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CAN STUDENT COMPETITIONS FOSTER THE INNOVATIVE DESIGN?

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1. Introduction

The educational use of competitions dates back to I century B.C., and over the centuries they acquired more and more importance in improving students' learning and foster their creativity. At the end of the XIX century, they started to become an international phenomenon, as it was everywhere recognized that, with their atmosphere of competition, these contests could promote the educational goal, challenging students in proving and matching their skills and their creative ideas.
In more recent times, companies have acknowledged the opportunities related to student competitions and the exploiting of young talents and their fresh and new ideas, knowing that these events are a way to innovate, without the classic constraints which characterize the world of research. So, companies have begun to set up their own contests, in order to complement the more traditional innovation sources, mainly related to their internal R&D activities.
Really, these contests do not bring only students into competition, but also professors, departments and, as a consequence, universities: student competitions become contests between the top universities which aim at fostering technology and innovation.
Among these, fuel economy competitions have had more resonance than others, because the emerging of energy issues in the last few years. Severe questions regarding the sustainability of the current mobility habits and the search for innovative and green solutions have involved regulatory issues and innovation policies in many countries.
The Shell Eco-Marathon (SEM) is one of the most famous in this field, mainly focused on achieving the highest possible fuel efficiency. SEM is certainly a great opportunity for students that gain a unique working experience, for universities that strike up talents for their professional technical courses and for organizers that promote technical careers among young people all over the world. In term of innovation, SEM is designed to foster the development of leading technologies for greater energy efficiency, spreading a culture that cares about sustainable mobility.
The research question addressed in this paper is to investigate, through the Shell Eco-Marathon case, if student competitions actually foster innovation or instead have more an educational role than being really a support for innovative design.
Commonly innovation simply means "something new" and it can thus be applied to any technical novelty. But really, innovating means designing something that will not only work from a technical point of view, but will also make business sense [Shilling 2008]. The doubt is that since student competitions are played out of the market, they are far from interpreting the actual market needs and hence creating something that defines real business opportunities. Although efficient in developing new ideas, they can not simulate, through a selection mainly based on performance, a choice as made by the market, whose selection criteria are notoriously not only technical [Calantone et al. 1993], [Griffin and Page 1996].

Even considering the novel feature of a technology alone, this paper aims to investigate whether student competitions are actually generating innovative solutions. In this sense, the paper concerns on those specific design processes and how these produce effectively solutions radically innovative.
Literature on how design processes should be in order to generate effectively innovative solutions is really wide and this paper does not aim at addressing a so extensive research issue, whose aspects refer to diverse fields from engineering design to psicology. The paper instead focuses on innovation paths of the teams' prototypes over time, in order to comprehend the evolution of these design processes in student contests and, in particular, the role played by the product architecture into design.
These design processes in fact are really specific since they take place into technical universities among students supported by professors. This if, on the one side, defines similar conditions to real-world design situations and improves student skills and knowledge introducing them to real-life, on the other side, has at least two natural drawbacks.
The former is the imitation phenomena. Imitation is a natural cognitive process and it is part of design (see a notable example in [Arciszewski and Cornell 2006]). However it is evident that if imitated principles or solutions are not overcomed, creativity and innovation are bounded. In student competitions, often teams seem to adapt their vehicles to the dominant design. This could be simply due to the goal of achieving the performance of the best vehicles, as well as can be due to the fact that students are not experienced designers and hence less confident in their possibilities.
Cultural issues represent instead the latter. The departments in technical universities are culturally used to work separately and students rarely are educated to multidisciplinarity. If one looks at those prototypes, it seems that teams mainly work on modules and less on the architectures of their solution. Designers in companies worldwide are used to work in multidisciplinary contexts and, perhaps because they have more resources, are more used to accept the challenge of architectural changes.
If these considerations on innovation paths and design processes into student competitions were true, it would mean that these contests lead to an absolute waste of resources and efforts in term of fostering innovation, leaving to competition the only role of educational platform. Therefore, the original goals of organizers (that aim to push innovation and technology forward) and participants (that want to improve student skills, knowledge and introduce them to real-world design situations) would be both not achieved.
The paper attempts to demonstrate this thesis, first investigating the theoretical elements that can frame the problem, then describing the case study and the methodology, finally presenting some interesting results from the analysis.

