TEAM DESIGN PROCESS FOR A 6X6 ALL-ROAD WHEELCHAIR

J.-C. Fauroux, S. Charlat and M. Limenitakis

ABSTRACT
This paper presents the design process of a 6x6 all-road wheelchair at French Institute for Advanced Mechanics (IFMA) and EACF Architecture School in Clermont-Ferrand, France. During four years, more than thirty students were involved in a team design process, which is detailed here. Initial choice, team organization, task dispatching, software problems and common mistakes found in this type of projects are described.

Keywords: 6x6, all-road, electric, wheelchair, team, design, concurrent engineering

1 INTRODUCTION

Mechanical design is a tough process to formalize and to teach. For breeding new generations of designers, many books have been written but no theory seems to be be general enough for covering the whole design process. Some books focus on design rules for isolated mechanical components such as gears, belts, bolted joints, truss. These rules are rather easy to teach in a classical form with theoretical lectures. Other books such as the extensive encyclopedia of Artobolevski [1] try to list as many elementary mechanisms as possible. This may help new designers to re-use pre-built mechanisms in the same way as bricks in a wall. Chironis [2] presents also a great number of mechanisms corresponding to given functions. This is very interesting for technical culture but it is not enough for learning how to design a new product or machine.
Some books offer a historical point of view on the design process of well known products [3]. Then came efforts in trying to conceptualize design process in itself. Those books describe and try to organize the product design process from birth of product (first expression of requirements) to final achievement of making [4,5,6,7], covering the complete Product Life cycle Management (PLM) range. More recent advances take into account concurrent engineering strategies [8,9,10] and also focus on team design [11].
These aspects are more delicate to teach. An efficient way to ensure that students master these concepts is to involve them in a real design process with a real product to create. This paper is about a four year experiment consisting in designing an all-road wheelchair called Kokoon. About thirty students worked on the project, so42metimes eight working at the same time in parallel on different topics connected to Kokoon.

2 PROBLEM SETTING

2.1 A changing context

This work took place at French Institute for Advanced Mechanics (IFMA) and EACF Architecture School in Clermont-Ferrand (France), from 1999 to 2004. It must be noticed this project changed twice its status in four years, which is sometimes the case in real world [11]. Consequently, changes on design process are noticeable. Initially, the Kokoon wheelchair was born through a final year project for a local medical company which should have endorsed its industrialization and marketing. In 2001, the company gave up for internal reasons and IFMA was alone for holding the project. The initial objective to create a commercial product was kept up to 2003. Then, decision was taken to transform Kokoon into a research mobile platform for testing obstacle climbing.

2.2 Defining global specifications

The initial idea was to offer a new type of vehicle on the wheelchair market, improving the moving capabilities of disabled people on every type of grounds, particularly at the country. From 2002, other applications such as delivering post-mail or goods in narrow streets were also envisioned.

The analysis of the wheelchair market in 1999 demonstrated that nearly no existing products could be used efficiently in all road conditions [12]. The only vehicles that could be found were suitable for disabled people but had a four wheel architecture with rear driving wheels and small front wheels, which is not very effective against a common urban obstacle such as a pavement edge. Efficient vehicles such as small tractors or amphibian vehicles were not designed for disabled persons.

It was then decided to create a new vehicle from scratch. For having a precise idea of what was possible and what was necessary, two actions were undertaken :

- First, ISO standards and legal texts about wheelchairs were analyzed. One of the clearest and most synthetic document was obtained from CERAH, the French organism in charge of testing wheelchairs [13]. This document gives orders of magnitude for several criteria : maximal dimensions of 80x130 cm ; electrical motors ; maximal speed of 10 km/h ; minimal range of 12 km ; minimal safety equipments such as electromagnetic brake, parking brake, declutching capability...
- Second, a functional analysis based on QFD method [10] was performed in order to emphasize the main constraints. A small statistical study was conducted with disabled persons and handicap specialists. Three constraints appeared to be major ones : stability, reliability and low cost (in decreasing order). On the contrary, criteria such as speed, power or silence were not considered to be as important.

