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ABSTRACT
This paper deals with the way manufacturing organizations use the Internet and other information technologies for design activities. The authors surveyed 105 companies in the state of Sao Paulo, Brazil, at two different moments in time: November 2003 until February 2004 and November 2006 until February 2007. In both situations respondents were asked about the impact of the Internet on the way they carried out design activities. The collected data was tabulated and analyzed, providing a better understanding of the extent to which Brazilian manufacturers are using the Internet and other IT in such activities. Results show that there is a trend towards using the new technology more intensively, but that there is still a lot to be done in order to achieve its full potential.
Keywords: Internet, design, virtual prototyping

INTRODUCTION

Most of the buy-sell front-end activities that can be performed through the Internet have been well analyzed by practitioners and academia during the last few years. There are, however, several other important activities, particularly those concerning back-office processes, for which the potential of the Internet deserves to be better explored.

This paper presents the results of two surveys that were carried out with manufacturing companies in order to identify how they use the Internet and other IT to carry out design activities. They were applied three years apart from one another, because most questions allowed the respondents to tell if they expected a specific activity to start being performed with the support of the Internet and other IT within the next three years (in case the company still didn't do so). The 2003/2004 survey was answered by 665 manufacturers in the state of Sao Paulo, the most important industrial area in Brazil. The 2006/2007 survey, on its turn, was answered by a sub-set of 105 of those companies that had participated in the previous survey.

The more agile development of products has become a critical issue for the success of many industries, regardless of the specific product. That has motivated the development of concurrent engineering techniques, during the 80's, capable of reducing cycle times by overlapping and performing in parallel different design activities (FORD e STERMAN, 1999).

In most of the cases of industrial production, prototypes need to be built prior to scale production, as reminded by Jons (1997). The construction of several physical prototypes to be used in order to test and evaluate design concepts that are independent from one another may require a lot of time and involve high, or even prohibitive, costs, according to Boswell (1998). In addition to that, the design of a product traditionally needs to be ready before it can be built.

Such physical restrictions make it difficult for different tasks to be performed in parallel, in order to test and ensure acceptance of a product, as professed by concurrent engineering.

Taking that into account, the purpose of this paper is to discuss the possibility of virtualizing design activities, based on the available support provided by the Internet and other IT. After doing that, the authors present the results of a survey that was carried out with manufacturers' from Sao Paulo in order to identify the extent to which they have been using those technological resources to improve their design capabilities.

VIRTUAL ENVIRONMENTS AND THE SUPPORT THEY GIVE TO DESIGN ACTIVITIES

Virtual environments, which can be used in order to enable the virtualization of design activities, originate from the convergence of advances in computer digital technology and advances in visual presentation technologies (JONS, 1997). First, technical design activities, which involved paper, pencil and a drawing table, migrated to the computer to benefit from the flexibility provided by features such as cut and paste, save, retrieve, change and print. Two dimensional CAD (*Computer Aided Design*) tools represent the same to technical designers as a word processor to a typist: a more efficient way of doing the same job as before. However, when the CAD tools started providing three-dimensional resources (3D CAD), they were responsible for an unprecedented quality leap towards the possibility of using virtual simulations to replace physical rehearsals, which were indispensable in the past, in the development of any product. In fact, according to Duarte and Barberato (2003), three-dimensional CAD is a design process completely different to what was done before: in the solid modeling tool, design takes place by adding required items, including information such as dimensions, tolerances and material specifications, which are attached to the electronic model that is built.

Another characteristic of CAD designs, which was not so relevant at first, but which became a very important issue with the possibility of electronic connectivity by means of computer/ telecommunications networks, is the virtualization of the drawing activity. "Dematerializing" the technical design may represent a fundamental step towards allowing information sharing among members of the development team, which doesn't even need to be located physically together, anymore in order to carry out their activities.

Each time it becomes easier to generate realistic graphic images and to transmit them quickly to other people who need them to perform their own work. The main developments in this area relate to: simulation based design, virtual prototyping, virtual reality and workflow, which will be discussed next.