2. Innovation and design in student competitions

Among the several means of fostering innovation, the most usual and well known are those linked to R&D activities inside firms. However, it is not so uncommon that, in order to exploit creativity and stimulate the development of new ideas under fewer constraints, companies set up competitions externally (e.g. AIAA in aerospace engineering, IEEE for the biomedical field, ASHRAE in architecture).
These contests theoretically should provide benefits both for organizers that aim to create innovation environments [Deroy 2003] and for participants that can get educational and recognition opportunities [Raina 1968], [Kaiser and Troxell 2005]. In order to substantiate these general aims and in particular to verify the role of these contests as promoter of innovation, there are various aspects that need to be taken into account.
First, it is important to understand which are the dynamics of innovation into student competitions.
In real industrial contexts, these dynamics can be described through the observation of changes in the technological paradigms [Nelson and Winter 1982], [Dosi 1982], or through the analysis of product evolutions until its maturity in certain industries [Abernathy-Utterback 1978] or still investigating the progress of the adoption processes [Moore 1991], [Rogers 1995]. Real world dynamics are well represented by "technology push" and "demand pull" mechanisms for the selection of the winner products.

It is clear that student competitions instead can refer mainly to the “technology push” side of the specific technological paradigms, going to analyze the product evolution and paying particular attention to the contingent emergence of Dominant Design.
Dominant design in general emerges when a specific product architecture comes to be adopted by a majority of the market. It is characterized both by a set of core design concepts that correspond to the major functions performed by the product and by a product architecture that defines the ways in which these components are integrated. Besides exogenous reasons (such as e.g. the reputation of the company), dominant designs emerge for aspects that are endogenous to the technical and economic environment. Leading technologies, economies of scale, relationships with complementary assets, network externalities, lock-in effects, etc. are some of these [Tushman and Anderson 1990], [Weil and Utterback 2005]. Many of these aspects are usual for traditional industrial environments, where companies compete for their innovative technical solutions and gain their competitive advantage also considering the industry and the market in which operate.
Student competitions are scaled down in respect to these conditions and hence they do not allow to investigate many of these effects (such as for instance economies of scale or network externalities); dominance of the technology represents surely the main reason that make a specific design dominant in these contexts.
Really, just because technology is the only one to determine the dominant design into these competitions, observe the progress of technology in these contests implies observe indirectly the evolution of the design processes. In particular, it is interesting analyse on one hand the evolution of the focus in the design activities and on the other hand the organizational aspects in these processes.
While it is known in the literature [Ernst 2002], [Cooper and Kleinschmidt 2007], [Bhuiyan 2011] that managerial and organizational elements (adequacy of people and resources, the presence of a cross functional team, good internal and external communication, etc..) make product development activities successful, more rarely people think about organizations as consequence of the product architecture and of the dominant design established [Gulati and Eppinger 1996], [Fixson 2005].
Product architecture has been widely recognized as a crucial aspect influencing the dynamics of innovation and defining innovation strategies [Henderson and Clark 1990], [Fujimoto 2002]. If designers in a company want not only incremental or modular innovations, but they wish to design radical ones, must really act on product architectures. Moreover, once a dominant design has emerged, the organizational structure that becomes apparent and the design processes performed often tend to mirror the product architecture developed [Yassine and Wissmann 2007].
The feeling is that the situation is just the opposite for student competitions. Design activities are performed in teams, whose organizational structure is based on the diverse skills from different departments. This naturally defines the design processes as focused on product modules more than on architecture, defining a modular approach to design. Fostering multidisciplinary, communication and coordination becomes perhaps the greatest challenge in these design contexts.
Different types of student competitions exist: Case study, Business Plan, Simulation, Ideation and Essay. It is quite obvious that if one wants to investigate the aspects mentioned above, the focus must be on those competitions that belong to the "Ideation" group and mainly relate to the engineering design field. Among them, one of the most famous is the Shell Eco-Marathon.