From these two actions, initial requirements were soon determined. The vehicle had to comply with specifications listed in Table 1.

Table 1. Specifications for the vehicle.

• Clean and silent electrical motors • Total weight lower than 350 kg with driver • To go through vertical obstacles of 15 cm • Independent suspensions with long travel • Maximal speed of 10 km/h	• Running on slopes of 36% (20°) at 6 km/h • More than 4h of autonomy on flat road • Protection bumper and roll-bar • Price around 15 kEuros

3 ORGANIZING DESIGN PROCESS

3.1 Choosing an architecture

From the specifications, a mechanical architecture had to be chosen. Figure 1-a shows several possible solutions that were envisioned. Solution 1 is the structure of classical wheelchairs and proved to be inefficient against obstacles. Solution 2 and 3 use track belts, which induce high ripping and are not easily compatible with suspensions. Wheeled solutions 4 to 6 are interesting. One could see the direct relation between number of wheels, wheel diameter and vehicle length. Solution 6 has too small wheels for climbing 15cm obstacles. Solutions 4 and 5 are quite interesting but the 6x6 solution is a superior choice for climbing obstacles because four wheels are still pushing the vehicle while the front wheels climb on it (Figure 1-b). Moreover, six wheels ensure best stability when running on urban stairs because most of the times four wheels load the vehicle while the two other retract when going through the step. As a conclusion, the 6x6 architecture was finally chosen because of its interesting capabilities for running through many types of obstacles. Other technical aspects are described in [12].

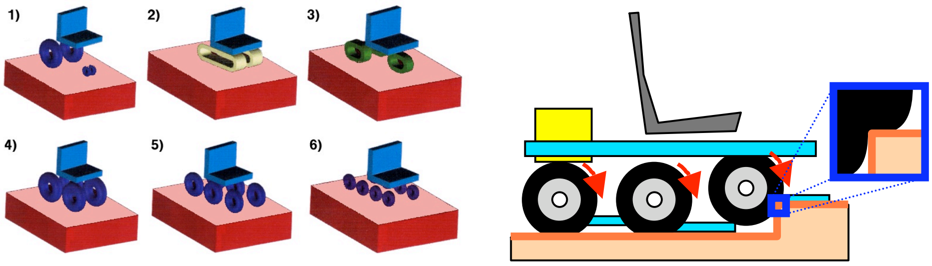


Figure 1. a) Six types of vehicle architectures. b) A 6x6 vehicle climbing an obstacle. [12]

3.2 Team organization

From this initial choice, the organization of work followed naturally, complying also with organization of studies. At IFMA, design projects occur each semester. Three types of projects were used for the Kokoon project :

