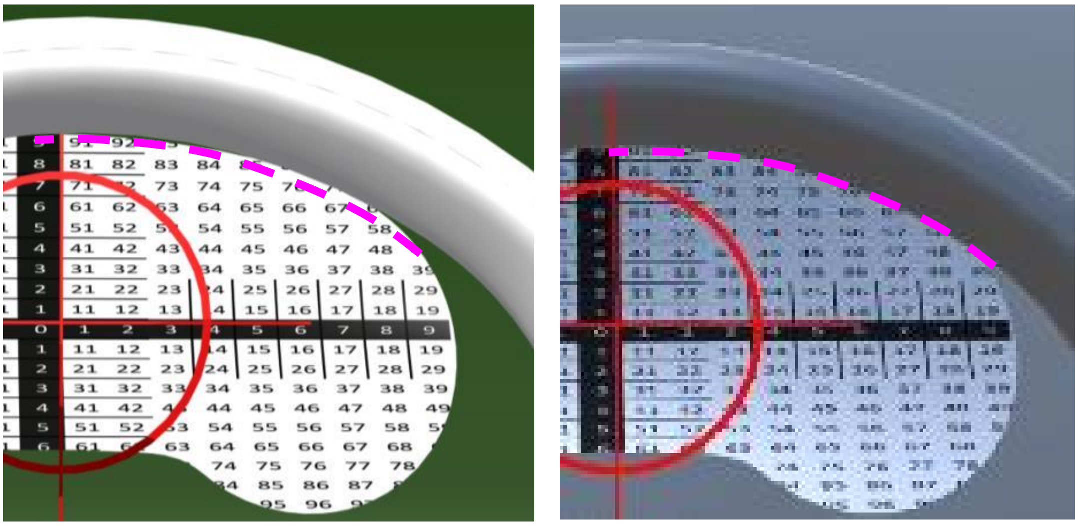


Figura3.9: Comparison between CATIA V5 and Unity environment. The pink line highlights the deviation between the two cases in the higher error configuration (2mm). [27]

3.5 Reachability Test

3.5.1 Commands Reach

Modern vehicles are characterized by the presence of several commands in the cabin compartment. Regarding to the driver's point of view not all of these commands have the same importance, for this reason a classification is needed to divide them into primary and secondary. The primary commands are that that allow the driver to control the vehicle and include the steering wheel, pedals, gear shift lever, hand brake and light switches. On the other hand, secondary commands are those that activate not essential functions for driving the vehicle such as air conditioning, radio and some of the lights.
The mentioned division is governed by the accessibility of the controls according to a priority criterion. It is obvious, indeed, that for safety reasons primary commands require the best reachability by the driver and must be placed as close as possible to it or however in an area that allows a fast and safe actuation.
The importance of this aspect and the need to create a minimum level of standardization in the positioning of the various commands inside the vehicle, brought the introduction of a standard, in particular the ISO 3958 and the ISO 4040:2009. ISO 3958 specifies passenger boundaries of passenger car hand-control locations that can be reached by hand by different proportions of male and female driver populations. ISO 4040:2009 specifies the location of controls in motor vehicle by subdividing the space within the reach of the driver into specific zones, to which certain controls essential to the safe operation of vehicles are assigned. It also defines certain combinations of functions for multifunction controls and the degree to which certain indicators and warnings have to be visible.
Dealing in particular with the ISO 3958, it defines some reach surfaces according to the importance of the command. For example, the steering wheel must lie closer to the surface with the higher reachability.
Besides the analytical definition of such surfaces their analysis and positioning in the vehicle compartment is nowadays obtained by the use of CAD tools that include three-dimensional manikins implement reach surfaces to carry out the reach analysis as depicted in the following figure.[5]

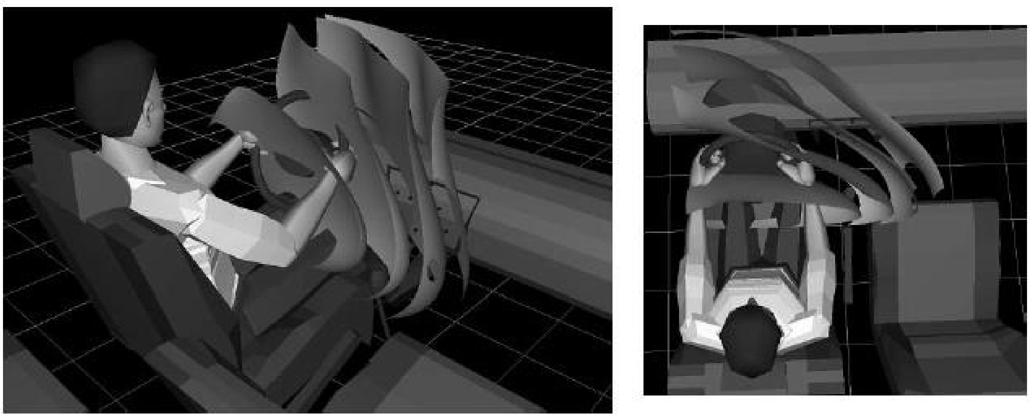


Figure 3.10: Commands reach surfaces obtained by 3-D tools [5]

3.5.2 Introduction to the test

The user interface and its interaction possibilities, play a fundamental role in the virtual-real world relationship.
The test described in the following deal with gesture-based user interfaces, that thanks to the latest technical advantages and the development of new devices, open several opportunities in the application of the Virtual Reality in specific application areas.
It is important to remember that gesture acquisition methods can be divided into two main families. On one side the one that provide a specific device that the user must physically hold or "wear" on his body, and on the other the hand/body free methodology.
The second approach is of particular interest regarding professional VR applications, letting the user the possibility to act in the virtual world without the unavoidable limitations given by a physical device utilization. In particular for such study it is necessary to let the user's hands-free form any form of devices in order to normally act on the physical model and reproducing its own movements in the virtual environment.
Such movements should be as precise as possible to correctly evaluate the analyzed parameters. For this reason, the aim of the test is to evaluate the accuracy of the tracking sensor to check the possibility of usage for an ergonomic validation.
The free hand tracking system used for the analysis is the Leap Motion Controller.
Several studies have been already carried out to offer a scientific evaluation of the precision of such sensor and different examples are available on the web. The main task of such analysis however, are intended to get an output in terms of three spatial coordinates of a tracked object, by introducing a part of code in the API (Application Programming Interface) that is easily accessible by the user.
Although the results of these tests demonstrate an accuracy that could be acceptable for some applications, have also pointed out the main limits of this type of controller. Has been demonstrated, indeed, a consistent error with the increasing of the distance between the tracked object and the device itself mainly due to an inconsistent sampling frequency of the device.
Regarding the described test, instead, the main scope it is essentially to evaluate the deviation that is perceived by the user seeing its hand in the virtual environment with respect to the position of its hand in the real world.

The controller performance was evaluated reproducing a virtual testing environment analogue with the real one and evaluating, by means of a measuring arm, the deviation between a virtual point characterized by fixed and known coordinates, and the actual position reached by the user's hand.

3.5.3 The Leap Motion Controller

The leap motion is an optical hand tracking system based on the stereo vision principle. It uses infrared imaging to determine the position of an object in a limited space.
The hardware it is essentially composed by a case of limited dimensions containing two IR LED emitters used in conjunction with two IR cameras. The controller field of view is an inverted pyramid centered on the device and its range extends approximately from 25 up to 600 mm above it (Figure 3.2).
The identified position is evaluated relatively to the controller's center point located at the position of the second centered IR emitter as depicted in Figure 3.11 [29] [30]

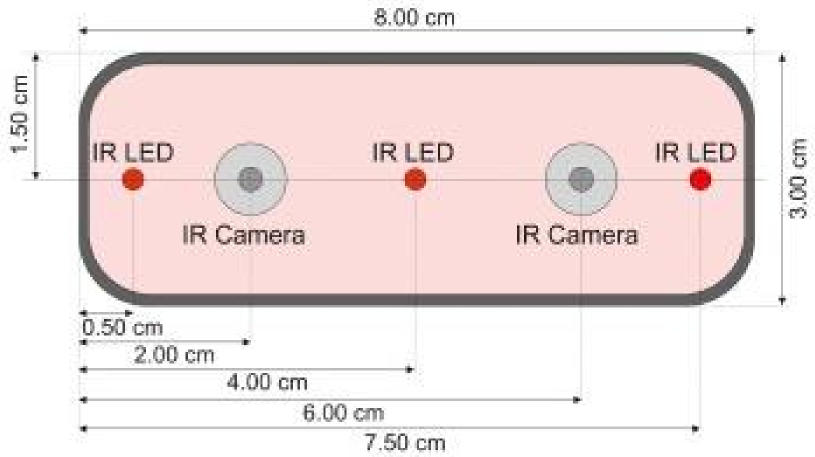


Figure 3.11: Leap Motion structure [29]

3.5.4 Experimental Environment

It is important to take into account that, since the gesture-based interface nature of the tested device, the accuracy of measurements is also affected by the so called human tremor. The tremor is defined as an involuntary movement of muscles. According to the age and other parameters, the human tremor lies in the range between 0.4mm +- 0.2 mm. For this reason, a correct evaluation of the measurement implies the use of a reference system that provides an accuracy that is below the tremor level. This is why a FARO Arm has been used, in order to set the reference frame and to correctly evaluate the reached position by the user's hand. [29]
The FARO arm is a high-accuracy measurement instrument that, by using a point or ball probe on an articulating arm allows the user to collect individual 3D data points of an object in the space.
Although the awareness to introduce a certain amount of error in the test it has been decided to put the leap motion controller on the visor, in order to reproduce the actual application that should be used during the integration between the virtual reality and the seating buck for the ergonomics evaluations.

This is a focus point of the test, and that probably justifies the obtained results, with respect to the better accuracy carried out with the Leap motion controller fixed on a surface but that would be inconsistent with the desired application.
With this configuration the leap motion, beside the evaluation of the spatial coordinates of the tracked object (user hands), must deal with the unavoidable movements of the head and so of the visor on which it is installed.

3.5.5 The Test

To make the test possible, as first step it was necessary to reproduce the testing area in the CATIA V5 environment. As depicted below such area simply provide a floor and the fixed reference frame defined by the FARO ARM Positioning. In particular has been chosen as zero the frame lying on the floor and belonging to the main axis of the cylindrical vertical structure of the FARO Arm. With respect to this system a series of targets, denoted by a letter followed by a number according to their positions, have been drawn in the CATIA environment as following:

A1	B1		D1	E1
A2	B2	C1	D2	E2
A3	B3	C2	D3	E3
A4	B4	C3	D4	E4

Table 3.1 shows X Y and Z coordinates of each target drawn in the CATIA V5 environment.

A1		B1				D1		E1	
X	1150	X	1000			X	1000	X	1150
Y	-600	Y	-300			Y	300	Y	600
Z	1900	Z	1900			Z	1900	Z	1900
A2		**B2**		**C1**		**D2**		**E2**	
X	1000	X	850	X	900	X	850	X	1000
Y	-600	Y	-300	Y	0	Y	300	Y	600
Z	1600	Z	1600	Z	1600	Z	1600	Z	1600
A3		**B3**		**C2**		**D3**		**E3**	
X	1000	X	850	X	900	X	850	X	1000
Y	-600	Y	-300	Y	0	Y	300	Y	600
Z	1400	Z	1400	Z	1400	Z	1400	Z	1400
A4		**B4**		**C3**		**D4**		**E4**	
X	1000	X	850	X	900	X	850	X	1000
Y	-600	Y	-300	Y	0	Y	300	Y	600
Z	1200	Z	1200	Z	1200	Z	1200	Z	1200

Table 3.1: Target Coordinates [31]

The second step consists into make possible the conversion of the testing environment created into CATIA, into a virtual environment in which the tester can dive by wearing the visor.
Such conversion is easily implementable in the UNITY platform without losing the informations regarding the correct positions with the respect to the reference frame.
Once the Virtual reality environment has been reproduced it was necessary to "force" the zero references of the visor in the virtual environment. To better explain this concept, it is important to keep in mind that, as previously explained, the visor continuously sends to the software interface the informations relative to its position. This means that it is necessary to set a coherence between the chosen reference frame and the visor positioning. In other words, the visor has to send an information of its position that is consistent with the chosen reference frame.
To do it, it is enough to put the visor on the floor (Z=0) and at certain known X and Y coordinates with respect to the zero-reference frame and to set such coordinates in the UNITY environment. Doing that the visor position is correctly related with the chosen reference frame.
At this point the test can be performed. Was asked to several testers with different anthropometrics to wear the visor and to touch the different targets with the forefinger. Once the "virtual hand" seen by the tester in the virtual environment crosses the center of each target, a measurement of the real position of the forefinger was taken by using the FARO Arm. The deviation between the measured coordinates and the actual coordinates of each target center (that are known) is taken as output. [31]