3. The Shell Eco-Marathon case study

Among the several types of these competitions, fuel economy ones are the most well known. Energy issues have become very critical in the last few years, rising severe questions regarding the sustainability of the current lifestyles. In particular, the search for new and sustainable solutions for mobility has acquired a huge importance, mainly from two perspectives. From an environmental point of view, global CO2 emissions are reaching too high levels, affecting dramatically everyone’s life and the transportation sector surely represents a great part of these. From a technological perspective, a new era of research is opened up and, there more than in other fields, the technological paradigm (avoiding the use of hydrocarbons) has been changed.

The Shell Eco-Marathon (SEM) is an annual educational contest organized by Royal Dutch Shell for teams of high schools and universities. The Royal Dutch Shell encourages this competition for diverse reasons [Siniawski and Patel 2010]:

- Provide a platform that fosters innovation and adopts the development of leading technology for greater energy efficiency,
- Spread especially among young people a culture that cares about sustainable mobility,
- Bring together academics, decision makers and experts on energy field,
- Demonstrate the Shell commitment to face challenging energy issues in a responsible way,
- Promote technical careers in the energy field.

The goal to achieve is clearly stated: design and assemble, under certain technical and regulation constraints, vehicles that has the objective of covering the longest achievable distance with the least possible fuel and emissions. As shown in Figure 1, two categories are possible for the race: Futuristic Prototypes (three/four wheel vehicles) or "Urban Concept" vehicles (four wheels vehicles that look like conventional ones). Teams can participate in one or both of the vehicle categories and a winner is declared for each of these two.

Regardless of the fuel really used, the overall ranking of competitors bases on the equivalent consumption of Shell Unleaded 95 gasoline, measured by the Net Calorific Value of the different fuels. Concerning the hydrogen Fuel Cell Prototypes, they use a flow meter to measure the H2 consumed and the consumption results are expressed in kilometres per kilowatt hour (km/kWh) and then converted in kilometres per equivalent liter of gasoline (km/l*).

Figure 1. SEM vehicles for the two categories: Futuristic and Urban concepts

For this study, the attention was focused on prototypes fuelled with hydrogen, as they constitute one of the most important research fields for future mobility and because in these years, participants in the fuel cell category have been considered providers of the most innovative designs.

The study has used data on registered performances from 2003 to 2012. They have been collected through the SEM portal or via the websites of most of the participants, while all the other information have been collected by questionnaires to the members of 9 among the 21 qualified teams (only qualified teams have their results recorded), reaching the answer rate of 42,9 %.

So, besides consumption results, the attention has been focused on obtaining as much information as possible about teams' work, circuits, vehicles and internal organization. Performance in fact is believed to be influenced by different aspects: the budget and the total man-hours spent for the project, the architecture and technical features of the vehicle, but also by the type of circuit where the competition takes place, possible alliances with other teams or the teams' internal organization.

The analysis until now has been quantitative on performances and budgets, while more explorative about all the other data. This preliminary analysis has led to interesting findings that are in fact discussed in this paper, nevertheless this study will be completed in future applying multivariate analysis or implementing regression models, in order to get which are the relevant factors that explain vehicle performance.

4. Data analysis and results

If one plots the performances of teams, which have participated in the SEM contest between 2003 and 2012, get the curves shown in Figure 2. Data show that in 2005 the Swiss team ETH Zurich registered with its Pac Car II an astonishing result, setting a record of 3836 km/l*, which lasted for 5 years until the French team of Polytech' Nantes seems to beat it in 2010. Really, if one investigates also performances during the tests and not only during the competitions, would discover that ETH Zurich had covered a distance of 5385 km/l*, establishing an unofficial, but documented, record still in 2010. It is represented in figure as asymptote. This means not only that the ETH record is undefeated but also that this team represents the reference limit for the other teams.