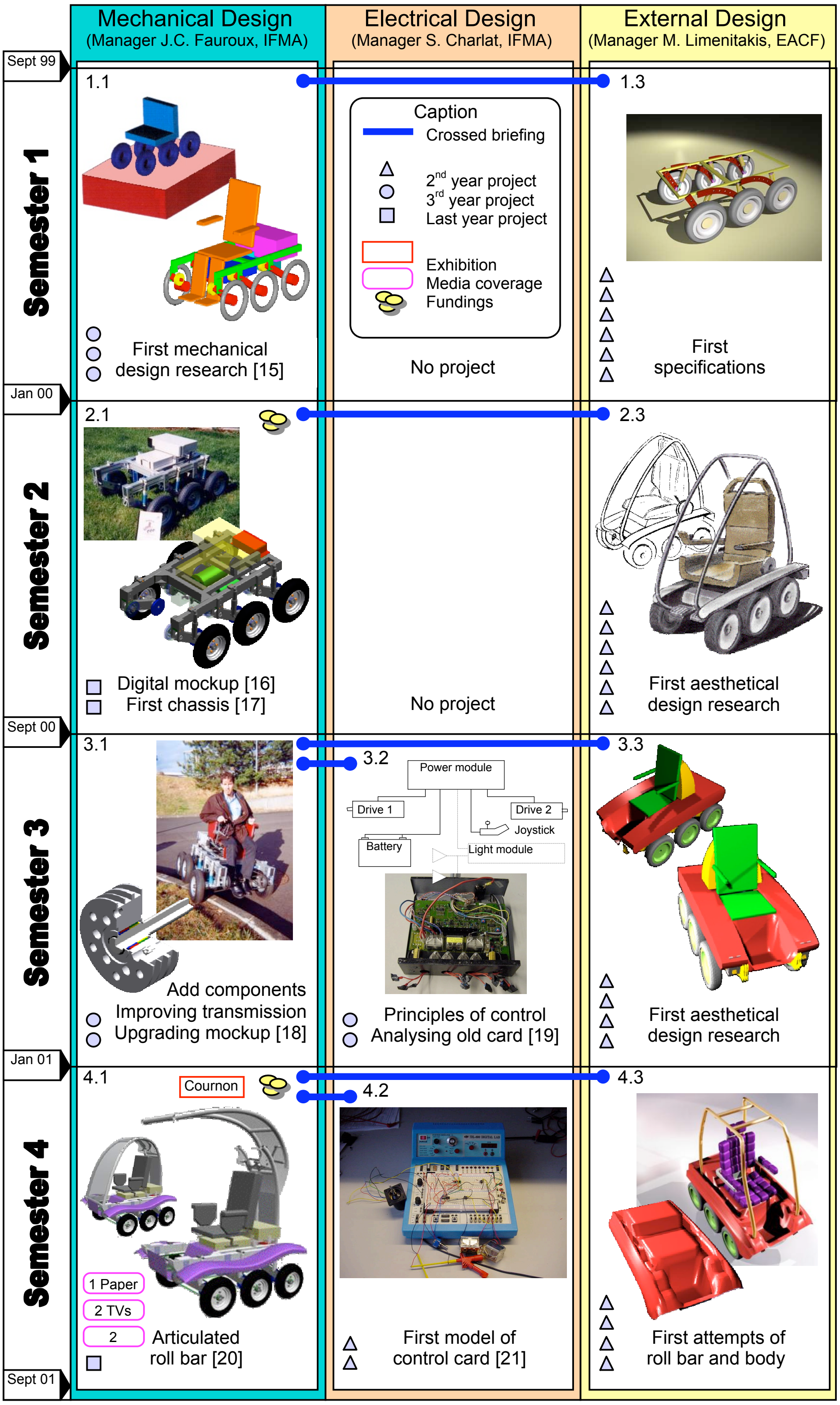
- 2nd year projects : two students working 90h from September to January, perfect for small design studies on detail points.
- 3rd year projects : two students working 150h from September to January, suitable for exploratory projects.
- Final year projects : one student working 500h (full time job) from February to June, who performs a real engineering work with ambitious objectives.

For enhancing product development, a concurrent design strategy was set. This was possible because some tasks can be clearly uncoupled and require complementary capabilities :

- Mechanical design of structure and platform. This includes suspension design and transmission and motors. Design manager was J.C. Fauroux.
- Electrical power transmission design. This is about choosing electrical motors and designing the control board and power supply and was managed by S. Charlat.
- External aesthetic of product must be carefully studied. Another critical point was ergonomics for disabled people. M. Limenitakis managed both aspects.

3.3 Chronology

Mechanical, electrical and external design was taken in charge by three different specialists. Groups of students started to work and exchange in parallel. Figure 2 shows the chronological occurrence of every task in the project, numbered form 1.1 to 8.1. At the beginning of each semester, a starting meeting was systematically organized for summarizing the goals and letting everybody discover its neighbor. During the semester, managers had regular appointments with students and wrote detailed notes on objectives and current work. At the end of semester, students were debriefed and gave back a CD summarizing their work for avoiding knowledge vanishing.