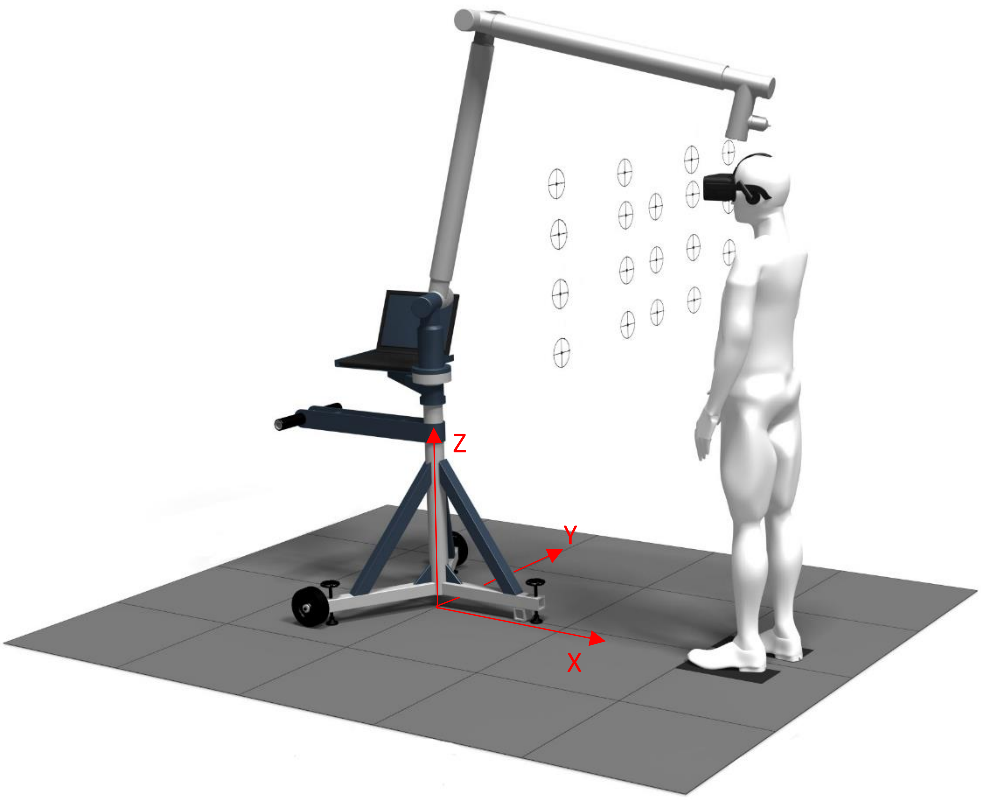


Figure3.12: Virtual Experimental environment reproduced in CATIA V5 [31]

3.5.6 Results

Table 3.2 3.3 and 3.4 contain the values of the measured deviations on the three spatial coordinates and the average value between two tests taken as example.

		X COORDINATE				
		A	B	C	D	E
Average	**1**	-35,50	-57,00		-58,50	-37,00
Tester 1		-53,00	-57,00		-54,00	-34,00
Tester 2		-18,00	-57,00		-63,00	-40,00
Average	**2**	-31,00	-49,50	-53,50	-44,00	-23,50
Tester 1		-32,00	-53,00	-47,00	-38,00	-32,00
Tester 2		-30,00	-46,00	-60,00	-50,00	-15,00
Average	**3**	-21,50	-21,00	-51,50	-24,00	0,00
Tester 1		-26,00	-24,00	-49,00	-29,00	0,00
Tester 2		-17,00	-18,00	-54,00	-19,00	0,00
Average	**4**	-6,50	-16,50	-25,00	-3,50	-4,00
Tester 1		-9,00	-14,00	-29,00	-4,00	4,00
Tester 2		-4,00	-19,00	-21,00	-3,00	-12,00

Table 3.2: Measured and average deviation in X coordinate

	Y COORDINATE					
		A	B	C	D	E
Average	1	-40,50	-25,50		20,50	16,50
Tester 1		-44,00	-34,00		1,00	3,00
Tester 2		-37,00	-17,00		40,00	30,00
Average	2	-16,50	-8,50	14,00	18,00	14,00
Tester 1		-25,00	-15,00	-2,00	4,00	7,00
Tester 2		-8,00	-2,00	30,00	32,00	21,00
Average	3	9,00	-1,50	20,50	-1,00	-2,00
Tester 1		-15,00	-7,00	5,00	-2,00	3,00
Tester 2		33,00	4,00	36,00	0,00	-7,00
Average	4	30,00	1,50	20,50	-5,50	-32,50
Tester 1		10,00	-7,00	11,00	-11,00	-27,00
Tester 2		50,00	10,00	30,00	0,00	-38,00

Table 3.3: Measured and average deviation in Y coordinate

	Z COORDINATE					
		A	B	C	D	E
Average	1	-20,00	-5,50		2,00	19,00
Tester 1		-20,00	2,00		3,00	26,00
Tester 2		-20,00	-13,00		1,00	12,00
Average	2	-27,00	-13,00	-7,50	-9,00	4,50
Tester 1		-28,00	-12,00	2,00	-9,00	9,00
Tester 2		-26,00	-14,00	-17,00	-9,00	0,00
Average	3	-11,50	-9,00	-16,50	-15,00	3,00
Tester 1		-17,00	0,00	-8,00	-17,00	6,00
Tester 2		-6,00	-18,00	-25,00	-13,00	0,00
Average	4	3,00	-11,00	-17,50	-6,50	12,00
Tester 1		-11,00	-3,00	-11,00	-6,00	11,00
Tester 2		17,00	-19,00	-24,00	-7,00	13,00

Table 3.4: Measured and average deviation in Z coordinate

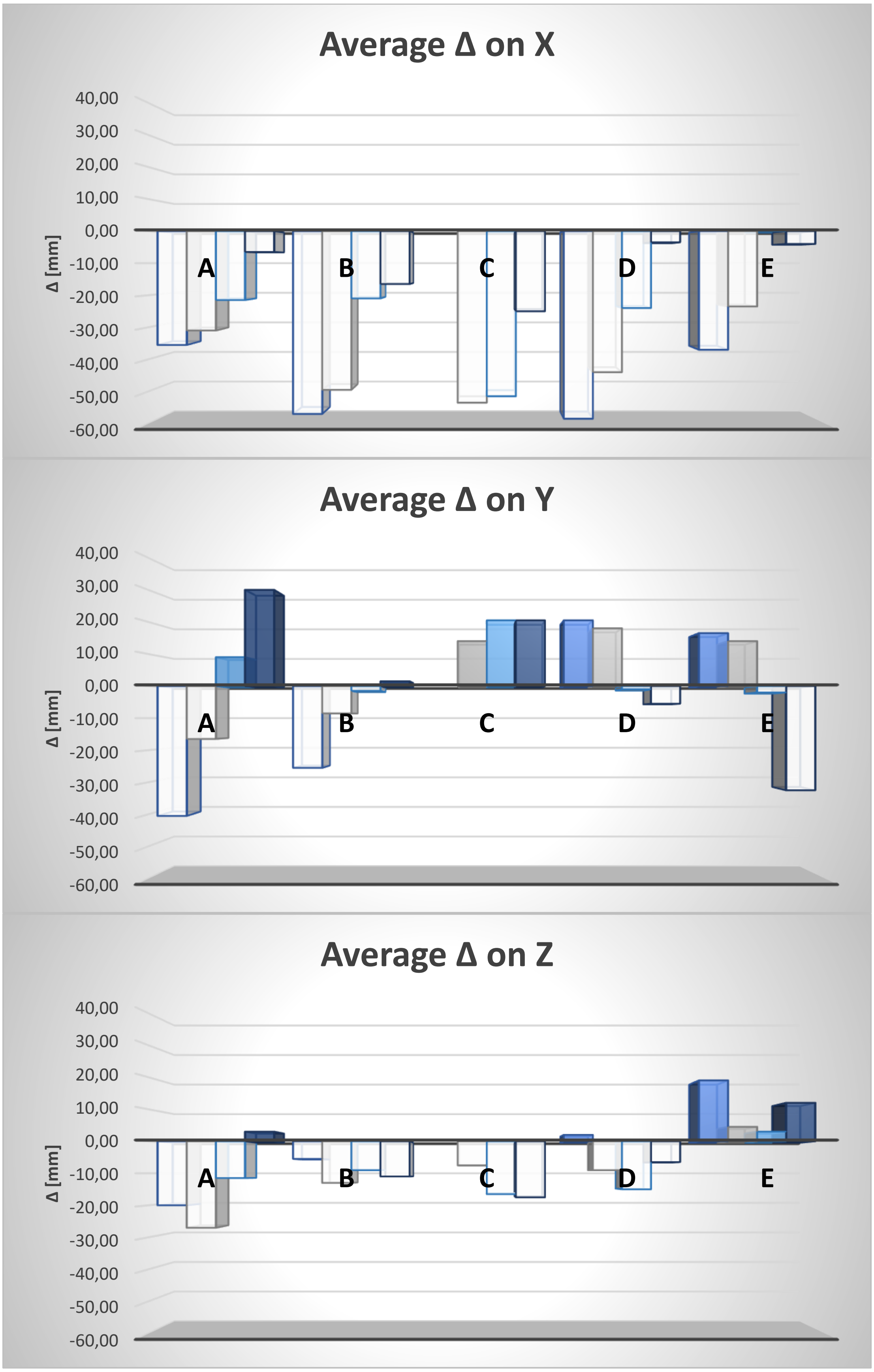


Figure 3.13: Average deviations between actual and measured X Y and Z coordinates. It is possible to notice that the higher error is obtained for the X direction. [31]

Figure 3.13 reports the average values of measured deviations obtained for two testers on the three spatial coordinates. It is possible to notice that the higher level of inaccuracy is reached with the X coordinate. This deviation, with maximum levels up to 60 mm, shall be considered as unacceptable for the type of applications needed in this case study.

3.5.8 Conclusions

From the obtained results it is possible to notice that the deviation between the real positions of the targets and those perceived by the user in the Virtual Reality environment is too much to consider this device reliable for such kind of application. The higher error is obtained in the X direction that is the one of major interest in a reachability test. Moreover, the deviation consistently increases when moving far from the sensor centre.
The inconsistent performance of the Leap Motion Controller is mainly due to its varying sampling frequency and to the difficulty to synchronize the movement of the head with the one of the hand. This aspect in particular, strongly affects the obtained results. Such strong limitation of course can be eliminated by placing the controller on a fixed position ahead the user. Tests performed with a such configuration shows a noticeable better performance, but it has been avoided because it would be not representative of the needed application. However, it is important to consider that such sensor is a grade-consumer device with a very low price mainly designed for video gaming applications. The increasing interest in the VR application in a working environment is bringing several companies that deal with hand trackers to create high precision controllers ensuring a trackability in the order of the millimetres. Surely these kinds of devices will represent the future choice for professional utilizations such the one described in this work.

4 The Seating-Buck

4.1 Introduction

Vehicle package development is a fundamental part of the whole vehicle design. It is aimed to the definition of the passenger's spatial environment, taking into account mechanical boundaries that will affect the overall exterior and interior dimensions. Validations regarding the occupant compartment configuration in terms of accessibility, comfort, visibility, reachability and so on, are carried out by the realization of a buck. With the term buck is intended a full-size model of a vehicle used to evaluate comfort, ingress, egress and vision, usually made of wood, metal, special foams or clay.

The building of the seating-buck is directly linked to the generation in a CAD environment the vehicle surfaces, package layouts and master sections. During the early development of the vehicle process such informations are incomplete and constantly changing. For this reason, the seating buck realization is nowadays inserted in a position of the vehicle development process characterized by an enough grown definition of these inputs. At the same time, during the early design stage the engineers would like to evaluate different design alternatives in order to find an optimal solution. The early stage, indeed, Is the one that offers to the engineers the higher design freedom to consider various alternatives without affecting too negatively the costs. [32]
It is known that design freedom decreases from the early project stage to the final one while costs follow an opposite trend. This behaviour is well depicted in figure 4.1.

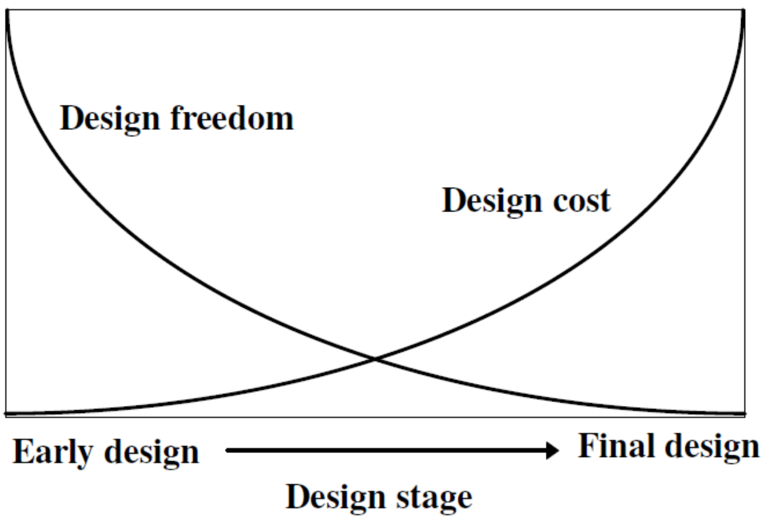


Figure 4.1 Design freedom vs Design Cost [32]

The challenge is always focused to the creation of the vehicle design as quick as possible with the informations available at time.