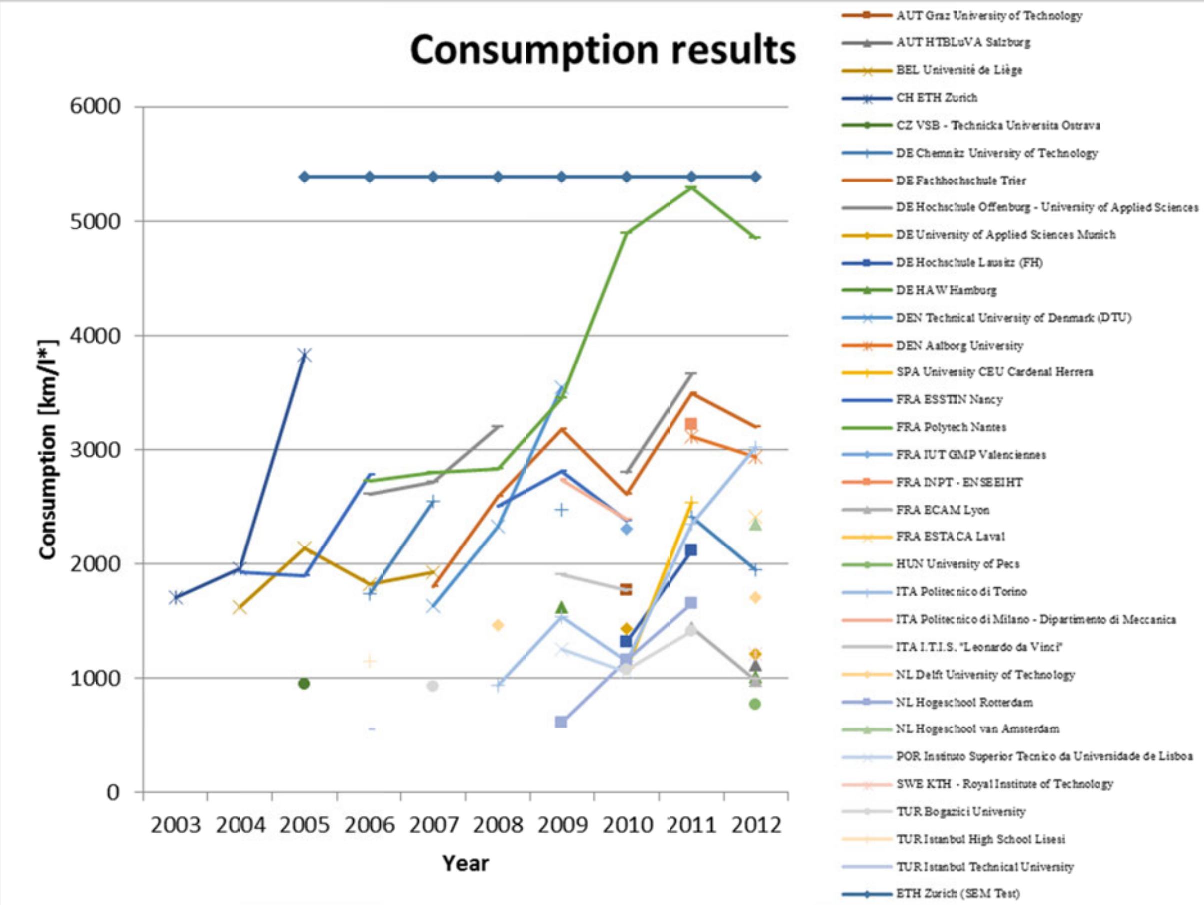
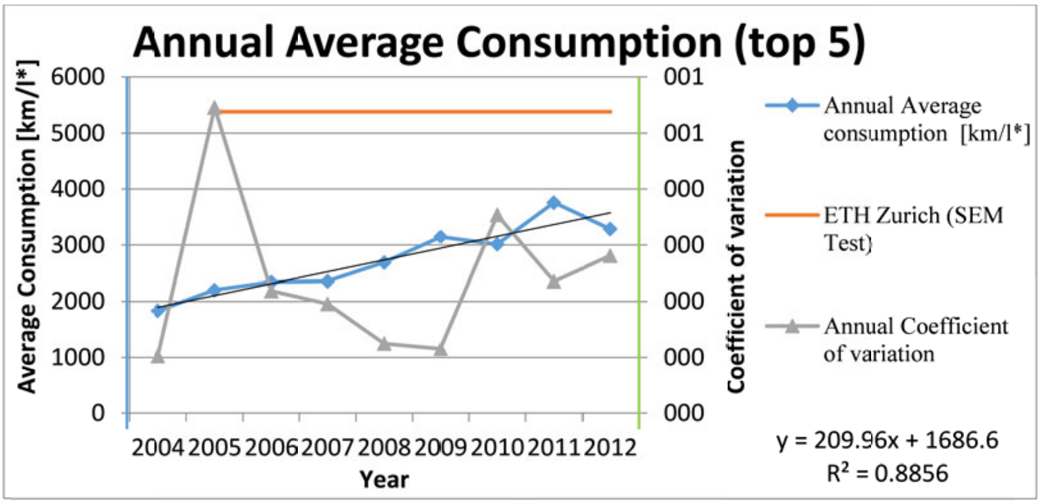