Simulation based design and virtual prototyping

There are many benefits associated to the use of concurrent engineering, but the techniques involved require an enormous human engineering effort and have limited capability for full life-cycle cost analysis, multidisciplinary integration and optimization and for the collaboration of geographically dispersed teams, according to Goldin, Venneri and Noor (1998).

In an attempt to compensate for the shortcomings of concurrent engineering, many companies develop simulation-based-design (SBD) approaches, which simulate the entire life-cycle of the project before physical prototyping takes place. Simulations may include detailed design, prototyping, operations, maintenance and disposal of the product. They postpone the need of a physical prototype or make it completely irrelevant.

Goldin, Venneri and Noor (1998) argue that, when engineers are immersed in a virtual design environment, they are able to create or modify their contribution to the overall project, in real time, observing the effects of their actions on the whole, immediately.

Virtual prototyping involves the development and "use", in a virtual environment, of a product that still doesn't physically exist. According to Deviprasad (2003), virtual prototyping has become a promising research field: there are already many papers in the mechanical engineering area that discuss the use of virtual prototyping and virtual reality for the design of parts, products and tools with cost, quality and time advantages. Ozer (2003) also mentions some empirical work that demonstrate that virtual prototypes may be so effective as physical ones.

The ideal virtual prototype should free design of the restrictions imposed by the requirement of a physical prototype. According to Jons (1997), a virtual prototype should allow for the design of the product, with good visualization of its appearance and good representation of its functionality; the construction of the product (virtual prototype) without the restrictions and costs incurred when a physical prototype is created; product testing (using the virtual prototype), in order to check the performance of the real product; the operation of the product (virtual prototype), in a realistic environment and having humans in control.

Another issue that has not been mentioned by Jons (1997), but which is also very important is the possibility of electronic distribution of virtual prototypes, allowing for separate development teams to work together, even when they are geographically disperse.

Boswell (1998) considers that digital prototyping, among other new technologies, is revolutionizing the way products are designed, providing for unprecedented flexibility, through the efficient integration of data and a concurrent engineering approach.

Virtual prototypes developed using 3D CAD tools can be easily virtually assembled and disassembled, allowing for more detailed studies, which can be repeated as many times as required.

The pace at which changes can be performed to virtual prototypes and the low cost of such alterations stimulate more rehearsals and tests to be carried out, with alternative part configurations. Better quality products can therefore be developed and quickly made available to the market.

For all those reasons, digital prototyping is being adopted at a fast pace by companies in the most diverse industries, especially when perfectly fitting parts are needed that are created by different development teams, working in different locations. The prototypes becoming virtual provides them with the "magic qualities" that make them perfectly suited to the Internet (GEOFFRION and KRISHNAN, 2001). Physical restrictions that made the collective work of teams difficult in the past do not exist anymore. Information can be simultaneously shared to all those interested, during the development of the virtual prototype, including shop-floor engineers, designers and machine/tool manufacturers (BAPAT, 2002).

Virtual reality

Boswell (1998) believes that the study of virtual environments through a sensorial experience in which a person is immersed in a computer simulation providing him/her with visual, acoustic and tactile stimuli, may represent powerful support in design projects that involve digital prototyping.

Virtual reality helps design teams to anticipate design difficulties, when 3D CAD systems are used, according to Duarte and Barberato (2003), reducing the integrated development cycle of the project. Ottosson (2002) has the same opinion and states that, by using virtual reality, users can test products "virtually", being trained to using them even before them being available. That may play a big role in improving the design with respect to usability and ergonomics. Thus, customers and users tend to play a more important role in the design of new products, influencing the results that are obtained and products that reach the market.

Although most practical applications of virtual reality are still related to the entertainment industry, it may soon become an important design tool and even an efficient marketing resource, to accelerate buy-in by potential customers of products that haven't yet left the designers' bench, or should we say, computer. An example of that is the case of Embraer's ERJ-170 airplane. The company adopted a strategy of early involvement of customers and was able to sell several aircrafts to customers that had only had access to the design of the ERJ-170, which was presented to them by means of sophisticated simulation and virtual reality resources (ERA, 2002; SHIFRIN, 2004).