For this reason, the possibility to realize a unique physical model with a high degree of freedom that allows to reproduce different vehicle layouts represents a noticeable advantage in the vehicle development process.
In particular with the seating buck presented in this work, mainly aimed to ergonomic analysis, it is possible to avoid the realization of the physical models used nowadays during the validation process. It has been estimated that its introduction in a vehicle development process can reduce up to 8 weeks the whole time-line of the project that translates in a significant reduction of costs and in an increasing competitivity on the market.
It is important to take into account moreover, that on average three seating bucks are realized during a vehicle development program and that those for ergonomics validation should have a high level of details to correctly perform all needed tests and this means high costs. For this reason, the opportunity to eliminate even one of these ergo-models can strongly improve the efficiency of the whole process.

A conventional seating buck represents a full-size property of interior seating area of a vehicle according to the occupant packages.
Data normally used for the realization of an engineering-aimed physical model are:

- Exterior surfaces;
- Master Sections;
- Packages of interest;
- Opening path (such as for the doors);
- Interior components.

The overall occupant packages are measured according to the SAE standards and should be met at the end by the physical model to guarantee a reliable instrument for the validation.

4.2 Hints of occupant positioning

The occupant positioning and the posture assumed on board a vehicle depends on some constrains given by the vehicle structure, the commands and the need of furnish a comfortable and safe overall arrangement.
Starting from the definition of three basic postures for automotive applications described in figure 4.2 It is possible to state that they are mainly depending on the type of vehicle.

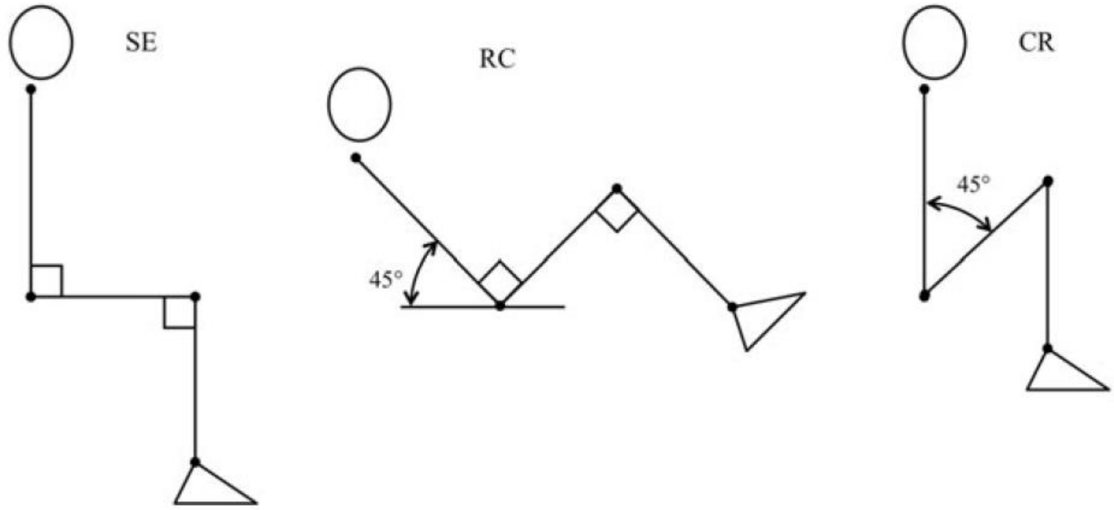


Figure 4.2 Basic postures for automotive field. SE: seated; RC: reclined; CR: camped [5]

Taking for example a sport car it will be characterized by a high reclined position for the driver while if rear seats are present the assumed posture of passengers will be closer to cramped one.
On the other side commercial vehicles and trucks offer to the driver a position that is closer to the seated one while passengers cars lie in the middle between the reclined and the seated position.
Such differences derive from a mutual influence of the vehicle main commands such as the steering wheel, the seats and the pedals.
During the design of the realized seating-buck it was necessary to take into account all these parameters and in particular to correctly dimension the range of positions that each one of these elements can occupy in the space.
Nowadays, during the design of a vehicle, several informations regarding the positioning of the main commands, the structural boundaries and the seats are managed together in order to realize the vehicle package. Such flow of data is regulated by rules and standards that must be complied simultaneously to get the final result.
In particular each assembly of components that forms part of the vehicle package design is characterized by a huge amount of reference dimensions that have been both defined for safety and ergonomics purposes.
However, since the starting point for the design of the seating-buck described in this chapter are package data already defined following the normal procedure, it is assumed that such informations are hidden behind the output represented by the package itself.
For this reason, is not the scope of this work to define in deep the laws and the standards that regulate the dimensioning and the positioning of each single component that is then reproduced on the physical model.

4.3 Seating-buck design process

This section is related to the description of the realized Seating-Buck and to the approach used for its design. Before entering in detail, it is important to underline that with respect to the conventional seating bucks aimed to ergonomic validations described up to now, this one will act as a link between the physical and the virtual world. For this reason, its design and realization are not aimed to emulate the vehicle package with a high level of details but only to reproduce the various layouts in terms of space and obstructions that characterize a vehicle package. The reproduction of the interior volumes with which the user does not directly interact (e.g. dashboard volume, some interior trims, pillar and roof obstruction) are indeed entrusted to the Virtual Reality representation.
This means that the final product it is essentially a frame on which are installed the main physical components that characterize the vehicle ergonomics and that cannot be substituted by the virtual reality since the user directly interact with them. Such components are:

- The seats
- The steering wheel
- The pedals
- The cabin Floor
- The central tunnel
- The door frame, including:
  - The arm-rest
  - The belt-line

Moreover, the frame allows to easily add supplementary devices such as screens or other types of controls according to the vehicle that must be simulated.
The approach used for the design of the seating-buck starts from a dimensional evaluation of the vehicle packages that must be reproduced. In order to guarantee the largest set of possible configurations several packages belonging to all vehicle segments have been overlapped in the CATIA V5 environment as depicted in figure 4.3.

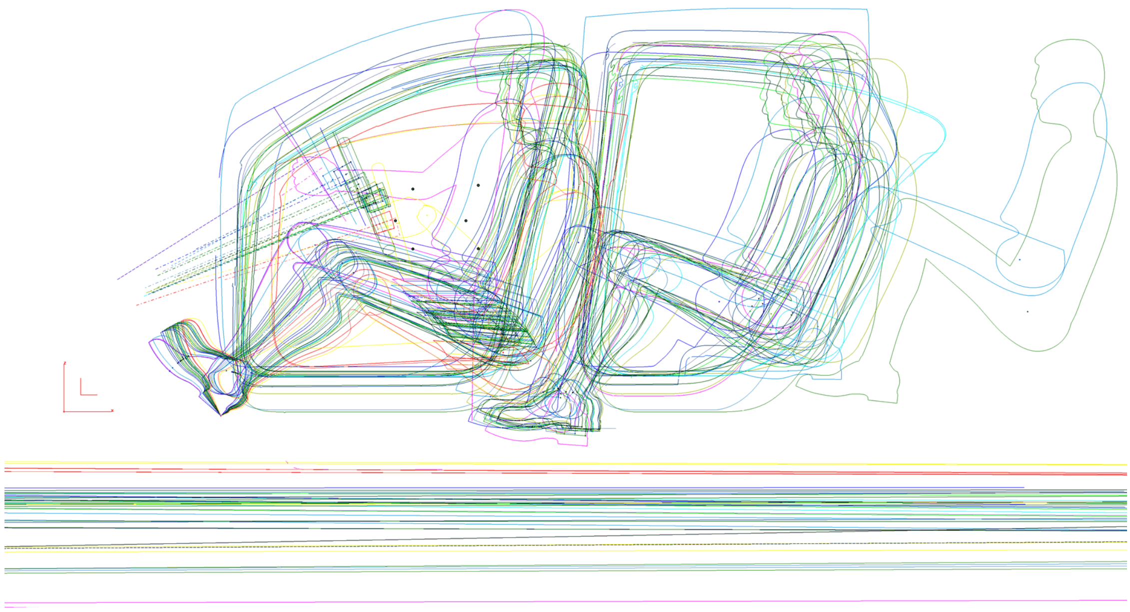


Figure 4.3: Reference Packages used for the seating-buck dimensioning

This figure is the property of Italdesign Giugiaro S.p.A.

From the figure it is possible to notice the amount of informations in terms of packages that has been managed in order to realize a physical model able to effectively reproduce all vehicles available on the market nowadays but also future layouts consistent with autonomous driving in which front seats are able to rotate facing the rear passengers.
Once the set of packages has been considered, in order to make a consistent evaluation of needed dimensions to correctly represent all, it was necessary to align them with respect to a reference point.
Among the points characterizing a side view packaging and regulated by the SAE standards as described in the first chapter of this work, it was chosen the HOS (hill of shoe) point. This choice is justified by the fact that it has been noticed that, with respect to other points of interests, the HOF is the one that undergoes to smaller variations among different packages configurations.
In particular all packages have been aligned with respect to the HOS of the Audi Q2 layout. Such choice is justified by the fact that this vehicle belonging to the B SUV Segment, represents a good compromise between different vehicle packages that must be reproduced lying in the middle between sport cars with low ground clearance and higher segment SUVs or Vans. This chosen procedure gives as output a series of various packages all aligned with respect to the Hill point and to start the design of the physical model around them.
Such alignment has been performed fixing the reference package (Audi Q2) in the ZX plane and bringing all other hill points to coincide with it. This means to fix the X and the Z coordinate letting as degree of freedom for the pedals positioning the inclination and the Y coordinates that of course will be related to the positioning of the H-point along the Y axis. After the packages alignment it was possible to actually perform the evaluation of the dimensional ranges that the model has to satisfy.

For each component in practice has been defined a dimensional box representing all the configurations in terms of positioning that it can assume with respect to the reference package. (Figure 4.4).

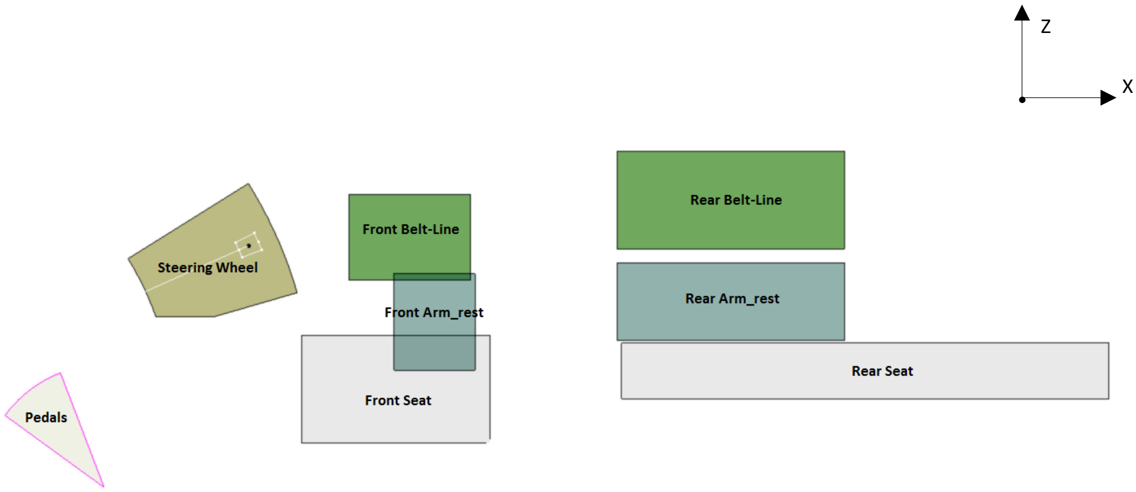


Figure 4.4 Positioning Ranges of the movable elements in the XZ plane

This figure is the property of Italdesign Giugiaro S.p.A.

The definition of such boxes allows to start with the design of the seating-buck structure and to the dimensioning of the strokes that each movable part must to cover in order to correctly reproduce the desired configuration. Table 4.1 shows the ranges covered by the movable elements in the three spatial dimensions and the inclinations of the pedals and the steering wheel assembly.
In the following are described all the macro-areas that constitute the buck and the technical solutions adopted for the handling of the relative movable parts.