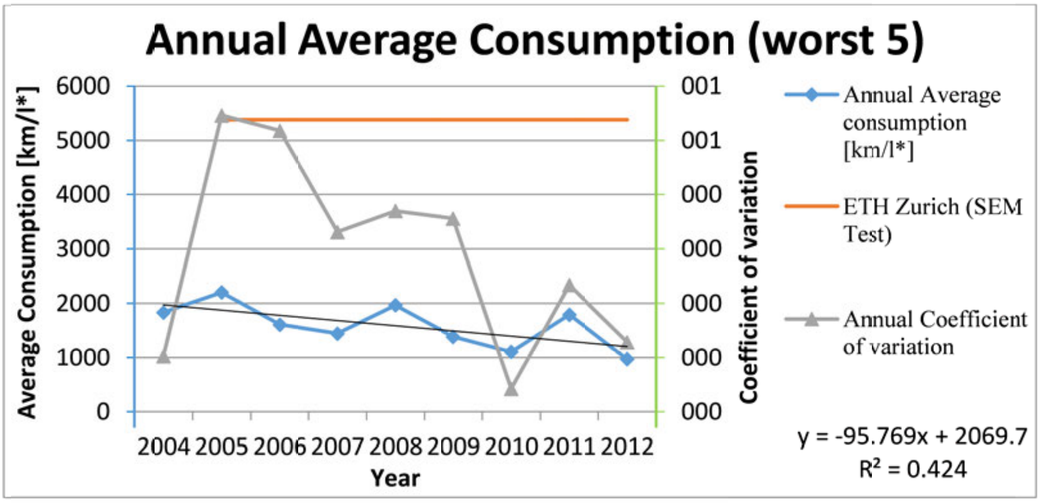