Mechanical Design
(Manager J.C. Fauroux, IFMA)
Electrical Design
(Manager S. Charlat, IFMA)
External Design
(Manager M. Limenitakis, EACF)
Sept 99
Semester 1
Jan 00
Semester 2
Sept 00
Semester 3
Jan 01
Semester 4
Sept 01
1.1
First mechanical
design research [15]
Caption
Crossed briefing
2nd year project
3rd year project
Last year project
Exhibition
Media coverage
Fundings
No project
1.3
First
specifications
2.1
Digital mockup [16]
First chassis [17]
No project
2.3
First aesthetical
design research
3.1
Add components
Improving transmission
Upgrading mockup [18]
3.2
Power module
Drive 1
Drive 2
Joystick
Battery
Light module
Principles of control
Analysing old card [19]
3.3
First aesthetical
design research
4.1
Cournon
1 Paper
2 TVs
2
Articulated
roll bar [20]
4.2
First model of
control card [21]
4.3
First attempts of
roll bar and body

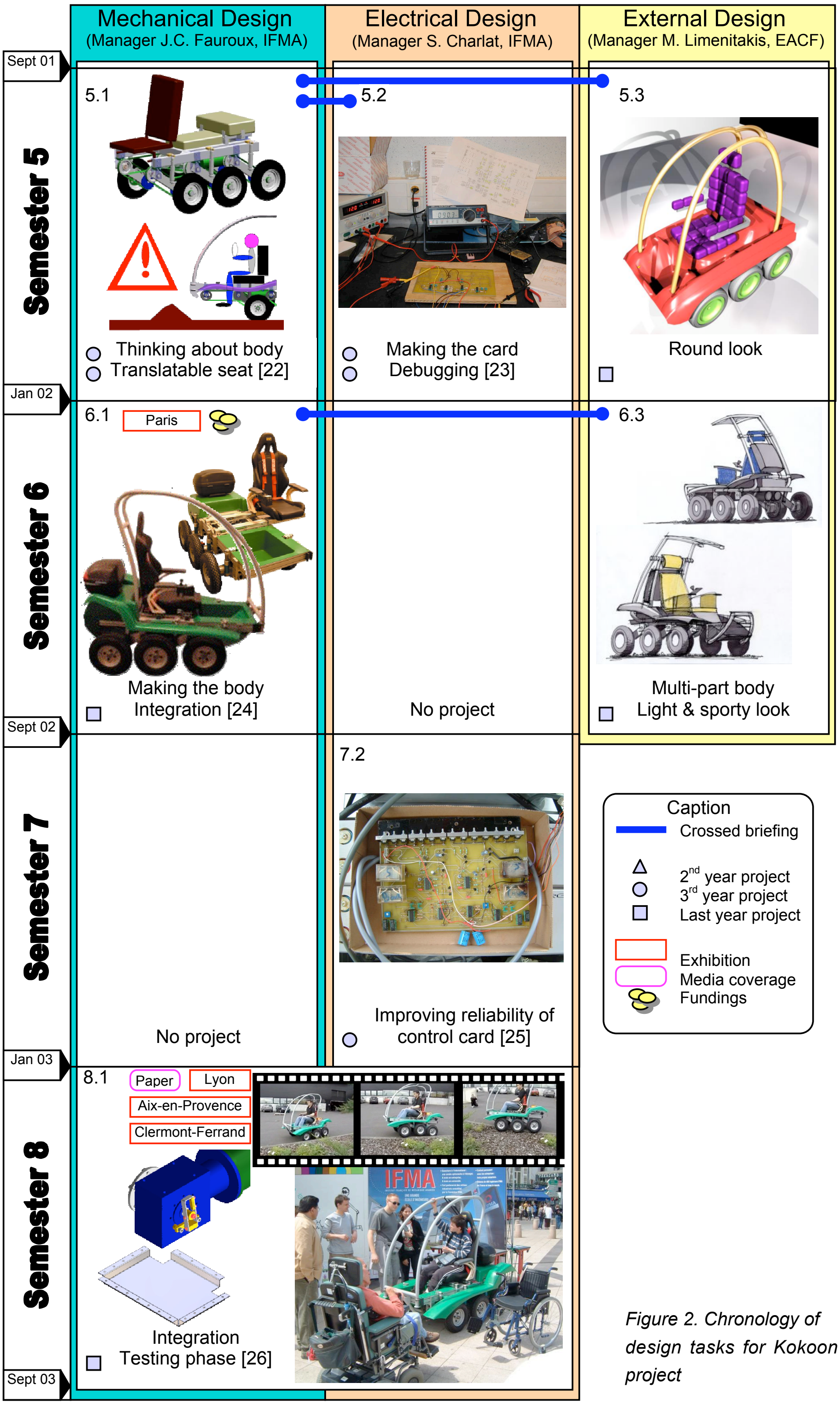


Figure 2. Chronology of design tasks for Kokoon project

3.4 Using software in the design process

The first sketches during project 1.1 were made with a simple CAD software. It was sufficient for having a 3D rendering of a rough prototype. However, the need of more powerful (though now classical [14]) features such as parametric / variational modelling, historic tree and undo function became obvious with project 2.1. In order to make a real digital mockup of Kokoon chassis, a software with efficient assembly capabilities was required. Two major high-end CAD software were available (Unigraphics and Catia) but the choice was made from a practical point of view for a middle-end software (Solid Edge) : even though this category of software lacks features such as manufacturing and advanced surface design, students appreciated its relatively ease of use and most of all the fact that it was freely installable even on their own computer, thanks to an educational licence.

At the end of the project, the Kokoon digital assembly contained more than six hundred parts. It was particularly appreciated for evaluating part interference in belt transmission and also calculating the center of mass of the vehicle. From one semester to the other, recurring problems with assemblies appeared. In fact, many of them came from references to parts : instead of referring a part