Assembly	***X [mm]***	***Y [mm]***	***Z [mm]***	**α**
Front Seat	537	185	308	/
Front Arm-Rest	231	95	275	/
Front Belt-Line	346	105	244	/
Rear Seat	650	155	220	/
Rear Arm-Rest	650	160	280	/
Rear Belt-Line	1390	167	158	/
Steering Wheel	343	185	393	32°
Pedals	200	125	95	33°

Table 4.1: Dimensional Ranges of the movable elements evaluated according to the dimensions of the boxes depicted in figure 4.4.

4.4 Kinematics design

4.4.1 Fixed Frame

The technical solution adopted for the realization of the seating-buck structure foresees the use of BOSCH Rexroth aluminium profiles. Such profiles are characterized by good mechanical properties maintaining relative low costs and weight. Moreover, their particular section and the big number of available accessories allows the realization of modular structures able to satisfy all needed requirements.
Figure 4.5 shows the profile section with its peculiar groove that grant the fastening of other elements by means of “T” shaped nuts or bolts.

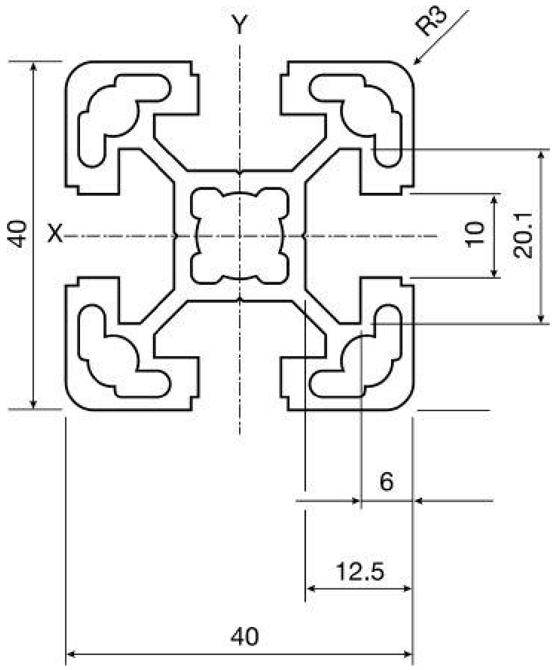


Figure 4.5 Representative section of BOSCH Rexroth Profiles [33] (From Bosch Rexroth)

The fixed frame constitutes the basis for the whole seating buck. It can be approximated to a rectangular structure with a central beam that beside the structural contribute furnishes the fastening surface for the central console.
Its dimensions both in X and Y directions are governed by the maximum distance measured between the boxes described above and deriving from the different packages taken as reference for the design.

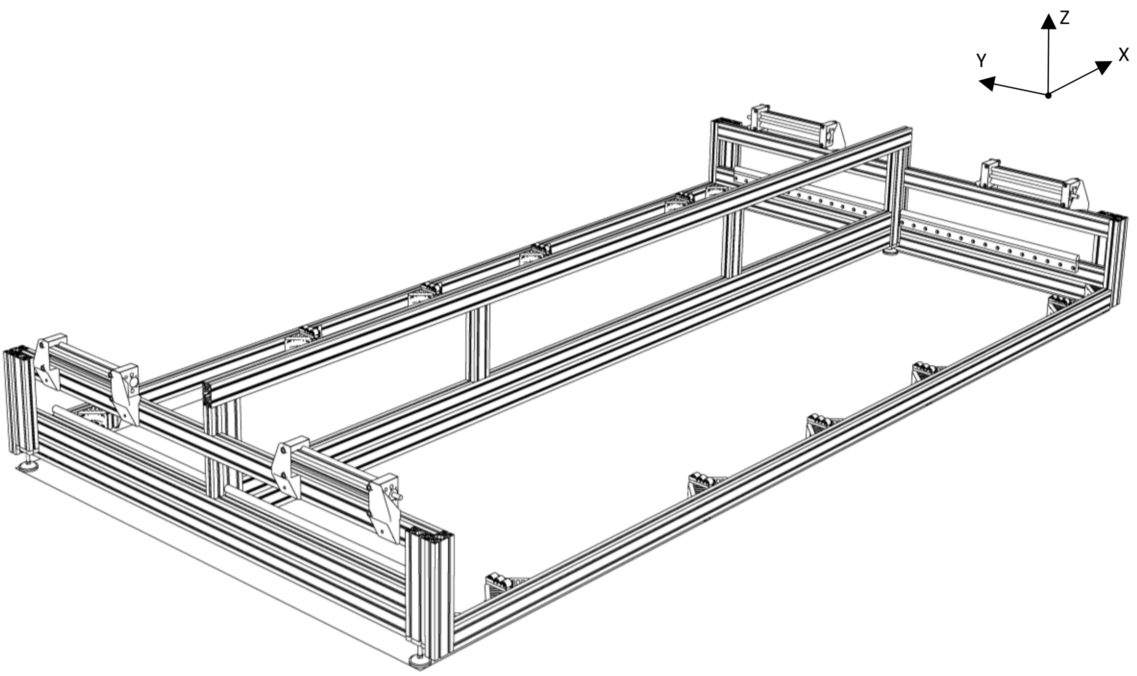


Figure 4.6 Representative figure of the fixed frame

This figure is the property of Italdesign Giugiaro S.p.A.

Regarding the height of the structure from the floor level (Z direction) it was necessary to deal in parallel with the seats stroke along the Z direction in order to correctly simulate the egress from the cabin compartment of all considered vehicles. This is a very important aspect of the design process and it has been decided to mainly manage this dimension by the use of the seats lifting system (that will be described after) containing as much as possible on the other hand the height of the fixed frame in order to simulate the lowest reference vehicle that is the Lamborghini Huracan.
Moreover, a higher degree of freedom for the fixed frame height has been obtained by using adjustable feet letting free the possibility to simulate other future configurations.
Since that frame provides the sustaining structure for all components constituting the seating buck, during its design a loads estimation and relative applications points was necessary in order to perform a Finite Element Analysis carrying out informations about deflections and displacements also in the elastic range. It is important to take into account, indeed, that although deformations under loads could lie in a range that does not affect the correct functioning of the movable parts, on the other hand could act in the whole tolerances chain affecting the tests for which the model has been realized.
For this reason, after the realization of the fixed frame it was necessary to evaluate and certificate by means of laser measurement devices not only the compliance with the desired dimensional tolerances but also the effect of the applied loads on the whole structure.

4.4.2 Y Movable Frames

As said at the beginning of this chapter, the alignment between the different packages has been obtained by the coincidence in X and Z coordinates of the Hill point with respect to a reference package. This decision allows to manage the X and the Z dimension of the package by simply acting on the movements along such directions of the occupant H-point that means to move the seats in order to replicate the desired package. To manage, instead, the H-point positioning along the Y axis has been decided to realize two movable frames on which seats, doors, pedals, floor and dashboard area are integral. (figure 4.7)

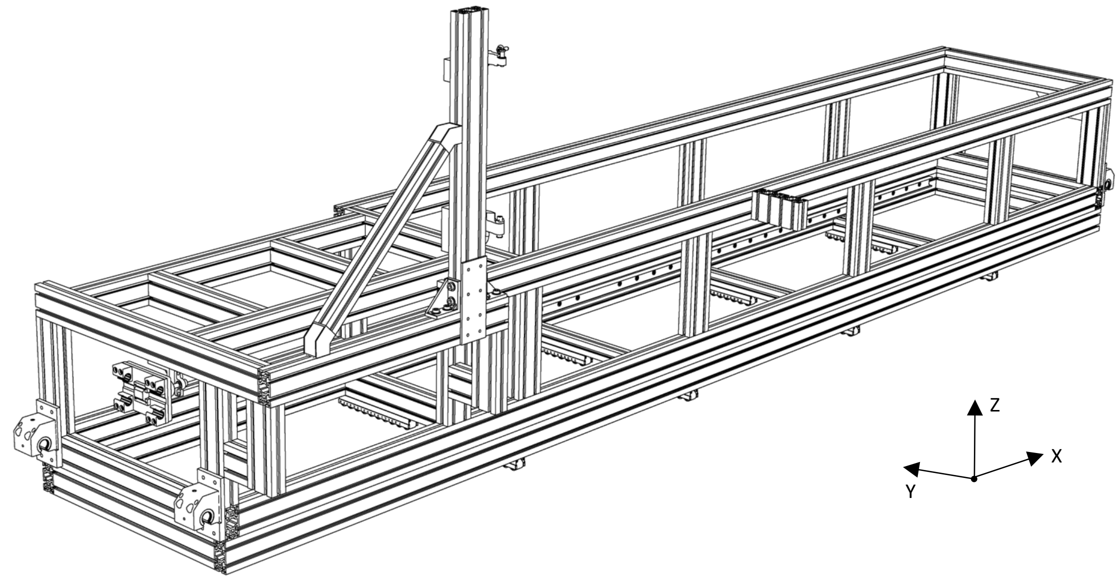


Figure 4.7 Representative figure of the left movable frame

This figure is the property of Italdesign Giugiaro S.p.A.

Also in this case the two frames are realized by means of BOSCH Rexroth profiles.
To make this more clear taking as example the distance W 20 that is representative of the distance between the H-point and the vehicle center line in Y=0 (figure 4.8), if such dimension differs of 20 mm in the positive Y direction with respect to the H-point of the target package it will be enough to move the whole frame of that value. Following this basic idea, it is possible to reproduce the cabin width since together with the frame will move the doors the pedals and the steering wheel that is fixed to the dashboard structure. This operation can be done both for the left and the right frame and allows at the end to complete the positioning of the hill point that as said before is the starting point for the vehicle package that must be reproduced. Other adjustments as for example those for the arm-rest or the belt line positioning are managed by other regulation systems and will be described later.

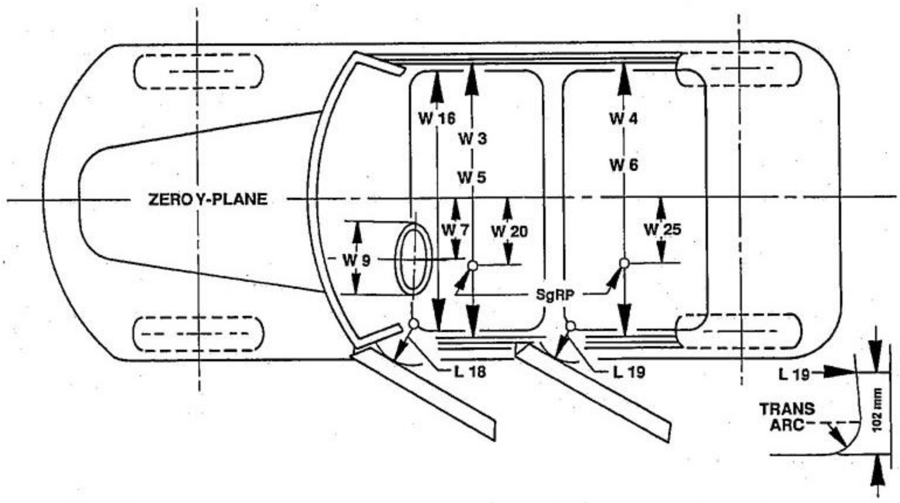


Figure 4.8 Vehicle interior side dimensions [7]

In order to guarantee an easy sliding of the two frames, that represent the heaviest assembly of the whole seating buck, two rails with recirculating ball bearings have been applied at the frame extremities and then connected to the fixed frame.

The actuation is guaranteed by four linear leadscrew guides (two for each frame) moved by a 12V DC motor controlled simultaneously by a programmable logic controller (PLC). The choice of leadscrew linear actuators allows to obtain precise displacements and allows the use of small electric motors also for the heavier applications.
The electric motor dimensioning is based on the formula 4.1 and 4.2 that define the torque needed in static conditions and 4.3 and 4.4 for the dynamic one.

$$T_s = \frac{F_{a_s} p}{2\pi \eta_s 1000} \tag{4.1}$$

$$F_{a_s} = \mu_s N \tag{4.2}$$

Where:

- T_s= Torque needed to start the motion expressed in Nm
- F_{a_s}= Static friction force in N
- η_s = Static efficiency of the leadscrew
- μ_s = Static friction coefficient
- p = screw pitch
- N = Weight of the load expressed in N

While for the dynamic condition:

$$T_k = \frac{F_{a_k} p}{2\pi \eta_k 1000} \tag{4.3}$$

$$F_{a_s} = \mu_k N + ma \tag{4.4}$$

Where:

- T_k= Torque needed dynamic conditions expressed in Nm
- F_{a_k}= Dynamic friction force expressed in N
- η_k = Dynamic efficiency of the leadscrew
- μ_k = Dynamic friction coefficient
- p = screw pitch
- N = Weight of the load expressed in N
- m= Mass to be displaced

During the dimensioning of the electric motors it has been necessary to evaluate for each movable element the needed reduction ratio of the motor in order to guarantee a displacement below the speed value of 10mm/s as requested by the regulations for safety reasons.