Figure 2. Team performances

Comparing the annual average consumption performance of the best and worst five teams as in Figure 3, one can observe that behaviors of the two curves become substantially different since 2006 and in particular, the trend of the average performance grows for the top 5, while decreases for the worst ones. The reason of this difference is in the allocation of resources by universities, whose decisions have been surely impacted by recent years of global economic crisis. Among worst teams in fact have been also “newcomer” teams with less experience and knowledge. If universities, for reasons of saving, invest less into projects (resources in average decreased from 160 KEuros to 60 KEuros), the youngest teams result penalized; for them it becomes more difficult to obtain improvements in respects to “incumbent” teams, that exploiting their knowledge can obtain an (even little) improvement.
Being more specific on the differences between incumbents and newcomers, one could compare not only best and worst teams in general, but instead can specifically take the best incumbents as, among new comers, the best ones.



a)



b)

Figure 3. Annual average consumption results for best (a) and worst (b) five teams

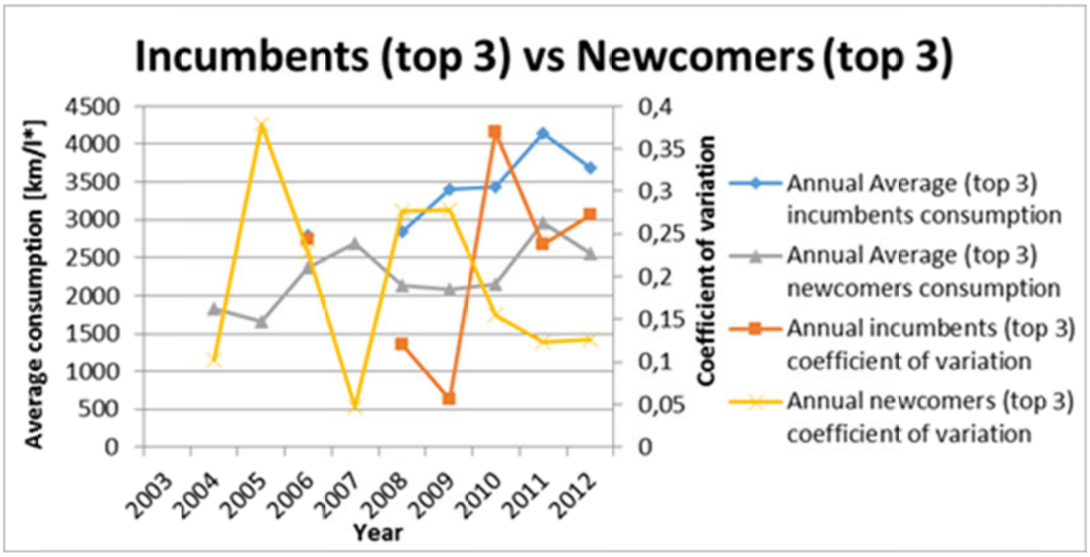


Figure 4. Performances of newcomers in respect to incumbents

Figure 4 shows the annual average consumption for both of these two groups. Really, teams that have been participating in the SEM for less than two years, in average 3 teams for year, have been considered newcomers. Hence, performances of present incumbents have been considered in the curve of newcomers for their first two years of participation. This is the reason why the curve of newcomers (grey line in Figure 4) appears longer than the one of incumbents (blue line in Figure 4). If one focuses specifically on the grey line, can see that it has a recurrent behavior. Taking in mind that it represents at the beginning the performances of incumbents, when they were newcomers, and at the end the performances of the present newcomers, it seems that newcomers are following the same performance path of the incumbents, simply with some years of delay. This would seem to show, even for the best teams, that learning paths are the same. Some of the reasons behind will be investigated further, but in any case, this evidence is coherent with the "similar innovation paths" described by Utterback and Suarez [1991].
ETH Zurich clearly has constituting since 2005 the asymptote and teams are chasing each other to reach and overcome this limit. In this sense, by looking at the coefficient of variation of the best teams (Figure 3a), one can observe that the more teams approach to the asymptote, the more the improvement rate decreases. This is because, more performance increases more the marginal increments decrease and the marginal cost associated to a smaller improvement increases.