Distance collaborative design (workflow)
Digital prototyping and the use of simulations based on virtual prototypes allow geographically disperse design teams to work together and simultaneously on the same project. But tools are required to manage the collaborative work of different people or teams, regardless of them being in the same room or thousands of miles apart.

Members of a virtual team can communicate with each other in a very effective way and exchange documents, design files and software by means of the Internet, as reminds Ozer (2003). In addition to that, virtual work also allows companies to use their best resources, with respect to specific knowledge, regardless of where they are physically located (KIRKMAN *et al.*, 2002). The integration of contributions from different participants in a project can be aggregated in a master model, which becomes available to the whole group, by means of visual representations and sharing of data required for the good flow of the collective work.

Good tools for collaborative work and tools for seamless communication among those involved in a design project are still difficult to find. There is a lot to be done in that field, from the creation of methods for managing conflicting objectives among different design teams, to the development of tools to support conceptual decisions, which have to be taken very early in the design cycle, but which dramatically impact future course of action. Galina and Santos (1998) consider Computer-Supported Cooperative Work (CSCW) to be a very important research area, with the purpose of improving the collaborative interaction of members of a design team. As CSCW concerns itself with the communication and collaboration among people that need to coordinate their group activities, it is a very useful tool to support concurrent engineering initiatives.

Even so, group decision making is not an easy task by means of the channels made available by the new technologies. Rheingold (2000) has the opinion that on-line conversations tend to diverge and loose focus, instead of converging to solutions. He believes that computer conferences are more useful to permit opinions to be presented than to create consensus on the way to be followed. Lebkowsky (1999) agrees with that, saying that on-line democracy is very difficult to be achieved. Another researcher that is skeptic about the exclusive use of electronic means for the communication of design teams is Ozer (2003), who considers that a certain degree of face-to-face contact is essential for the generation of mutual trust in a group of virtual collaboration.

In spite of those warnings, most researchers agree that workflow software and other tools for team collaboration will develop fast, taking advantage of recent technological advances and the interconnection provided by the Internet and other electronic networks.

METHODOLOGICAL APPROACH

The research project that originated the data analyzed in this paper was developed with the purpose of improving the understanding of the way Brazilian manufacturing companies use the Internet to support their strategies and business practices. This paper, specifically, discusses the findings related to possible uses of the Internet and other IT to support the design of new products and processes.

Manufacturing companies of Sao Paulo, the most industrialized state in Brazil, were surveyed in two different occasions:

- from November 2003 to February 2004
- from November 2006 to February 2007

The questionnaire was pre-tested, in 2003, with respect to the content, having been presented to a group of executives working in the field. They gave important contributions in order to make the questions more accessible and understandable to the actual participants, in a later stage. With respect to the format, the authors randomly separated one per cent of the whole database and sent the questionnaire to those companies a month in advance, for the 2003/2004 survey. No changes in format were required as a result of the pre-test, in 2003.

No pre-test was carried out for the 2006/2007 survey, because the questionnaire was almost identical to the one applied in 2003/2004.

The convenience sample used for this research project consisted on the respondents that participated of both surveys (2003/2004 and 2006/2007). The fact of the sample being a convenience sample posed a problem to the researchers: it could not be considered as a probabilistic distribution of the population, prior to careful statistical analysis being carried out. Thus, special attention was required to validate the sample.

Although no simple and definite solution was found to ensure sample representativeness, measures were taken to improve the 2003/2004 survey's acceptability. One hundred companies, whose e-mail addresses contained in the database were invalid, were contacted by telephone, in order to obtain an alternative (working) e-mail address. In addition to that, one hundred companies that didn't have any e-mail address in the database were also contacted by telephone, with a request for an existing e-mail address. The great majority of them did provide a valid e-mail address, then, which made the researchers assume that those companies were not different to the ones that had valid e-mail addresses in the database.

The researchers were especially concerned with issues of resemblance between sample and population, because, as the survey was on the companies' use of the Internet, contacting companies via e-mail could be biasing. The two hundred additional phone calls to non-respondents (invalid e-mail and no e-mail in the database) helped them to refute that possibility.