4.4.3 Seats

As seen in the first chapter of this work the seat H-point represents one of the main reference point for the vehicle package definition.
For this reason, it was necessary to guarantee to each seat of the seating buck the motion in X Y and Z directions in order to correctly represent the H-point of the desired package in the space.
As can be seen in the table 4.1 the ranges that must be covered by front and rear seats are considerable different. For this reason, it is appropriate to make a separation in the description of the seats kinematics.

4.4.3.1 Front seats

As said in the previous paragraph the Y motion of the seats is governed by the movable frames while the X and Z displacements must be managed by other solutions.
One of the main problem found during the design of the seats motions has been the coverage of a stroke along the Z direction (that is more than 300mm) containing at the same time the dimensions of the structure. Such stroke it is mandatory to represent different vehicle layouts from the sport cars up to commercial vehicles.
The first solution provided the adoption of a low-profile scissor lifter operated by a lead screw actuated by an electric motor.

The strong advantage of this mechanical system is its ability to keep very small dimensions in closed configuration that could correctly match with the searched application. The main problem, however, it is the low efficiency given by the small angle in the closed configuration that brings the necessity to apply a significant longitudinal force with respect to the weight that must be raised.
According to the formula 4.5 indeed, it is immediate to notice that a reduction in the angle Φ results in an increase of the actuation force needed to lift the weight W (figure 4.9). (the weight of the structure it has been neglected).

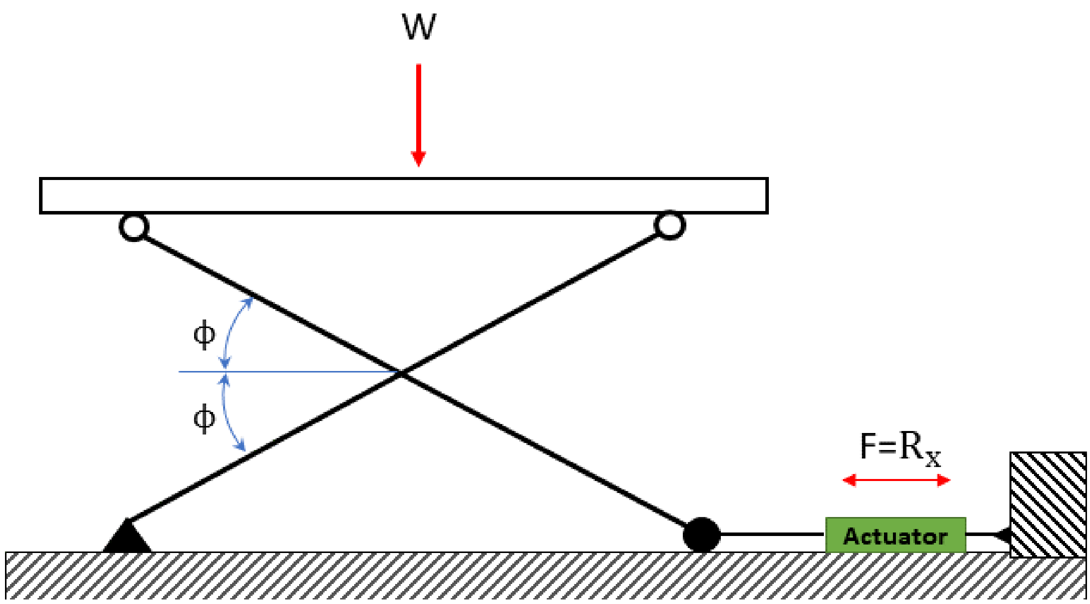


Figure 4.9 Sketch of a scissor lift structure

$$F_{act} = R_x = \frac{W}{\tan(\Phi)} \tag{4.5}$$

Such drawback together with the necessity to realize a tailor-made scissor lifter in order to match with the dimensional boundaries given by the movable frames brought a change in the design of such component.
The new solution, then chosen for the described application, provides the use of two lifting column inserted between two aluminium platforms.
As depicted in figure 4.10 the lower platform is linked to four sliding elements of a two parallel low friction rails allowing the motion in the X direction, while the upper one guarantees the fastening points for the factory seat rails. In between the two platforms two medical-grade lifting column governs the Z motion.

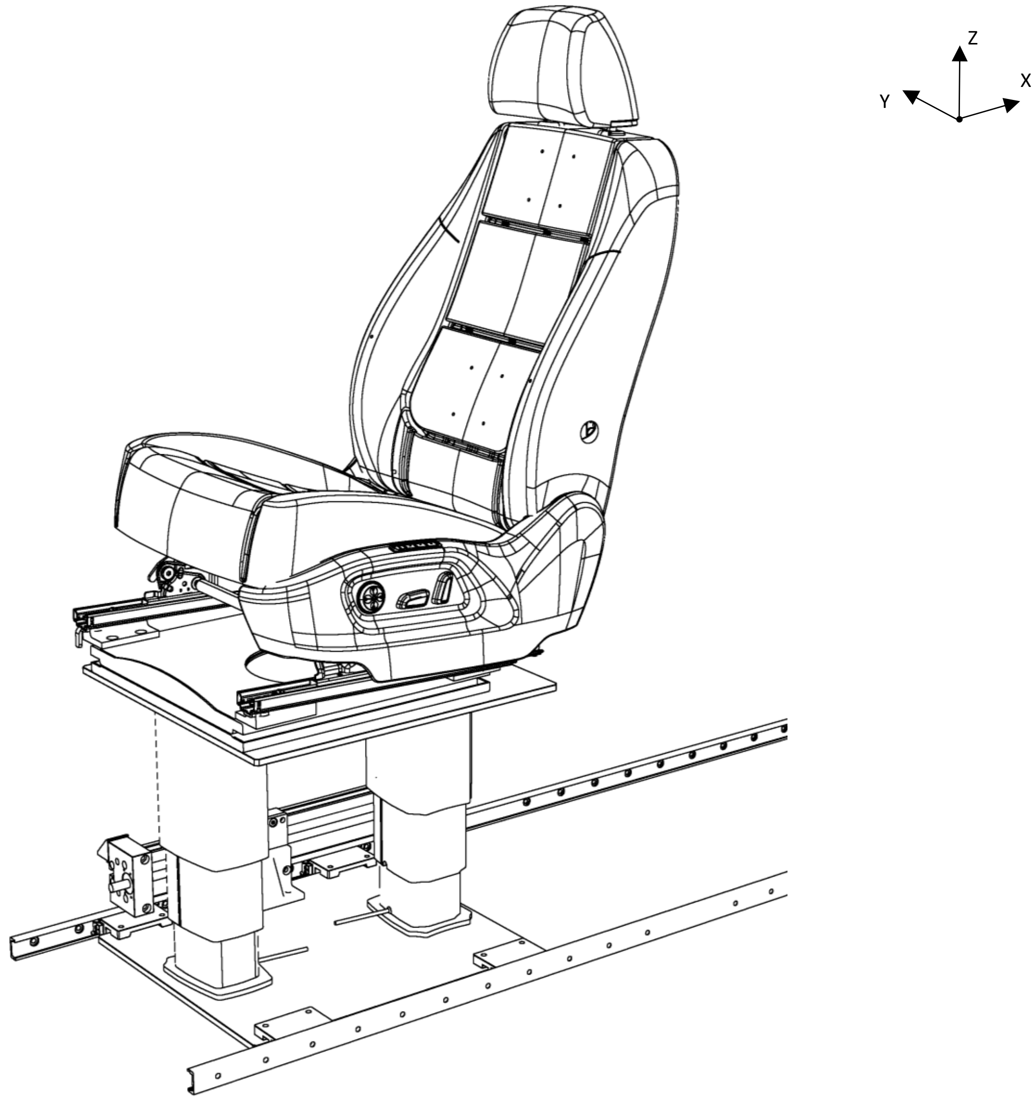


Figure 4.10 Representative figure of the front seat assembly. in the lower part it is possible to notice two parallel rails that governs the displacement along the X direction

This figure is the property of Italdesign Giugiaro S.p.A.

Such self-supporting columns are made of extruded anodized aluminium and thanks to a three-stage telescoping leadscrew allow to reach a stroke that is approximately equal to the completely closed configuration. This characteristic was mandatory for the required application to give the opportunity of simulating the egress from vehicles with a very low H5 dimension representing the height of the H-point from the floor according to the GCIE. (figure 4.11)

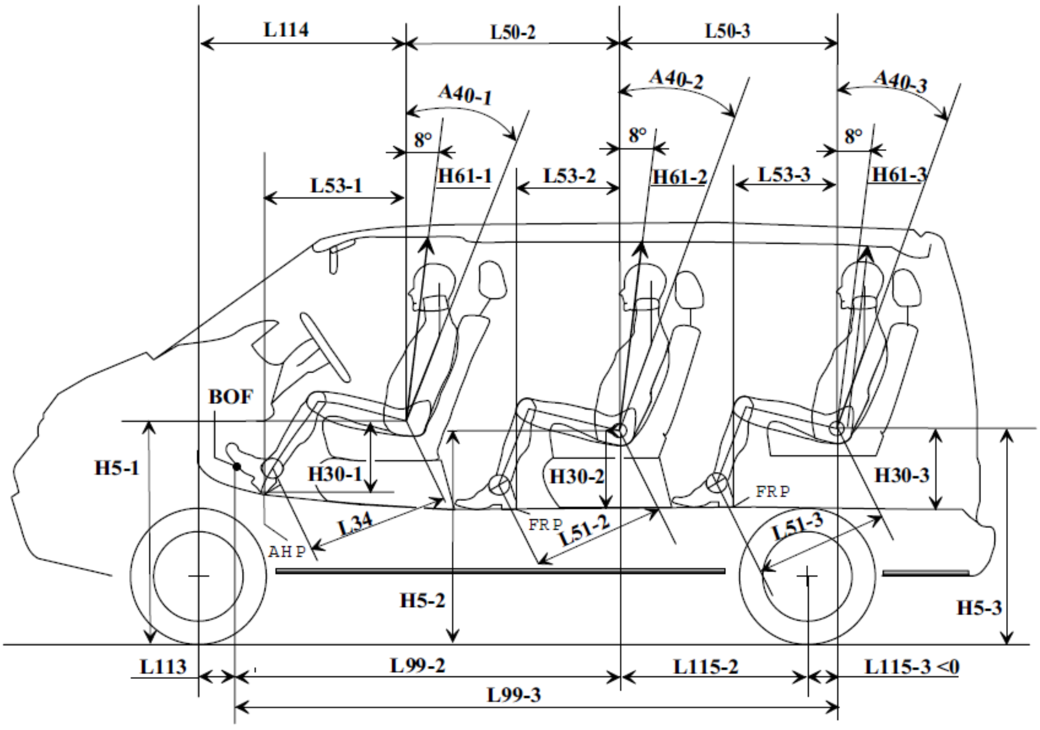


Figure 4.11 Main vehicle dimensions [7]

Regarding the X motion, a leadscrew linear actuator moved by a 12V DC electric motor manages the stroke that must be covered by the seat according to the box length defined in the first design process.
It is important to underline, however, that besides the range obtainable by the designed system, the seats maintain all factory adjustments and that they can be easily substituted in order to simulate different kind of vehicles attitudes.

For the simulation of the vis a vis configuration both front seats can be rotated of 180° by means of a rotating platform opportunely modified in order to match with the factory seats fastening points.