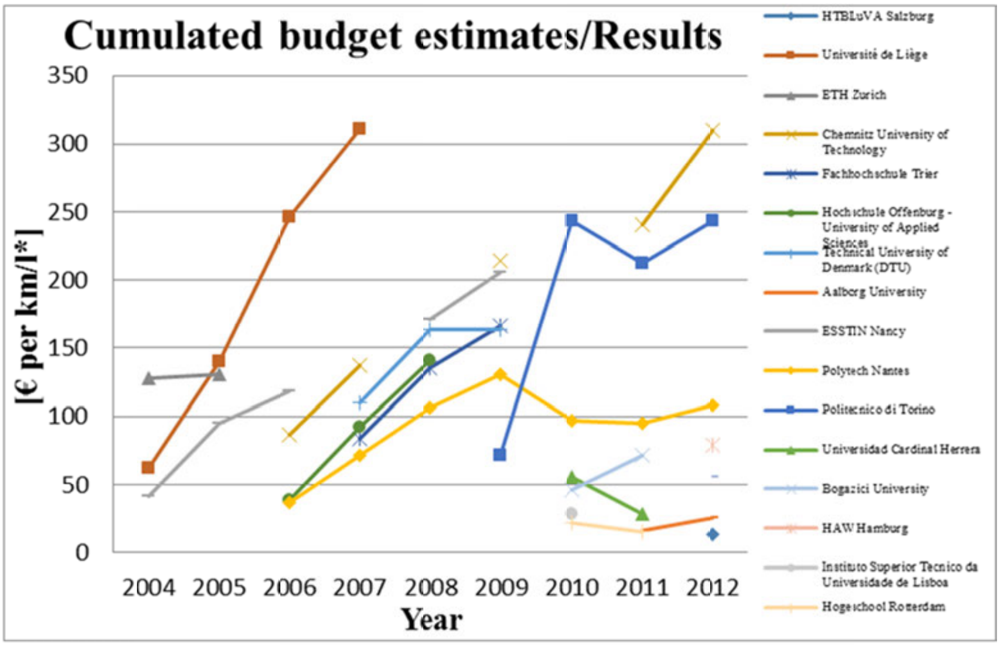


Figure 5. Cumulated budget estimates over performances in the fuel cell category

The correlation between cost, in term of effort spent, and performance is evident and hence it has been the further step of the study. The effort spent has been investigated, both in term of money and in term of man-hours employed. Unfortunately, data about the man-hours amount on the project by teams has been not enough, and so this aspect can be used neither as a dummy cost nor to infer some link between performances and work effort.
Despite that, on the basis of budget data, the ratio over consumption has been calculated in order to understand how much teams were spending to improve their performance and therefore the trend for the marginal cost of improvements. This in general helps to get if it is worth continuing to spend resources in order to improve results or funds should be directed elsewhere. If there is a growing trend, in fact, teams are spending more money for a marginal increase of performances, thus demonstrating that for that category technology has already reached its maturity and big improvements on performances cannot be achieved anymore even with consistent budgets. If there is a decreasing trend, this means that performances are growing in comparison with the committed budget and hence technical improvements are therefore still possible. As Figure 5 shows, even if neither budgets nor performances are available for every year (in this case the point was excluded by the chart), the ratio

appears to be growing for almost all teams; that means that marginal improvements in consumption are becoming increasingly expensive.
It is interesting to note that ETH has invested more than others at the beginning, but has not invested anymore after having defined the asymptote; while the others teams have continued to spend thousands of euros although obtaining little improvements. All the work done and the resources spent by others hence go to waste; if one thoughts that the annual effort is at the minimum 1800 hours with an additional budget that can reach 60000 €, this evidence seems to be even more significant.
Really, comparing the architectures of teams' vehicles, one can realize that ETH Zurich constitutes not only an asymptote in terms of performance, but that the product architectures of all the competitors, even though very different at the beginning, have become very similar to the winning team's architecture at the end. So that, this architecture in effect has defined the dominant design for the category.

