TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue I, March, 2021

DESIGN AND ERGONOMIC ANALYSIS OF CAR DOORS MADE FROM COMPOSITE MATERIALS

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Abstract: *This paper presents the design of an interior panel of a door for a small electric car intended for urban traffic. The design incorporates a display that replaces the mirror, the ambient light in the storage compartment is activated automatically by a proximity sensor, and the whole panel can be made entirely out of carbon fiber or in combination with plastic parts/components.*
Key words: *AHP, carbon fiber, interior car design.*

1. INTRODUCTION

The composite materials used in the construction of structures in various fields (automotive, naval, civil, aerospace) are becoming more and more effective in providing good mechanical properties, temperature resistance, abrasion and cracking resistance, high resilience, stability to chemical agents, etc. [1]-[4]. Carbon fiber reinforced plastics (CFRP) are one of the most used composite material because of their excellent properties [5]-[8], such as light weight mass, high durability, high modulus, good fatigue and corrosion resistance [9]-[11].

Car design has evolved from simple shapes to complex ones (Fig. 1) due to the growing needs of end users and technological progress. Today, in the dashboards and door panels, there are sensors and displays that increase the comfort of end users. For example, the rearview mirrors are replaced by cameras and displays, mounted on the door or on the dashboard, there are proximity sensors that turn on ambient lights in the door when the user inserts his hand in the storage compartment, fingerprint sensors for opening and closing the vehicle or exterior lights that illuminate the area when exiting the vehicle or displays various patterns, such as the car logo [7], [12]-[15].

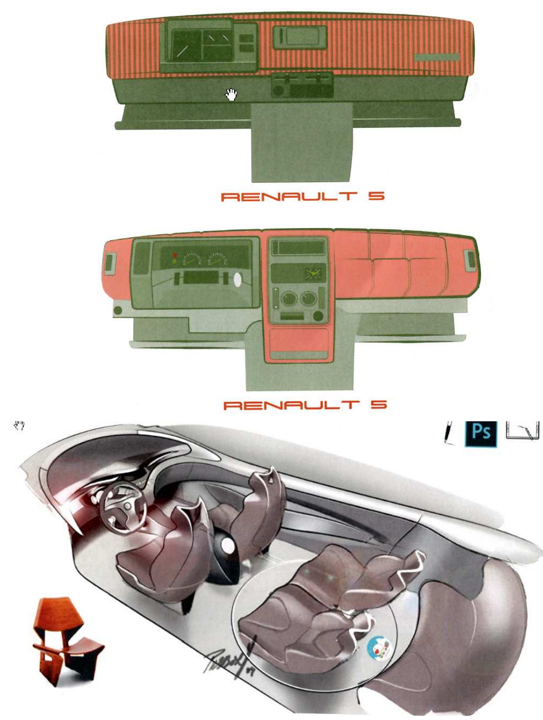


Fig. 1 Design concept evolution [1]

2. DESIGNING THE DOOR PANEL FOR AN ELECTRIC CAR

The aim of the paper is to present the way in which the design of the interior panel of a door from a light electric vehicle (indicated in Fig. 2), intended for the urban environment, has unfolded. The main constraint was the use of carbon fiber composite material in the manufacturing of the interior side of the door (Fig. 3).

Fig. 4 Design concept of electric vehicle

The design has evolved from a simple one-piece door panel to one that has storage space, space for the audio system components and a built-in screen for the electronic system that replaces the mirror.

The main instruments used in the development of the concept were the Analytical Hierarchy Process (AHP) analysis and ergonomic analysis of the occupant's position for determining the critical requirements that an end user might have when seated inside the vehicle.

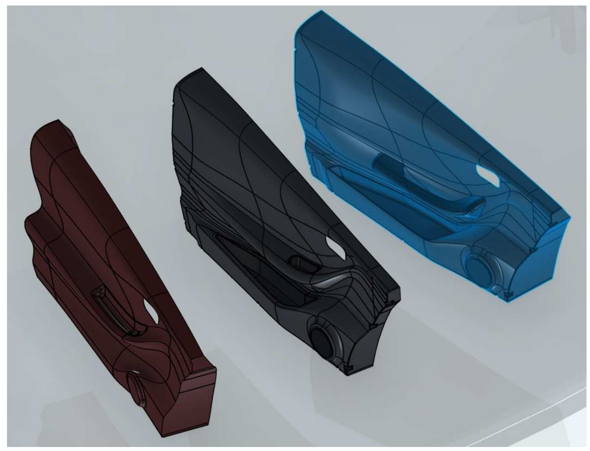


Fig. 5 The design development of the interior part of the door.