4.4.3.2 Rear Seats

The stroke in Y direction of the movable frames has been dimensioned according to the range of positions occupied by the front seats H-points. The package analysis has shown that for several vehicles the distance W25 that is the analogue to the distance W20 (figure 4.8) but related to the rear seats could be higher with respect to the W20 one. This means that the box representing all possible positions that the H-Point of the rear seats can reach is bigger with respect to the one characterizing the front seats in the Y direction.
For this reason, a further system has been introduced under the rear seats as depicted in figure 4.12

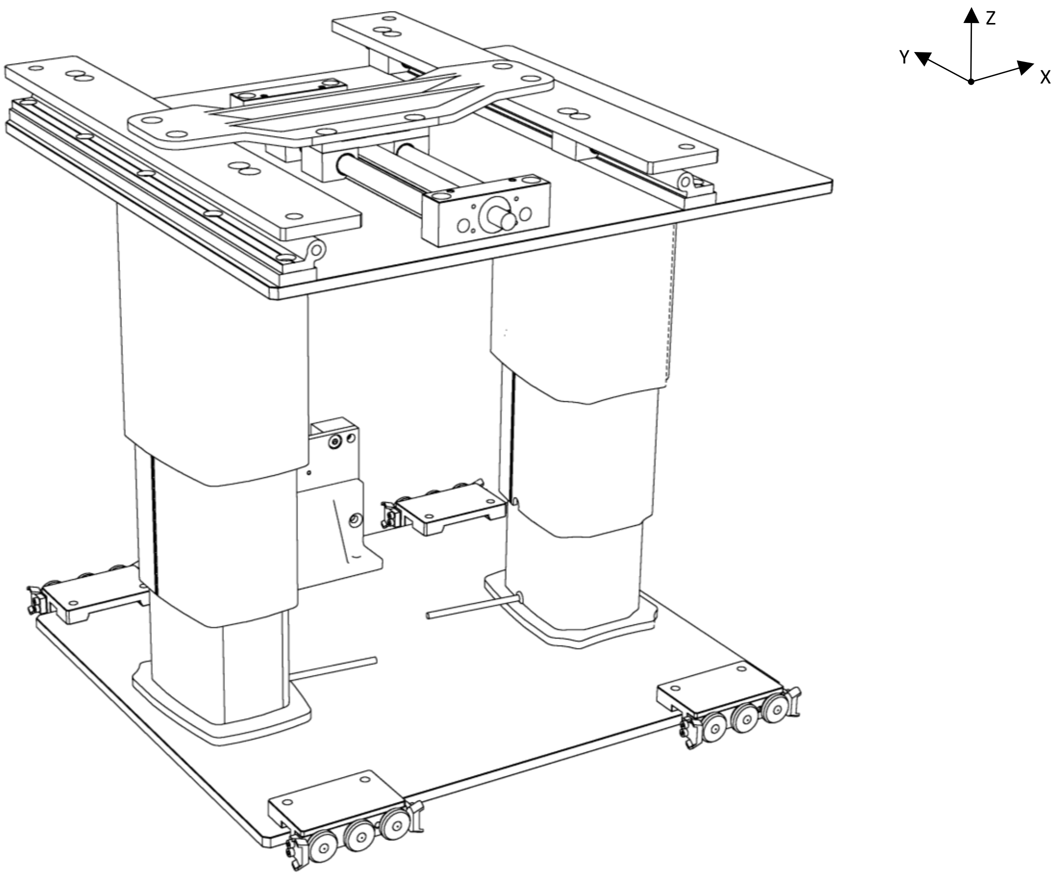


Figure 4.12 Representative figure of the rear seat assembly. In the upper part it is possible to notice the system aimed to the rear seat Y displacement

This figure is the property of Italdesign Giugiaro S.p.A.

It provides a leadscrew linear guide acting on a bracket integral with the seat that will slide on two transversal rails by means of four low friction polymeric bearings. This system allows to manage the W 25 dimension independently on the front seats positioning, ensuring the representation of all studied packages.
Regarding the stroke of the rear seats along the X direction it was necessary to add an extra-stroke with respect the vehicle package with the higher L50-2 dimension (distance between H-points of first and second row) (figure 4.11 Side dimension) to reproduce the vis a vis package configuration for autonomous driving vehicles.

4.4.4 Steering wheel

The steering wheel positioning depends not only on the coordinates X Y and Z that it will assume in the space but also on its inclination in the XZ plane.
In order to correctly manage all degrees of freedom of such component a representative frame of the dashboard has been realized. This structure moves together with the movable frames in the Y direction while its coordinate in the X direction can be independently managed by means of an electrically controlled linear guide as indicated in the figure 4.13

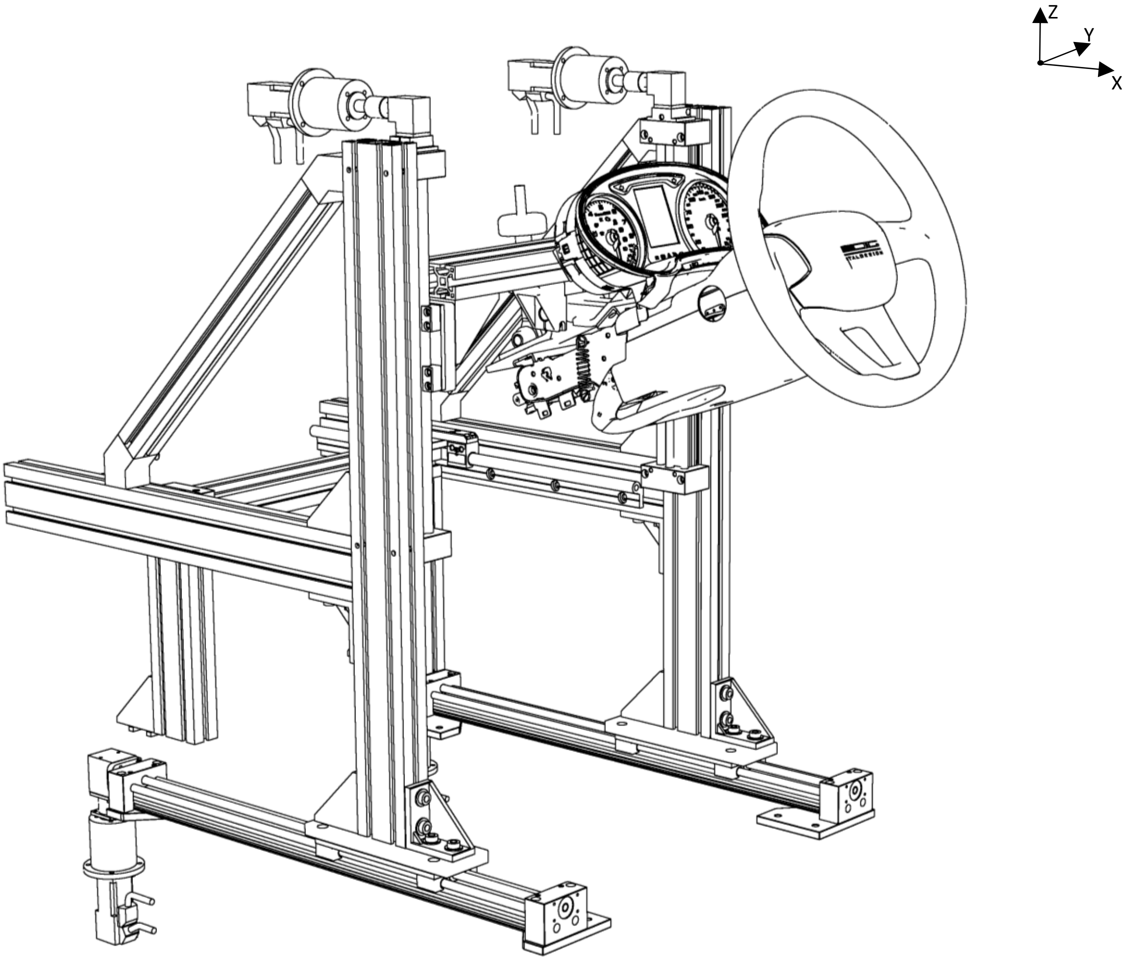


Figure 4.13 Representative figure of the dashboard area structure

This figure is the property of Italdesign Giugiaro S.p.A.

The same technology moreover, allows to control the steering wheel Z position.
At this point the three spatial coordinates that the steering wheel can assume are defined. The fourth degree of freedom, represented by the rotation in the XZ plane, is controlled by means of a hint characterized by an axis about which the whole steering column can rotate. To control the inclination a manual adjustment composed by a knob acting on a threated rod has been designed as depicted in figure 4.14

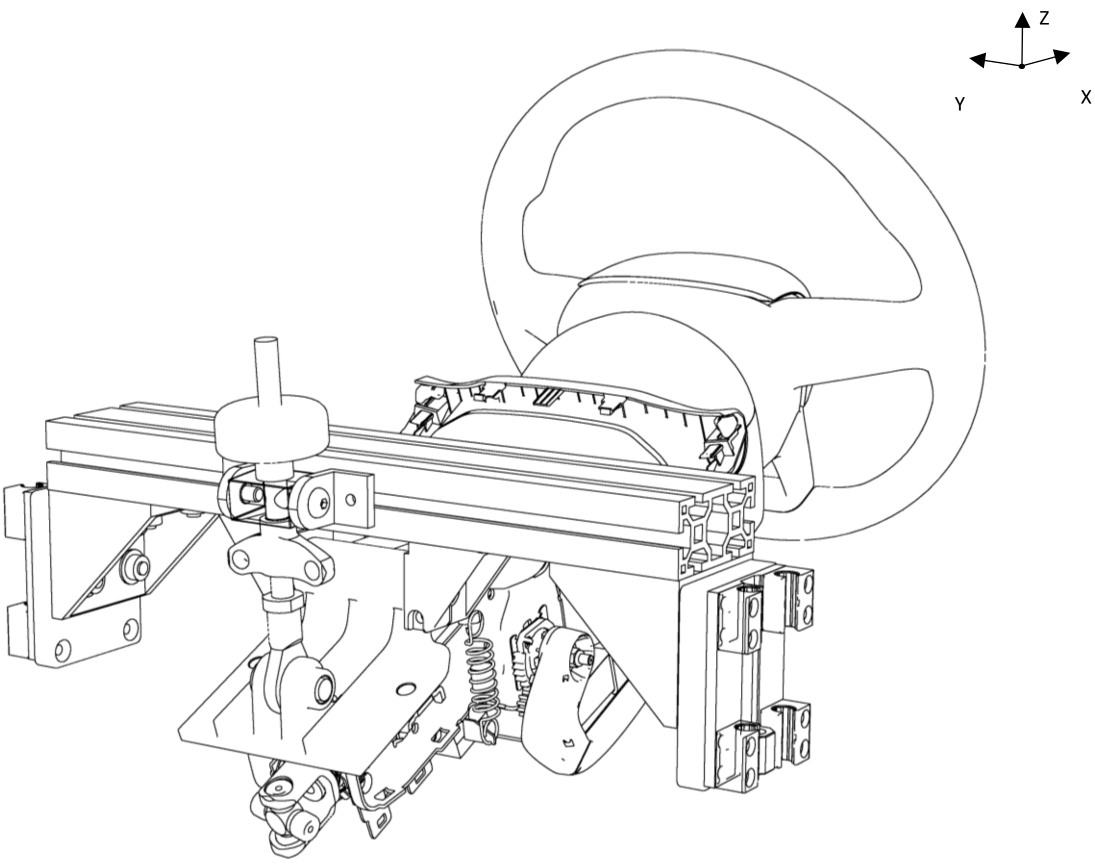


Figure 4.14 Particular of the steering wheel inclination system. Acting on the upper knob it is possible to modify the angle assumed by the steering column.

Once the inclination of the steering column has been evaluated in the CAD of the package that must be reproduced, it can be measured on the physical object by means of an electronic level that measures the angle with respect to the horizontal plane.
Regarding the dashboard structure it is symmetrically reproduced on the right hand of the model in order to represent a right-side driving configuration.
Moreover, the use of the BOSCH profiles also for these structures allows to easily add all the devices that must be physically simulated such as screens, control knobs, or representative dashboards volumes.

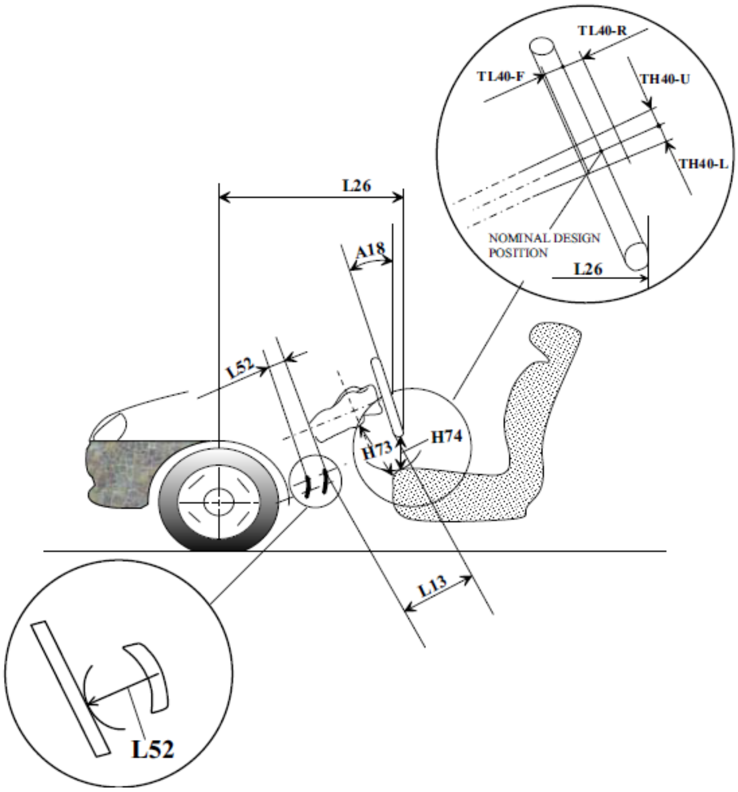


Figure 4.15 Steering wheel characteristic dimensions [7]

4.4.5 Pedals

As previously seen, pedals positioning represents another fundamental aspect for the vehicle package design.
To reproduce as closely as possible all pedals packaging was another challenging task for this project because of the high number of variables that affect this assembly.
It must be considered, indeed, that besides each pedal positioning in the X Y and Z coordinates and their inclinations in the XZ plane also the shape of the pedals changes according to the type of vehicle that must be reproduced.
For this reason, the design approach used for this part of the seating buck tries to follow
A path that allows a large degree of freedom into the positioning of the pedals and also let free the possibility to change such components when necessary.
Nevertheless, the idea behind all the needed displacements is analogue to the one used for the other components.
Two leadscrew linear guides govern the motion of the pedals assembly in the X and Z directions while two additional rails allow to move each single pedal along the Y direction independently.
Moreover, each pedal, realized by means of rapid prototyping technology, can be rotated around their pivot axis and dismounted if necessary to substitute them with the proper model that must be simulated.