For the 2003/2004 sample, comparisons were also carried out with respect to demographic data available in the database about the population. No evidence was detected of significant differences between sample and population. On the contrary, χ^2 tests based on the location of companies (region within the state of Sao Paulo) and size were very favorable.

For the 2006/2007 sample (a sub-sample of the previous one) the only additional precaution was the χ^2 test with respect to the size of surveyed companies. It was not possible to check resemblance with the population with respect to location because the possibilities were many and the size of the sample not large enough (105 respondents). The authors found no reason to believe that the sample was biased.

In 2003/2004, companies were contacted through an e-mail message that had an MS Word automated form attached to it. The questionnaire needed to be returned by the respondent after completion. 655 answers were obtained, which represented ca. 8% of the companies with valid e-mail addresses in the database.

In 2006/2007, participants were also surveyed electronically, but, instead of the form being attached to an e-mail message, companies only received a message indicating the survey's web-site and inviting them to participate. 105 companies provided valid answers, corresponding to 16% of the population (the convenience sample of the 2003/2004 survey).

The two surveys consisted on the same set of questions, which could be quickly answered by clicking the mouse on the suitable alternative from drop-down menus, such as those shown in Figure 1.

What is the level of usage of the tool [name of tool] made available by the Internet?

What is the level of change caused by the Internet and other IT in the way your company performs [activity]?

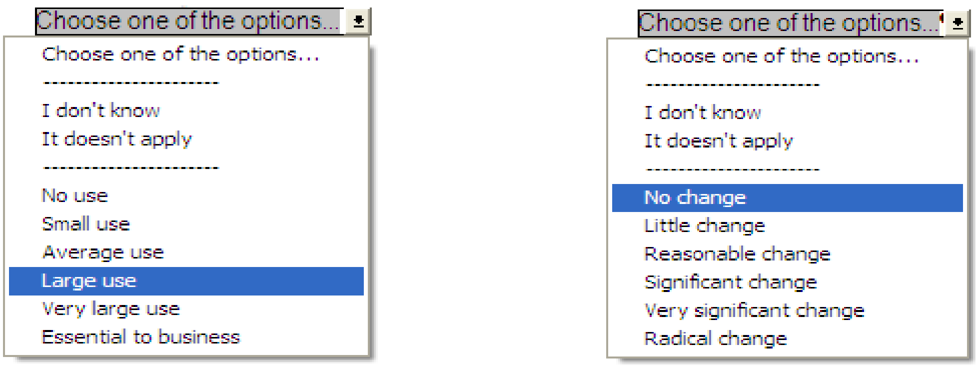

Figure 1 Drop-down menus like the ones used in the surveys

The next section presents the results that were achieved for the following questions, which were part of the survey participants filled in in Nov2003/Fev2004 and again in Nov2006/ Fev2007):

- Did the Internet and other IT cause changes in the way your company designs its products, within the last 3 years?
- Did the Internet and other IT cause changes in the way your company designs processes to manufacture its products, within the last 3 years?
- To what extent the company uses design approaches that simulate on a computer the several stages of the design's life cycle?
- To what extent the company uses virtual prototypes to design products that are still not physically available, in a computer based virtual environment?
- To what extent the company uses virtual environments to provide sensorial experiences (visual, hearing or tactile) to people participating in computer simulations?
- To what extent the company uses tools that allow for collaborative work to take place among participants of teams that are physically dispersed?

PRESENTATION AND ANALYSIS OF SURVEY RESULTS

Considering that more than 600 companies participated in the 2003/2004, but only 105 of those participated again in the 2006/2007 survey, the authors decided to use only the information on companies that took part in both surveys. The collection of data at two different points in time may not be enough to establish a true longitudinal study, but, by doing that, some trends may be spotted that can be further studied by means of additional research, in the future.

Another reason for the choice of concentrating on those 105 companies is that for 88 of them, the respondent in 2006/2007 was exactly the same person as in 2003/2004. In other 11 cases it was not possible to identify if that happened and only for 6 companies, respondents were definitively different people in the two occasions. The fact that, in general, the same people answered the same questionnaire, three years apart, improves comparability between the two samples (remember that surveys deal with perceptions, which vary from one person to another, even if they work in the same company and are faced with the same reality.