	Item Number	1	2	3	4	5	6	7	8	9	10
	Item Description										
1	Integrated controls for windows, mirrors, lock / unlock doors	1.00	6.00	7.00	6.00	7.00	9.00	5.00	6.00	5.00	9.00
2	Extendable trim panel tray with proximity / motion sensor and integrated light	0.17	1.00	5.00	0.50	4.00	7.00	4.00	5.00	4.00	7.00
3	Ergonomic grip for door handle and door release knob	0.14	0.20	1.00	0.25	0.20	2.00	0.17	0.50	0.33	2.00
4	Realiable inside door handle	0.17	2.00	4.00	1.00	4.00	7.00	4.00	3.00	7.00	6.00
5	Integrated bottle/cup holder	0.14	0.25	5.00	0.25	1.00	4.00	2.00	5.00	5.00	3.00
6	Warn light reflective strip / reflector dots	0.11	0.14	0.50	0.14	0.25	1.00	0.17	0.50	0.20	0.17
7	Integrated left arm rest	0.20	0.25	6.00	0.25	0.50	6.00	1.00	6.00	4.00	7.00
8	Easy to clean / antiseptic materials	0.17	0.20	2.00	0.33	0.20	2.00	0.17	1.00	0.50	2.00
9	Customizable finishing materials for panel trim	0.20	0.25	3.00	0.14	0.20	5.00	0.25	2.00	1.00	2.00
10	Use of highly insulating materials	0.11	0.14	0.50	0.17	0.33	6.00	0.14	0.50	0.50	1.00
	Sum	2.41	10.44	34.00	9.04	17.68	49.00	16.89	29.50	27.53	39.17

Fig. 6 Pairwise comparison matrix

The AHP method was preceded by a classic brainstorming session, through which a team of 8 engineers (including the authors) determined some critical requirements regarding the car door panel. The obtained set of 10 requirements was inputted into an AHP analysis with the purpose of ranking these criteria, similar as in [16] and [18]. The analysis unfolded through three main stages.

In the first stage, an NxN matrix was devised, and all the criteria were compared to each other in a pairwise fashion. Thus, the matrix was completed using the Saaty scale of comparison: if a row item is more important than a column item a whole number is used (n), else a fractional number (1/n) is inserted; in both cases "n" represents the end user's assessment of the importance ratio between the two compared items. Based on the values from the matrix the sum for each column was calculated (see Fig. 6).

The values from the "standardized matrix" were obtained by dividing the corresponding number from the "pairwise comparison matrix" with the sum obtained for each column (e.g. the value from row 3, column 1 from the standardized matrix is equal to the value from row 3, column 1 from the pairwise comparison matrix over the sum of the first column – 0.14/2.41≈0.06). Next, by calculating the average on each row, the weight of each requirement is obtained (see Fig. 5).

		1	2	3	4	5	6	7	8	9	10	Weight
1	Integrated controls for windows, mirrors, lock / unlock doors	0.42	0.57	0.21	0.66	0.40	0.18	0.30	0.20	0.18	0.23	33.5%
2	Extendable trim panel tray with proximity / motion sensor and integrated light	0.07	0.10	0.15	0.06	0.23	0.14	0.24	0.17	0.15	0.18	14.7%
3	Ergonomic grip for door handle and door release knob	0.06	0.02	0.03	0.03	0.01	0.04	0.01	0.02	0.01	0.05	2.8%
4	Realiable inside door handle	0.07	0.19	0.12	0.11	0.23	0.14	0.24	0.10	0.25	0.15	16.0%
5	Integrated bottle/cup holder	0.06	0.02	0.15	0.03	0.06	0.08	0.12	0.17	0.18	0.08	9.4%
6	Warn light reflective strip / reflector dots	0.05	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.00	1.6%
7	Integrated left arm rest	0.08	0.02	0.18	0.03	0.03	0.12	0.06	0.20	0.15	0.18	10.5%
8	Easy to clean / antiseptic materials	0.07	0.02	0.06	0.04	0.01	0.04	0.01	0.03	0.02	0.05	3.5%
9	Customizable finishing materials for panel trim	0.08	0.02	0.09	0.02	0.01	0.10	0.01	0.07	0.04	0.05	4.9%
10	Use of highly insulating materials	0.05	0.01	0.01	0.02	0.02	0.12	0.01	0.02	0.02	0.03	3.0%

Fig. 7 Standardized matrix

Finally, for making sure that the "pairwise comparison matrix" was filled out as correctly as possible and to determine how consistent the judgements have been when completing the AHP pairwise comparison matrix, the "consistency ratio" (CR) is also calculated. Normally, as Thomas L. Saaty suggests (the inventor of the AHP mathematical model for decision support) to be tolerable, the CR should be between 0 and 0.1, in this case it's CR = 0.08 [17].