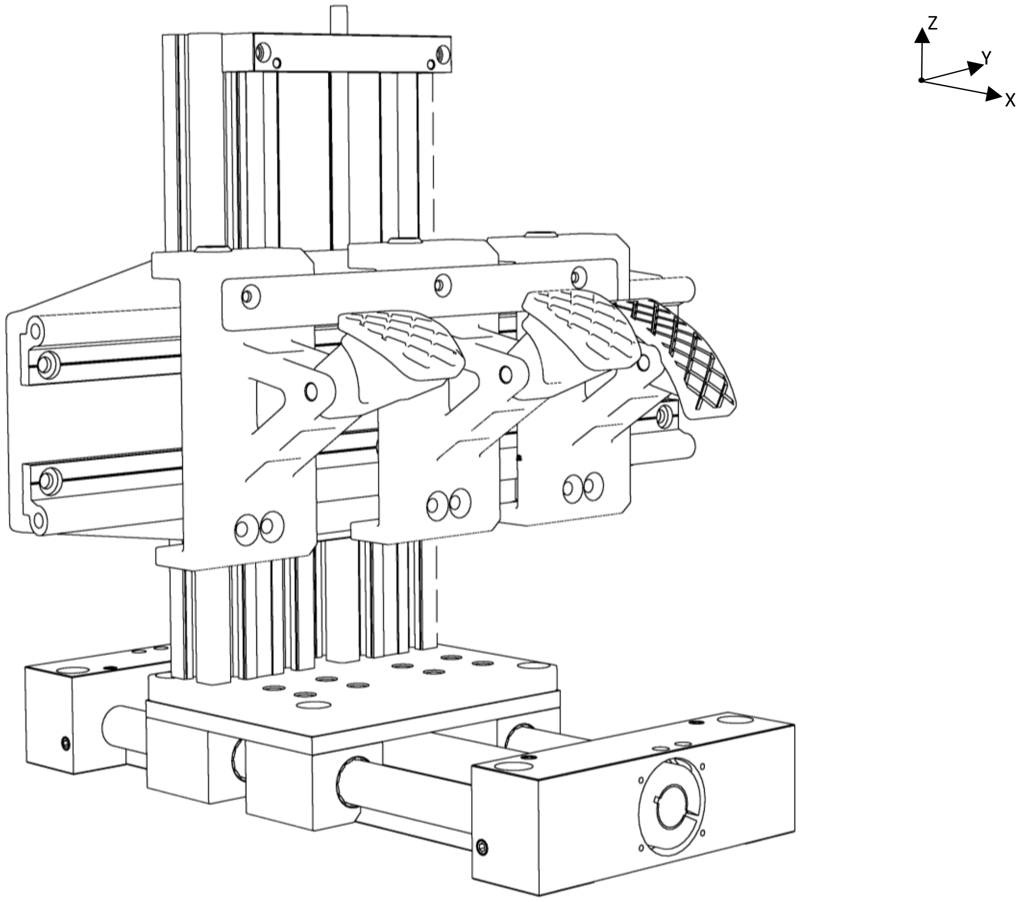


Figure 4.16 Representative figure of the pedals assembly

This figure is the property of Italdesign Giugiaro S.p.A.

This regulation must be manually performed, and the inclination can be evaluated by using an electronic level.
It is important to take in mind that when a real pedal is pressed by the driver due to its upper hinge positioning, besides the variation in terms of inclination, it undergoes X and Y displacement.
Over the nominal positioning, during ergonomics evaluations, different levels of the accelerator pedal depression are considered so that this design of the pedals assembly allows to reproduce all these configurations.
Despite the large degree of freedom that this system guarantees for the pedals positioning, it still represents a weak point of this seating-buck and further improvement will be probably needed. The problem is mainly related to the difficulty to reproduce starting from the informations deriving from the CAD data a realistic configuration on the physical object really consistent with the package informations.

4.4.6 Doors

Besides the distance among the two H points of left and right-side seats, during ergonomics analysis it is necessary to consider also the boundaries in the Y direction given by the doors. In particular, according to the GCIE the two dimensions that must be managed are that related to the arm-rest and the belt line as indicated in figure 4.17

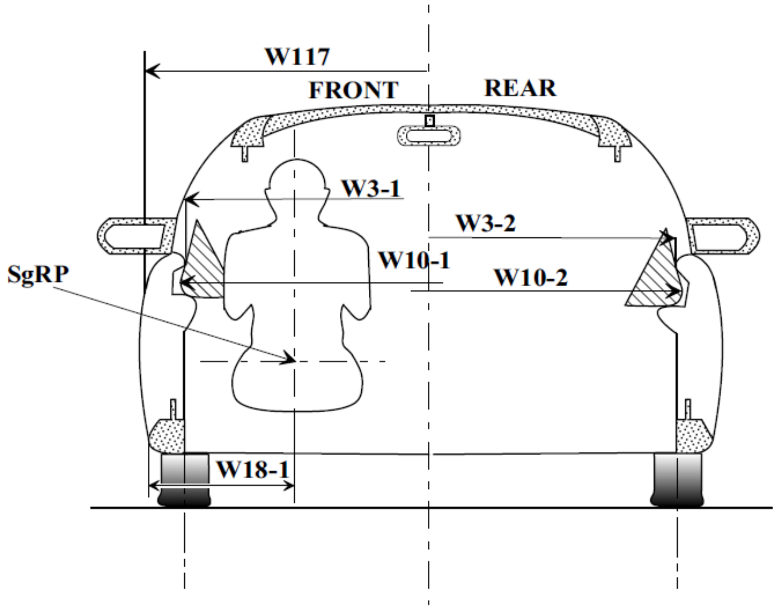


Figure 4.17 Characteristic width dimensions [7]

The evaluation of these dimension is usually evaluated by the use of CAD tools or putting in coincidence with the belt line volume an elbow width template (figure 4.18) landed on the arm-rest.

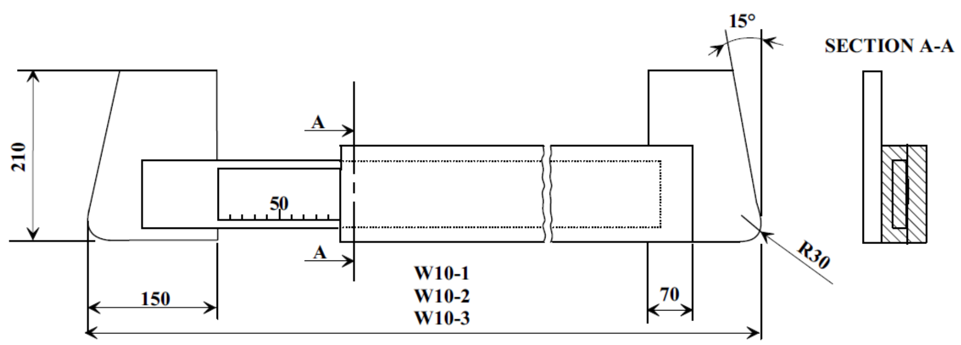


Figure 4.18 Elbow width template [7]

In order to simulate such condition two doors frames have been realized: one for the front and one for the rear. Such frames are integral with the relative movable structures so that

they move in the Y direction when the H-point positioning is performed. Moreover, their length in the X dimension is designed in order to correctly represent all reference packages.
Each door provides a milled model of the armrest and the belt line that reproduce the volume intrusion in the cabin compartment. The satisfaction of the ranges previously measured for these two elements is guaranteed by a complex system of rails and lead screw guides as depicted in figure 4.19 and 4.20

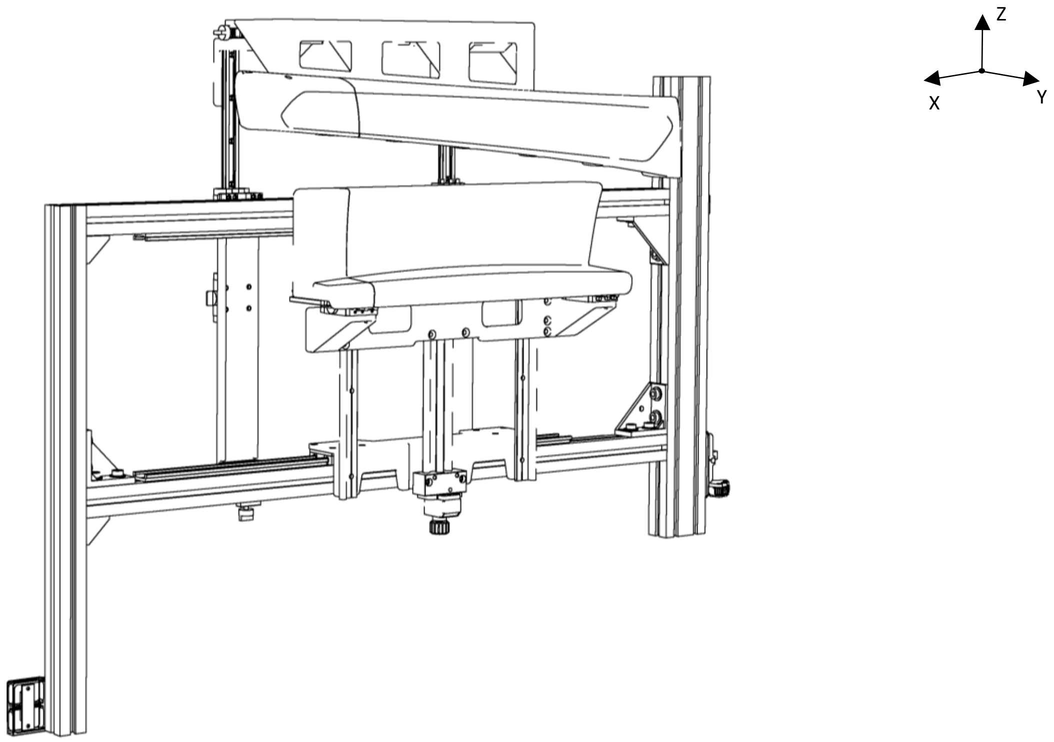


Figure 4.19 Representative figure of the door frame. It is possible to identify the two milled models for the arm-rest and the belt-line volume representation

This figure is the property of Italdesign Giugiaro S.p.A.

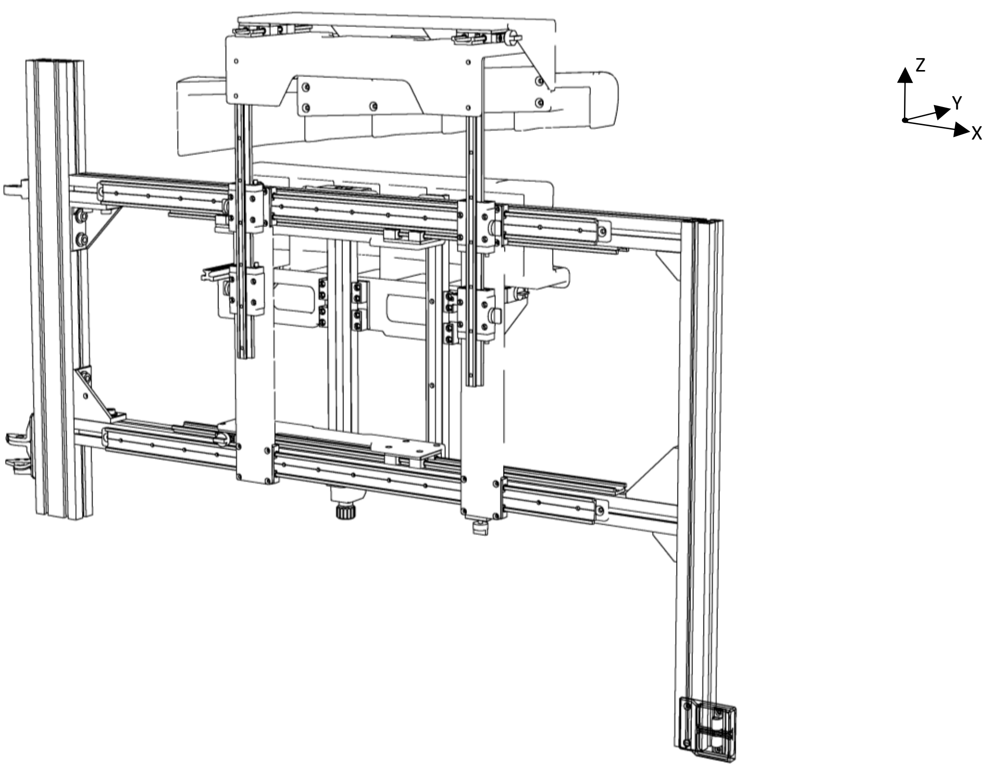


Figure 4.20 Same door frame of figure 4.19. In this view the system for the spatial displacements of the movable elements can be appreciated

This figure is the property of Italdesign Giugiaro S.p.A.