The analysis of the tabulated data was carried out using MS Excel Pivot Table, computing the number of occurrences of possible answers, for each question. After that, bar graphs were drawn, comparing the results for 2003/2004 and 2006/2007, which allow for quick identification of patterns and trends in the set of data.

As all figures presented here follow the same concept, it is worth to explain how those graphs were elaborated. The y axis distinguishes companies with respect to their size. Such separation was carried out because the authors had already noticed, in previous studies of their own and of other researchers, that size is an important discrimination factor when one is dealing with the adoption of technology. This will become clear when one analyzes the data contained in Figures 2 to 6, where, except in very few situations, larger companies are seen to adopt the researched techniques and tools more intensively than smaller ones. The upper category of the *y* axis ("general") includes the aggregate figures for companies of all sizes, i.e., it represents the information without size discrimination. Numbers contained in each of the boxes that comprise different horizontal bars indicate the absolute figures related to the number of companies that provided a specific answer to the question, according to the legend presented below the graph. However, as the number of companies of different sizes is not the same in the sample (neither in the population) – there are many more small companies than large ones –, a percentage scale was used in the *x* axis, to improve comparability among different sizes of companies.

When questioned if the Internet and other IT had caused changes in the way the company designed its products, within the last 3 years, participants provided the answers shown in Figure 2. One notices that, contradicting to certain extent the general rule proposed above, according to which larger companies use new technologies more intensively than smaller ones, the category of companies that stated to have had greater change caused by the use of the Internet and other IT for the design of products was that for companies with 50 to 100 employees. Another interesting finding, in this case, is that among the really small companies (less than 50 employees), it seems that there was a retraction in the effect of the Internet on design activities. It is impossible to determine the reasons for what seems to be incongruent, based merely on the results of the survey. One should keep in mind that surveys deal with the respondents' perceptions. And perceptions relate to people's moods. It is possible that in 2003/2004, when the Internet still represented more of a novelty to many, in Brazil, the fascination of the web's potential prevented some respondents from having a clearer and more realistic understanding of the actual situation. Further research would be required, however, to confirm this speculation.

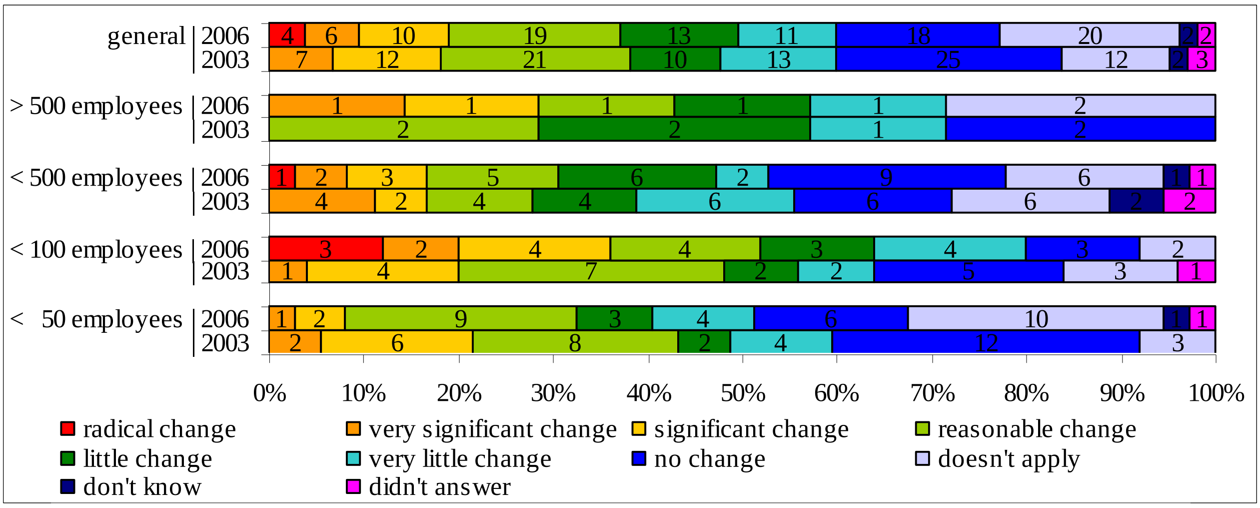

Figure 2 Perception of change caused by the Internet and other IT on the design of products