with its absolute pathname on the hard disk, it is important to exclusively use relative path. Moreover, naming conventions excluding blanks and accents have to be strictly respected. These problems became so intense that half of the time of project 3.1 was dedicated to digital mockup cleaning and re-ordering. A tree structure with sub-assemblies was also adopted.

Another acute problem occurred with project 3.3, when it became necessary that Mechanical Design team gave a copy of the digital mock up to the External Design team. External designers did not use a CAD software but a rendering software (3D Studio Max) for sculpting easily complex shapes and surfaces. Data exchange between CAD software is not an easy problem. In most of the cases, internal data and parameters are lost during translation so no modification on the translated file can be performed anymore. This proved to be true in our case but we finally succeeded in sending the data through DXF format, which is for now one of the oldest and most reliable exchange format, with IGES and STEP. Even if the file was extremely heavy (several tens of megabytes), team 3.3 succeeded in creating a first body for Kokoon. However, this experiment illustrates perfectly why most of big industrial groups tend to impose their software platform to sub-contractors and also why the CAD world tends slowly to concentrate on a few software and standards.

For managing projects from one generation to the other, particularly between Mechanical Design team (IFMA) and External Design team (EACF), which were distant from a few kilometers, the use of a Product Data Management (PDM) software could have been interesting [14]. However, these software keep being costly and difficult to deploy. Another problem is the slow data rate between IFMA and EACF.

The Electrical Design Team was nearly uncoupled from the two other teams from a CAD point of view. The overall dimensions of the electric card were small compared to the entire vehicle so there was no particular geometrical problem. The software were used mainly for routing and wiring the two-sided card. Most of the professional software in this area are extremely expensive so we used freeware that did the job at the cost of a little more effort.