Based on the hierarchy of identified requirements, a preliminary 3D model was created (Fig. 8), which was then used in the ergonomics analysis using CATIA V5-6 software.

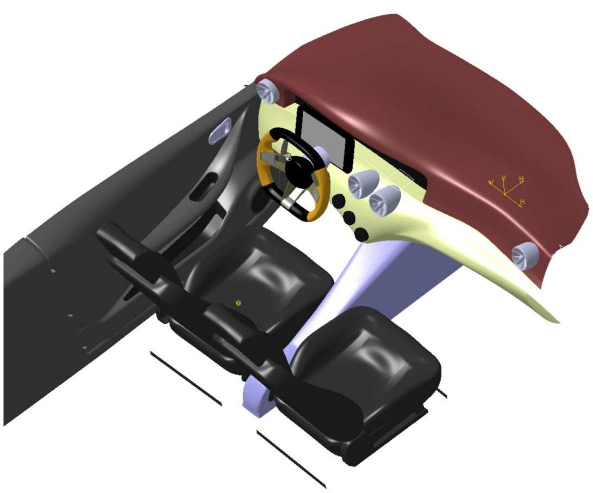


Fig. 8 Preliminary 3D model

The initial set-up includes the parameters from Table 1 and Fig. 7.

Table 1 Ergonomics parameters for driver's seat

Param.	Value	Param.	Value
L31-1	1200mm	A40-1	25deg
W20-1	-380mm	L11	440mm
H30-1	200mm	W7	-380mm
A19	0deg	H17	580mm
TL2	50mm	W9	380mm
TL18	200	A18	20deg
A27-1	20deg	SWDiam.	30mm

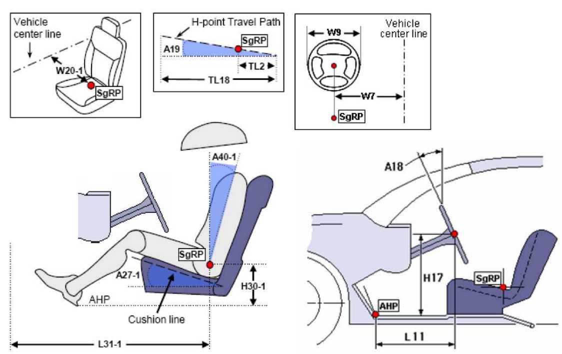


Fig. 9 Driver's seat parameter illustration

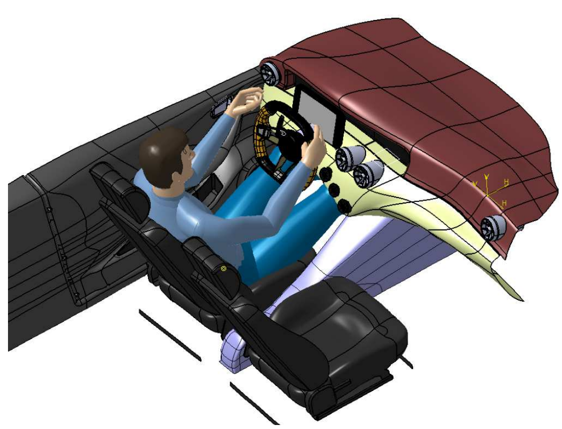


Fig. 10 Initial set-up

3. RESULTS

For the design of the armrest and the handle (Fig. 11) the final angle at which the design was made is 50 degrees for the elbow joint (minimum value is 0 degrees and maximum is 140 degrees) and 8 degrees in horizontal plane for the shoulder joint. In order to verify the way in which a display can be integrated into the design to replace the rear-view mirror, the "Vision" function was employed in CATIA (Fig. 13), through which the field of vision of the driver can be determined and analyzed, when the driver is seated in a normal driving position. Thus, the position of the mirror(s) relative to the seats and steering wheel can be determined, so that the mirror or the display that replaces it is permanently in the driver's field of vision.