The answers with respect to the design of production processes (see Figure 3) followed the same pattern as those for the design of products (presented in Figure 2), although with less intensity for all sizes of companies. This may result from the fact that Computer Aided Design software (CAD) is usually focused on the development of products and not processes. There are only a few software tools dedicated to the development of production processes, with the possibility of simulating production capacity, identifying bottlenecks and other features that are important for the definition of the best way to produce something.

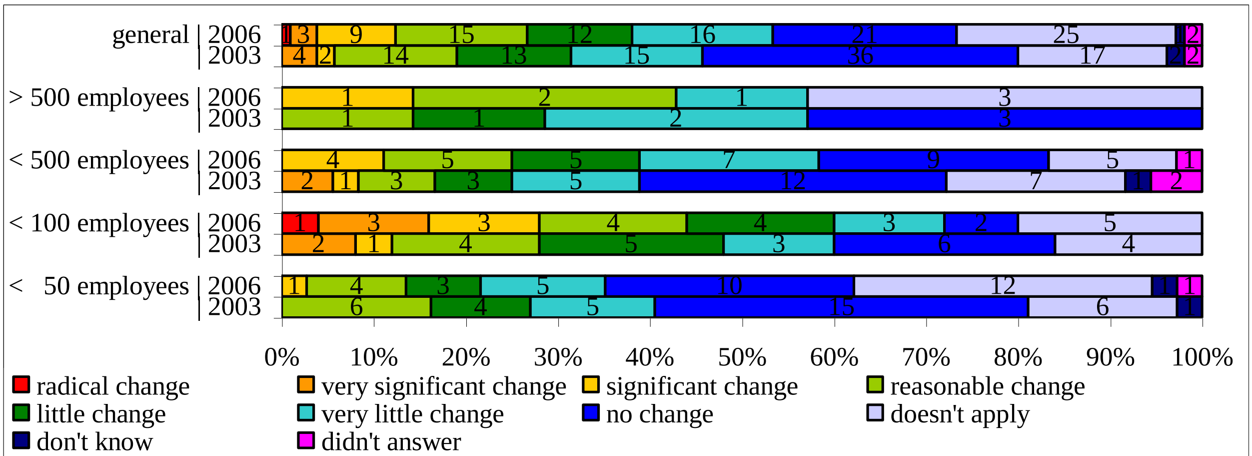

Figure 3 Perception of change caused by the Internet and other IT on the design of production processes

As it was discussed before, simulations may replace physical prototypes, shortening design cycles and reducing costs. The surveys contained a question about the intensity of use of design approaches that simulate the several stages of the design life cycle. Figure 4 shows that large companies are more concerned about this possibility than smaller ones. This probably occurs because of the high cost of software tools with that kind of functionality and/or due to the need of advanced knowledge in order to use the features of such computer programs, which are beyond the possibilities of small companies.

It is also important to note that there seems to be a trend of amplification of the intensity of use of computer simulations for design purposes, as the boxes that comprise the bars for 2006/2007 are wider at the left of the graph than those for 2003/2004 in Figure 4.