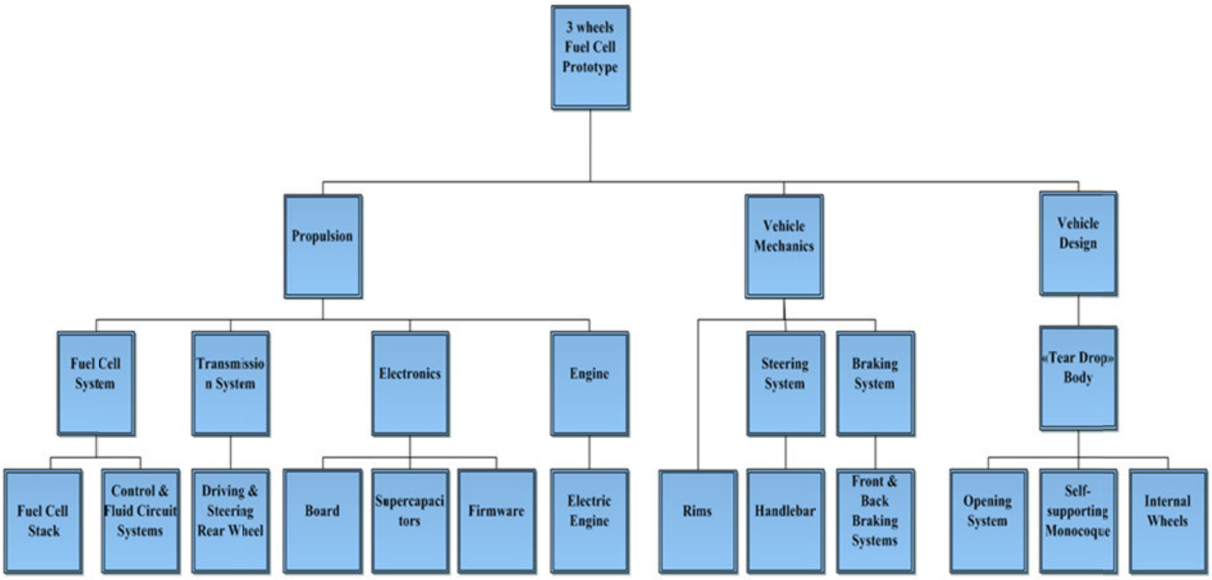


Figure 6. Dominant design architecture for the fuel cell category

People interviewed have confirmed that a dominant design seems to be reached in the last years of competition and that their vehicles have now almost the same structure shown in Figure 6. Considering little differences in term of components, teams have recognized this architecture as the dominant design. It is structured on three main levels: the macro areas (Propulsion, Vehicle Mechanics and Vehicle Design) at the first level, the systems embedded at the second level, the main components at the third level. All the prototypes differ minimally only at this last level. Moreover, if one surfs on the official websites of the teams, can realize that even the aesthetics makes vehicles very similar in the category, since most of them are characterized by the so called "tear drop" body shape.
Summarizing therefore, the newcomers follow the footsteps of the incumbents in their learning processes (as in Figure 4), so that their performance tend to the best performance that is defined since the beginning (as in Figure 3) and the marginal increments in performance do not justify the efforts spent (as in Figure 5). All these elements is mirrored also into product designs, leading most of prototypes similar in terms of aesthetics and architecture.
So, according to Abernathy and Utterback's model, the SEM can be considered in the specific phase of this dominant design, which seems to be emerged mainly for dominance of one technology and a limited creativity. Raina's theory about the positive influence of competition on creativity is therefore not completely confirmed and this indeed seems to be bounded for many reasons.
First, the SEM official competition rules are really strict and this could constrain the perimeter in which teams can operate and impose many restrictions that affect critical automotive design aspects. Moreover, after having set the record, the Swiss team ETH Zurich described its prototype in a book, from design to realization. This means that some part of knowledge was made explicit and available

for competitors. People interviewed admitted to have taken inspiration and perhaps imitation processes have limited design creativity.
In addition, if the goal of the competition has focused on improving the performance as much as possible to reach the asymptote, design efforts would have been concentrated on those modules of the architecture that allow greater improvements. The fuel cell stack and the control system appear to be the most important in this sense (its efficiency depends on humidity and temperature), as well as the most common cause of problems during the race. This could be the reason why interviews report that design attention of most of the teams primarily have been dedicated on this module, besides aerodynamics and weight reduction. Focusing on consumption has led to a technology push perspective, far from real problems like the sustainable mobility that really was the original aim of the innovation efforts.
Hence, the design approach has been typically module driven, but also some organizational issues can be considered a strong reason of that, confirming the direct link between organization patterns and the vehicle designs, as stated by Yassine et al. [2007].
Data from interviews clearly show that teams have been not well-organized yet and that people in team have been more similar to a "group-of-friends" than a "well-structured-organization". The majority of teams interviewed have declared that university departments supported the design of single modules, in relation to the competences needed. Also in more structured teams sustained by a higher number of departments, these have worked like independent units. Integration and coordination has been obtained only through meetings, but anyone has been the owner for the architecture. The main consequence is that innovation, which characterizes vehicles, would be most likely incremental or modular, as deign efforts have not regarded the architecture, but have concerned only the optimization of specific modules.
Moreover, since in every university analogous departments (usually the department of Mechanical Engineering, Electronic Engineering and Energy Engineering) have generally the same competences, an additional source of similarity among teams and consequently among prototypes has been generated, neglecting the role of multiciplinarity for the success, as instead suggested by Cooper and Kleinschmidt.

5. Conclusions

Student competitions, besides being thought to foster the educational goal of improving students' skills and knowledge, aim also at fostering creativity and innovation, developing leading technology and sustaining the flow of innovation through new ideas, in order to face and solve actual problems. However, it can happen that, instead of bringing positive effects, competitions create collateral effects to the innovation design, with as result a large waste of resources and efforts.
The case of the Shell Eco-Marathon competition described in this paper has, in this sense, provided some interesting evidences. Student competitions are thoughts by companies, but really occur mainly in academic contexts, that affect prototype design processes. They, in fact, define conditions that are rather different from real word situations and moreover, because cultural reasons, generate design processes more focused on modules than on the product architecture. This modular approach, beside the imitation processes natural into these contents, limit creativity and consequently innovative solutions into design.
Therefore, both the original goal of organizers that aim to push innovation and technology forward and the one of participants that want to introduce student to real-world design situations would be not achieved, leaving to these competitions the only role of educational platform.

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