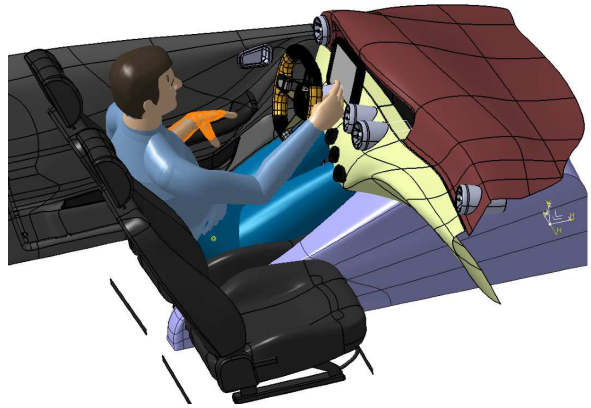


Fig. 12 Position of the driver when the door is closed

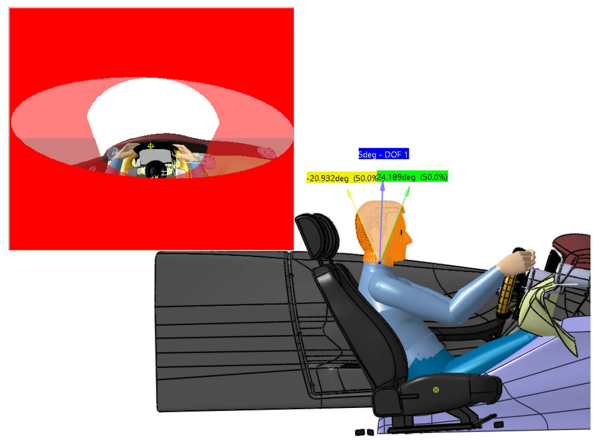


Fig. 13 Visual field

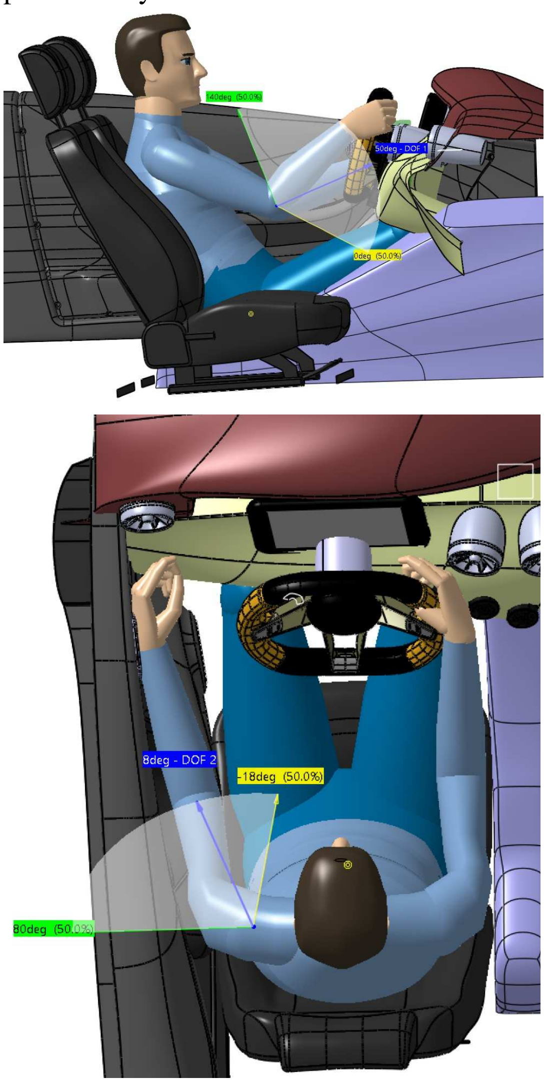
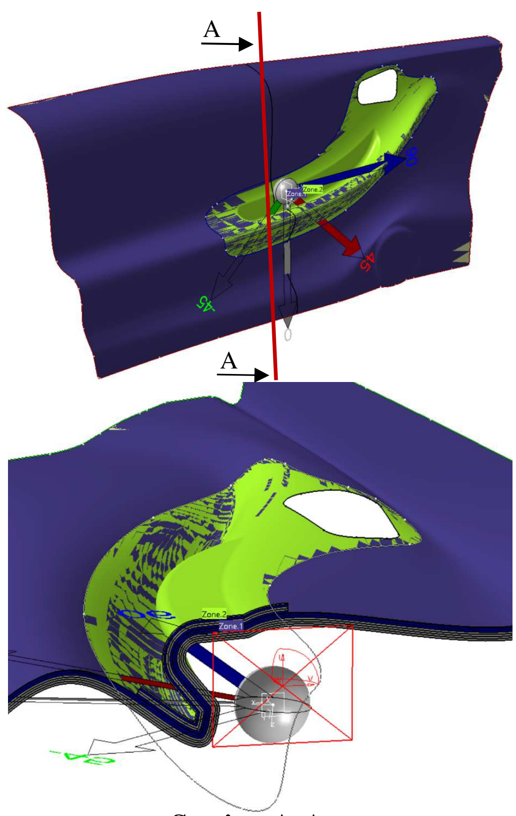