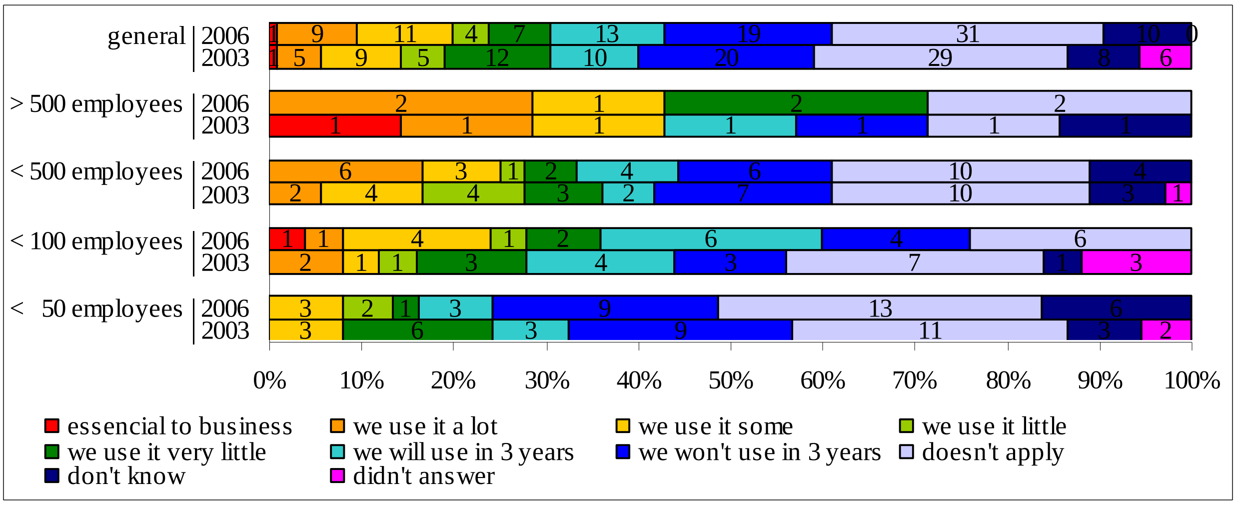

Figure 4 Perception of the intensity of use of simulation based design

A similar pattern to that obtained for simulation based design (shown in Figure 4) was achieved for the use of virtual prototyping (see Figure 5). It couldn't be different, as simulation based design depends on the creation of virtual prototypes that are used in replacement of physical ones, traditionally used to test characteristics of the products before they are manufactured in large scales.

In fact, the perception of the intensity of use of virtual prototyping evolved even at a faster pace than that for the use of simulation based design. Note that the fact that there is no intersection of light blue boxes for the answers to the questionnaire in 2003/2004 and 2006/2007 (with the exception of very small companies) shows that all companies that intended to use it within 3 years, when the first survey was applied, did so and even some that weren't expecting that have started using it by 2006/2007.

The use of virtual reality was not expressive. Only 3 out of the 105 companies that participated in the 2006/2007 survey stated that they used computer simulations to provide visual, audio or tactile sensations used for design purposes to an extent they considered it very important or essential to their businesses. It is interesting, though, that none of the companies had that perception in 2003/2004. At that time, only 5 companies said that they intended to start using the technique within the next 3 years. Eleven of them say they did it, in 2006/2007, and 13 say they will do it within 3 years from now.