3.5 Problems and mistakes in design process

One of the major interests in this design process is to confront students to real life problems. A major difficulty comes from time management at two levels. In the first case, it is at the student level. Of course, a graph such as Gantt chart is always highly recommended. But even with this precaution, people often underestimate duration of provider delays and manufacturing time. This last point is also often a hard point if designers do not take precaution to involve strongly people who manufacture. This is compulsory because design stage is always before manufacturing stage in a product life. If all the manufacturing actors feel concerned by the project, they can have an active attitude, make suggestions and give the benefit of their experience.

The second time management problem is at the manager level. It appears that concurrent engineering relies strongly on time evaluation [10]. To make a comparison, the whole concurrent design process can be compared to a modern vectorial microprocessor. These type of processors are particularly efficient and gain time by various techniques, among which parallel treatment and cache prediction branching. In that case, the central unit predicts that reading data will occur probably at a particular place in memory and so gains a few clock cycles. But when prediction fails, it generates a considerable delay and sometimes even slows down the global result. However, prediction is generally interesting because it proves to be true in 90% of cases. This can be directly transposed to concurrent design : putting tasks in parallel is very efficient if and only if managers are able to predict task duration for a good synchronicity. In the case of Kokoon project, there were two slowdowns. In task 4.1, neglecting the real needs of customers conducted to designing a seducing though over-complicated articulated roll-bar. The good solution was in fact to offer a lateral access to the chair, that suits better disabled people, but it was found after a one semester delay. The other error in managing the project was about time for card development. This was deeply under-estimated and led to a delay in Semester 7. Involved students had the opportunity to learn many very interesting concepts. However, from the strict product point of view, the card lacks of reliability and should be very soon replaced by a commercial electronic speed controller.

The last point is an important problem. As mentioned in section 2.1, IFMA managed the project by itself from 2001. This means we had to perform a rather uncommon task in design departments : finding funds. This was obtained through public organisms and also via private sponsors. It forced the design team to communicate around the Kokoon project, to go to exhibitions and to contact media. This media coverage was the *sine qua non* condition to obtain sponsor help. It had one very positive consequence : participating to specialized handicap exhibitions and meeting associations of disabled persons gave us a far better idea of real needs. But this exhausting task, though extremely challenging and socially helpful, had also the consequence to take a lot of time that was not used for design. This is why all the students that participated had to involve deeply in the project to obtain results, even by working during their leisure time, for some of them. This is perhaps a good premonition of what will make their future career a success : passion and organization.

4 CONCLUSION

To summarize, this paper presented the whole design process of a complete electro-mechanical product, a 6x6 all-road electric wheelchair. The process started from birth of product to the final design and making. Work was organized in a concurrent way, with three teams and more than thirty students working together during four years, with constraints of knowledge inheritance, use of different types of software, exchange problems, management of digital mock-up, team synchronization, financial management, media communication and marketing prospection. This real life experiment allowed us to deeply test several engineering and design software, showing sometimes discrepancies between what CAD should be and what it is. It also demonstrated importance of work organization and difficulty to reach optimal team design.

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REFERENCES

[1] Artobolevski I., *Les mécanismes dans la technique moderne*, Éditions MIR, 1975-1977, 4 volumes, Vol. 1 - Mécanismes à leviers (710 p.), Vol. 2 - Mécanismes à leviers (suite), (Deux tomes de 720 p. et 595 p.), Vol. 3 - Mécanismes à engrenage, (745 p.), Vol. 4 - Mécanismes à cames, mécanismes à friction, mécanismes à éléments flexibles (672 p.)

[2] Chironis, N.P., *Mechanisms, linkages and mechanical controls*, Mc Graw-Hill, 1965, 356 p.