As can be seen both the arm-rest and the beltline can move along the three spatial dimensions ensuring the simulation of each considered package.
For the moment each element of the door must be manually moved in the desired position, but the design used for this area foresees the possibility to apply electronic controllable actuators implementable in the future.
As said for the pedals section, it is important to consider that each vehicle will present different types of door trims that will be characterized by different volumes and shapes that cannot be always simulated by the chosen milled model. Nevertheless, it has been considered for the first phase of the project to neglect the error given by this aspect that however has been evaluated to be very small and does not affect too much the interior obstruction perceived by the user. However, the fastening points are placed in a way that allows to easily substitute the representative masks with models that can be realized, if needed, according to the vehicle that must be simulated.

4.5 Seating-buck Configuration

The final aim of such project is the realization of a self-configurable seating-buck able to reproduce the interior package of a certain vehicle on which ergonomics and dimensional validations must be performed. To achieve this result, beside the realization of the physical object, it is necessary to find an unequivocal methodology that allows to reach the desired configuration starting from the CAD package data.
This section is aimed to the definition of the procedure that must be followed in general for the positioning of the movable elements of the seating-buck.
The final output of the model will allow, by means of a programmable dedicated control system, to reach two different results:

- The possibility to select, by a dedicated graphic interface, the desired package after the loading of its dimensional data into a "packages database". This means to create a package library that can be fast reproduced by the seating-buck when some analysis must be performed also for vehicles that are already on the market for benchmarking comparisons.
- The possibility to set the stroke that each movable element has to cover starting from a zero-reference positioning in order to reproduce and modify in real time the interior package of a vehicle even during the first the development phases.

The analysis described in the following sets the method used for the seating-buck configuration starting from the CAD data of a package taken as reference and the one that must be reproduced. Since the procedure it is essentially the same for all movable components it is taken as example the seat positioning only.

As already said all the packages taken in consideration for the seating-buck design have been aligned with respect to the Hill point of a certain package taken as reference, in particular the one of the Audi Q2.
This means that the starting point for the first set-up of the seating-buck are the CAD data package of each vehicle with the HOFs all aligned in the X and Z direction.
Among all this reference packages it is supposed the necessity to reproduce on the physical model one of them that will defined as target.

4.5.1 Seat Positioning

The target package that must be reproduced is loaded in the CAD environment together with the seating-buck. In the case of seats, the reference point for the positioning will be of course the H-point. The aim is to let coincide the manikin H-point (green point in the figure 4.20) with the one of the seat (red point in the figure 4.21).

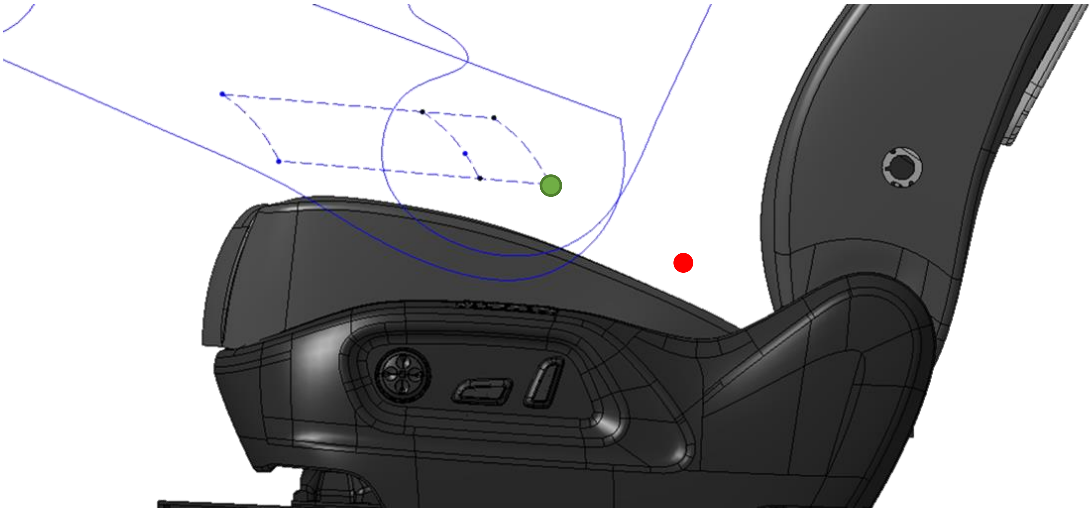


Figure 4.21 During the seat positioning the seat H-point in red must coincide with the rearmost lowest manikin H-point in green

In order to achieve this result, the seat is brought both in the CAD environment and in the real seating-buck into its lowest and rearmost positioning. Such condition, neglecting the structural tolerances that will be corrected after, sets a unique position in the space for the seat that is limited by the stroke of the linear guides. At this point it is possible to evaluate in the CAD environment the distance in X Y and Z directions between the seat H-point and the one of the target package that must be reproduced. The output will be three dimensions along the three spatial coordinates that represent the displacements that must be performed on the physical model by acting on the electric actuators.

Once such displacements have been applied, the 3-D H-Point Machine is positioned on the seat and the deviation from the package data is evaluated in order to correct errors due to structural tolerances and foams deformations.

The idea of let coincide a virtual CAD point taken as reference for a given movable assembly with its equivalent physical point can be applied for the positioning of all the other movable elements characterizing the buck.

It is important to take into account, however, that the physical object does not present physical points. For the seat described above, for example, the H-point is visible only in the CAD environment, this is why it is necessary for each movable assembly to define a unambiguous position representing the starting point before perform the needed displacements. Such position it has been considered appropriate to be the lowest rearmost one of each assembly.

Moreover, for elements in which it is necessary to deal also with inclinations such as the steering wheel and the pedals the manual adjustment and the empirical evaluation of the reached angle is mandatory.

Although this process could seem long and elaborate, it is the only procedure to correctly reproduce a vehicle package with all considered degrees of freedom. However, must be taken into account that once the various steps in terms of displacements that must be applied have been defined, they are loaded into a database able to reproduce a given configuration each time is needed.

5 Conclusions and further developments

In this work it has been described the approach used for the introduction of Virtual Reality tools in the ergonomic validation process.
In order to achieve the required tasks, it was necessary to realize a configurable seating-buck able to substitute the standard procedure normally adopted by car manufacturers.
As described, indeed, when the design process is able to guarantee enough reliable informations regarding vehicle surfaces and package at least one or more physical models have been realized. Such objects allow to perform the required validating tests and offer a haptic and visive perception of the developing vehicle.
Due to the high levels of details that such models have to guarantee the impact both in terms of cost and time needed for their realization is anything but negligible.
It has been demonstrated that the seating-buck carried out from this project allows at the time to avoid the construction at least of one of the two ergo-models usually realized during the design process. This results into a significant reduction of the time to market increasing the competitiveness in a more and more starving market as the automotive one.
Moreover, other noticeable applications can be benchmarking comparisons currently needed in the first phases of the vehicle package definition, and the possibility to offer a service for other companies that requires to perform some dimensional evaluations for which the construction of a dedicated physical model is not reasonable.
With respect to the conventional bucks aimed to ergonomic evaluations the one descripted in this work is not representative of typical volumes and surfaces characterizing a vehicle cabin compartment since it is simply composed of structural frames. The representation of such volumes and their relative details is indeed delegated to the Virtual Reality tools that, taking as input the data deriving from the 3-D model, reproduce vehicle compartment including the interior trims.
For this reason, beside the design and the realization of the configurable seating-buck, it was necessary to acquire a series of informations regarding the VR technology in order to justify the undertaken path. In particular the preliminary tests described in the third chapter of this work have shown how the used consumer-grade devices can give acceptable results in terms of visualization of the virtual environment also for applications that are far from those for which they were designed.
On the other side, the reachability test has highlighted an inconsistent performance for what concerns the controller used for the hand tracking revealing positioning errors that are not acceptable for the required application.
However, during the drafting of this work, alternative solutions have been investigated in order to achieve the needed precision. Of course, Such alternatives, still under analysis, provide the utilization of VR tools aimed to professional applications increasing on the other side the amount of the initial investment.

Bibliography

[1] E. Chatzopoulou, A. Vlassopoulou. Evaluating Comfortable Driving – Three case studies on driver's behaviour in different driving situations. Master of Science Thesis in the Master's Degree Programme Industrial Design Engineering – Chalmers University of Technology, Gothenburg, Sweden, 2015.

[2] http://www.iea.cc – Definition and Domains of Ergonomics.

[3] Italdesign S.p.A Internal Report: Vehicle Seating Accommodation, Moncalieri, Turin, Italy.

[4] S. Pheasant. Bodyspace – Anthropometry, Ergonomics and the Design of Work, 2003.

[5] L.Morello L.Rosti Rossini G.Pia A.Tonoli – The Automotive Body. Springer, Turin, Italy, 2011.

[6] M. P. Reed. Statistical and biomechanical prediction of automobile driving posture. University of Michigan Transportation Research Institute, Detroit, USA, 1998

[7]. GCIE – Global Cars Manufacturers Information Exchange group. Package Drawing Exchanges, 2016.

[8] M. P. Reed et al. New Concepts in Vehicle Interior Design Using ASPECT. International Congress and Exposition – University of Michigan Transportation Research Institute, Detroit, USA, 1999.

[9] Ayala, S. Holgesson. Driving Position Assurance in Passenger Cars. Master's Thesis in Product Development – Chalmers University of Technology, Gothenburg, Sweden, 2015.

[10] SAE J1100 - Motor Vehicle Dimensions. SAE International, 2009.

[11] SAE J826 - Devices for Use in Defining and Measuring Vehicle Seating Accommodation. SAE International, 2008.

[12] A. Naddeo. Postural comfort inside a car: development of an onnovative model to evaluate the discomfort level. SAE International Journal of Passenger Cars – Mechanical System, 2009.

[13] SAE J4004 - Positioning the H-Point Design Tool – Seating Reference Point and Seat Track Length. SAE International, 2008.

[14] SAE J4003 - H-Point Machine (HPM-II) Procedure for H-point Determination – Benchmarking Vehicle Seats. SAE International, 2008.

[15] M. P. Reed et al. Design and Development of the ASPECT Manikin. International Congress and Exposition – University of Michigan Transportation Research Institute, Detroit, USA, 1999.

[16] SAE J4002 - H-Point Machine (HPM-II) Specification and Procedure for H-point Determination – Auditing Vehicle Seats. SAE International, 2005.

[17] M. P. Reed. Driver Preference for Fore-Aft Steering Wheel Location. SAE International – University of Michigan Transportation Research Institute, Detroit, USA, 2013.

[18] R. U. More, Dr. R. S. Bindu. Comfort Analysis of Passenger Car Vehicle Seat. International Journal of Engineering Science and Innovative Technology (IJESIT), 2015.

[19] J. Webe. Automotive Development Processes. Springer, Munich, Germany, 2009.

[20] G. Genta, L. Morello, F. Cavallino L. Filtri, The Motor Car Past, Springer, Turin, Italy 2014.

[21] G. Genta, L. Morello, The Automotive Chassis Vol1: Components Design, Springer, Turin, Italy, 2008.

[22] Italdesign S.p.A, Internal Report: Physical Models, Moncalieri, Turin, Italy, 2017.

[23] www.oculus.com.

[24] www.vive.com.

[25] www.autodesk.com.

[26] www.unity3d.com.

[27] Italdesign S.p.A, Internal Report: Virtual Reality Visibility Test, Moncalieri, Turin, Italy, 2017.

[28] SAE J1050a – Defining and Measuring the Driver's field of view- SAE. international, 2009.

[29] Frank Weichert, Daniel Bachmann, Bartholom¨aus Rudak and Denis Fisseler, Analysis of the Accuracy and Robustness of the Leap Motion Controller, Dortmund, Germany, 2013.

[30] Jože Guna, Grega Jakus, Matevž Pogačnik, Sašo Tomažič and Jaka Sodnik, An Analysis of the Precision and Reliability of the Leap Motion Sensor and Its Suitability for Static and Dynamic Tracking, Ljubljana, Slovenia, 2014.

[31] Italdesign, S.p.A, Internal Report: Virtual Reality Reachability Test, Moncalieri, Turin, Italy, 2017.

[32] Nanxin Wang, Jian Wan, and Gianna Gomez-Levi, A Parametric Approach to Vehicle Seating Buck Design, Dearborn, Michigan, USA, 2004.

[33] www.boschrexroth.com.