Fig. 11 Vertical and horizontal angle for the elbow and shoulder joint

Fig. 14 Model 3D final

The final version of the door (Fig. 14) can include a detachable plastic handle or an integrated carbon fiber handle, a light source (LED) in the storage compartment controlled by the proximity sensor and a display that replaces the rear-view mirror.

The first version of car door was entirely fabricated using composite materials: the first layer is CFRP prepreg type GG245TSE-DT121H-42 and the enforcement material is the Twill 2X2 fabric, 240g/mp, 3K HR threads; the second and third layer is prepreg GG430TSE-DT121H-42 and the enforcement material is the Twill 2X2 fabric, 430g/mp,12K HR threads. The configuration of the layers is [0/90/±45/0/90]. A reinforced area also is included (the green area from Fig. 15), to which a prepreg type GG245TSE-DT121H-42 material is added, in two layers, with the [0/90/±45] configuration. In this area the door flap and the opening/closing mechanism is added, alongside the door handle, which can be pulled or pushed to close or to open the door.



Section A-A

Fig. 15 Arrangement of the layers of material for the first version of the door

The modeling of the composite material was completed in CATIA V5 (see Fig. 15), the obtained results are presented in Table 2.

Table 2. Surface area and mass for the 1st version of the door

	Area	Mass
Zone 1	6.14 m^2	1.939 kg
Zone 2	0.61 m^2	0.254 kg
Total	6.75 m^2	2.193 kg

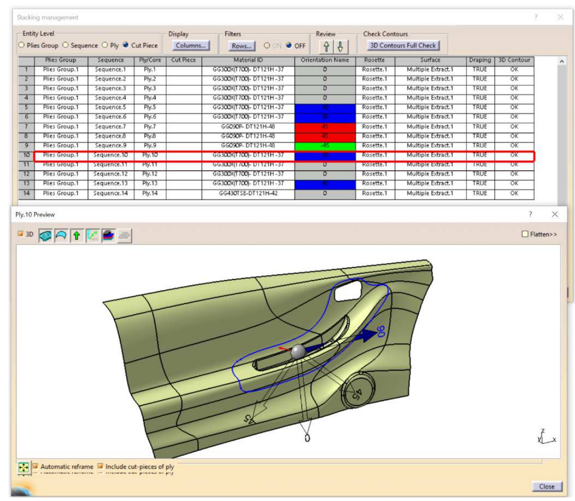


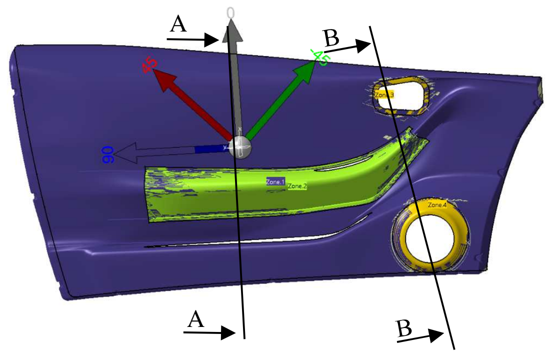
Fig. 16 Stacking management for the composite material layers

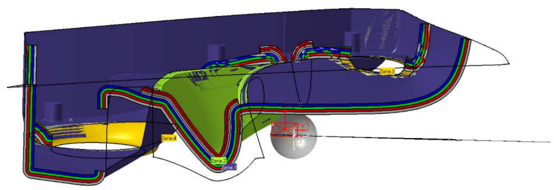
The second version of the door is made of the same composite material as the first version with the mention that here there are three reinforced areas. The first area is that of the handle, the second that of the opening flap and the third area in which the car audio system speaker is mounted. In these three areas prepreg type GG245TSE-DT121H-42 is added, in two layers, in the [0/90/±45] configuration.

In Fig. 17 are presented the three areas, as well as two sections through these areas in which it is possible to observe the way in which the material layers are arranged. As it can be seen in Table 3, the material quantity is lesser and implicitly the weight is lighter, too, which is due to the fact that the reinforced areas have a smaller unfolded surface than in the first case.