[3] Petroski, H., Invention by Design – How Engineers Get from Thought to Thing, Harvard University Press, 1996, 242 p., ISBN 0-674-46367-6

[4] French, M., *Invention and Evolution – Design in Nature and Engineering*, 2nd Edition, Cambridge University Press, 1994, 367 p., ISBN 0-521-46911-2

[5] Dieter, G.E., *Engineering Design – A Materials and Processing Approach*, 2nd Edition, 1991, McGraw-Hill, New York, 721 p., ISBN 0-07-016906-3

[6] Pahl, G. and Beitz, W., *Engineering design. A systematic approach*, Springer-Verlag, 1988, London, 397 p., ISBN 0-85072-239-X

[7] Perrin, J. (ed.), *Conception, entre science et art – regards multiples sur la conception*, Presses Polytechniques Universitaires Romandes, Collection des sciences appliquées de l'INSA Lyon, 2001, ISBN 2-88074-480-6

[8] Tollenaere, M. (ed.), *Conception de produits mécaniques*, Hermes, 1998, Paris, 575 p., ISBN 2-86661-694-7

[9] Prasad, B., *Concurrent Engineering Fundamentals – Integrated Product and Process Organization – Volume I*, Prentice Hall, 1996, 478p.,ISBN 0-13-147463-4

[10] Prasad, B., *Concurrent Engineering Fundamentals – Integrated Product Development – Volume II*, Prentice Hall, 1997, 490 p., ISBN 0-13-396946-0

[11] Hales, C., *Managing engineering design*, Longman Scientific & Technical, 1993, 212 p., ISBN 0-582-03933-9.

[12] Fauroux, J.C., Charlat, S. and Limenitakis M., *Conception d'un véhicule tout-terrain 6x6 pour les personnes à mobilité réduite*, Proceedings of 3rd Conference Handicap 2004, 17-18 juin 2004, Paris, http://www.handicap2004.iut-amiens.fr

[13] CERAH (Centre d'Études et de Recherche sur l'Appareillage des Handicapés), *Cahier des charges fauteuils roulants à propulsion par moteur électrique*, Notice de 4p., Bellevue-BP719, 57147 WOIPPY Cedex, France.

[14] McMahon, C. and Browne, J., *CADCAM Principles, practice and manufacturing management*, 2nd Edition, Prentice Hall, 1998, 665 p., ISBN 0-201-17819-2

STUDENT WORK

[15] FABRE, S., GUILLOT, R. and E. PELLE, *Kokoon, le fauteuil roulant tout-terrain*

électrique, Projet de 5ème semestre IFMA, janvier 2000, 47 p.
[16] CARNEAU, S., *Kokoon : réalisation d'une maquette numérique et d'un prototype*, Projet de fin d'études IFMA, juin 2000, 36 p.
[17] CHAUX, L., *Dimensionnement et réalisation d'un prototype de fauteuil roulant électrique tout-terrain Kokoon*, Projet de fin d'études IFMA, juin 2000, 32 p.
[18] G. GAUTIER, R. TACHOIRE, *Fabrication et mise au point du système Kokoon*, Projet de 5ème semestre IFMA, janvier 2001, 28 p.
[19] ENDRIZZI, P. and THIEBARD, S., *Kokoon : conception de la carte de commande*, Projet de 5ème semestre IFMA, janvier 2001, 34 p.
[20] BELER, C., *Projet Kokoon : intégration de la carrosserie*, Projet de fin d'études IFMA, juin 2001, 50 p.
[21] DENIZART, J. and PAYOT, M., *Kokoon : conception de la carte de commande (2)*, Projet de 4ème semestre IFMA, juin 2001, 24 p.
[22] ALACID, J.C. and PARIENTE, M., *Kokoon : conception de la carrosserie (2)*, Projet de 5ème semestre IFMA, janvier 2002, 32 p.
[23] BOURILLON, W. and PRADET, M., *Kokoon : réalisation de la carte de commande*, Projet de 5ème semestre IFMA, janvier 2002, 31 p.
[24] F. JEANNE, *Finalisation du prototype Kokoon*, Projet de fin d'études IFMA, juin 2002, 29 p.
[25] J. MICHELOT, *Kokoon : finalisation de la carte de commande*, Projet de 5ème semestre IFMA, janvier 2003.
[26] M. RAVENT, *Projet Kokoon : Finalisation et tests du véhicule*, Projet de fin d'études IFMA, juin 2003, 35

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