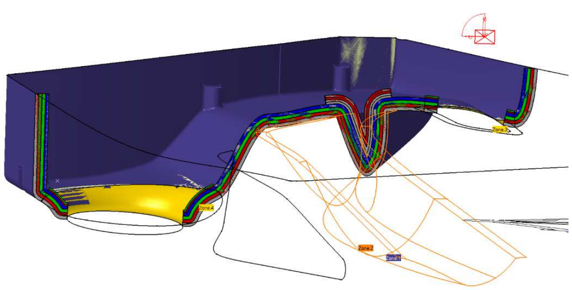
Table 3. Surface area and mass for the 2nd version of the door

	Area	Mass
Zone 1	3.55 m^2	1.60 kg
Zone 2	0.48 m^2	0.135 kg
Zone 3	0.008 m^2	0.002 kg
Zone 4	0.034m^2	0.007 kg
Total	4.72 m^2	1.737 kg



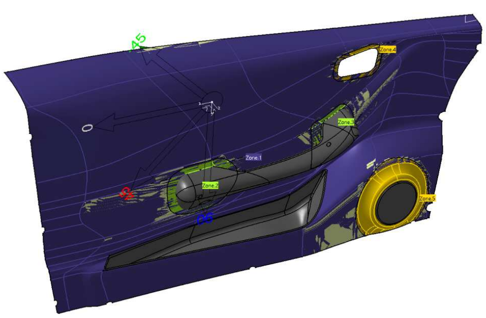


Section A-A



Section B-B

Fig. 17 Arrangement of layers of the composite materials, second version



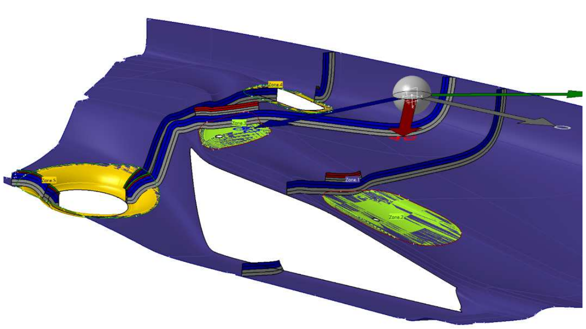


Fig. 18 Arrangement of layers of the composite materials, third version

In the third version of the interior door panel, the handle is made of plastic and is fixed to a similar panel, as in the case of classic doors with a threaded assembly. Consequently, only the areas where this type of assembly is made have been reinforced. There are two other reinforced areas at the opening flap and in the area where the audio system speaker is mounted.

Table 4 shows the material requirements and the final weight of the door panel.

Table 4. Surface area and mass for the 3rd version of the door

	Area	**Mass**
Zone 1	2.45 m^2	1.10 kg
Zone 2	0.09 m^2	0.25 kg
Zone 3	0.042 m^2	0.012 kg
Zone 4	0.008m^2	0.002 kg
Zone 5	0.046 m^2	0.009 kg
Total	2.636 m^2	1.373 kg

4. CONCLUSIONS

The validation of the 3D model was completed using interactive virtual reality environments (Fig. 19), in which the developer/designer was fully immersed and interacted with the 3D model of the door panel, as well as the dashboard.

Fig. 19 The validation process in the interactive virtual reality environments

Using the Composite Design module from CATIA V5, the composite material from which the door panel can be manufactured was modeled for each constructive solution (variants/versions). The optimal version in terms of material consumption and weight is the is the third version of the door, in which the reinforced areas are the smallest, thus the material consumption is lesser, and the weight is lower.

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Acknowledgement

This work was supported by the project "*Advanced technologies for intelligent urban electric vehicles*"- URBIVEL – Contract no.11/01.09.2016, project co-founded from the European Regional Development Fund through the Competitiveness Operational Program 2014-2020

PROIECTAREA ȘI ANALIZA ERGONOMICĂ A UNUI PANOU INTERIOR DE UȘĂ PENTRU UN AUTOMOBIL FABRICAT DIN MATERIALE COMPOZITE

Abstract: *Lucrarea prezintă designul unui panou interior al unei uşi pentru o maşină electrică de mici dimensiuni destinată traficului urban. Designul încorporează un display care înlocuieşte oglinda, lumină ambientală în compartimentul de depozitare, activată automat printr-un senzor de prezență și care poate fi fabricat integral din carbon sau în combinație cu piese din plastic.*

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