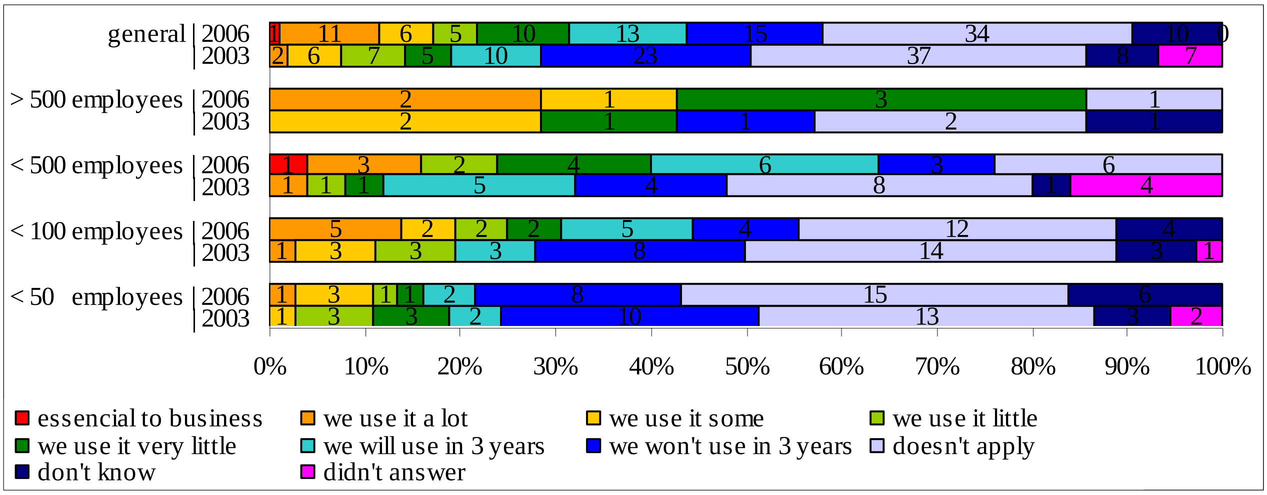

Figure 5 Perception of the intensity of use of virtual prototyping

At last, companies were questioned about the use of tools that allowed for collaborative work of design teams that were physically dispersed. Although results show little use of such resources (see Figure 6), once more it seems that there is a trend towards a more intense use of that in the future, something that will have to be confirmed by further research, considering that the current levels of use are still very low.

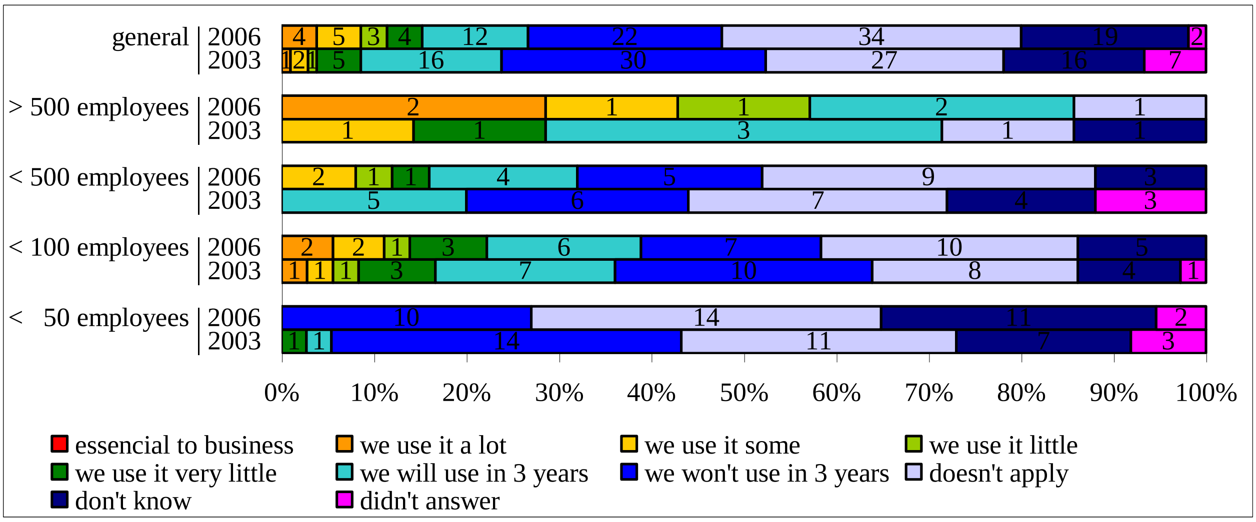

Figure 6 Perception of the intensity of use of workflow and other techniques of collaborative work

With respect to the data in Figure 6, one thing that calls the attention is the fact that the percentage of companies that do not intend to use workflow tools within the next three year decreased in the 2006/2007 survey. On the other hand, the number of respondents that now state that workflow doesn't apply to the company's situation increased. As that happens in parallel to an increase in use of the tool, it may reflect a better understanding of its potential benefits for team collaboration and of its limitations.

CONCLUSION

Surveys are very useful tools in collecting data for scientific research analyses, particularly in cases of projects of broader scope, developed with the intent of achieving an overall understanding of the phenomenon under study. This paper was concerned with one of the several areas in which the Internet can contribute to changes in the way manufacturing companies do things. The fact of the same survey having been applied to the same companies after a pre-determined period of time, allowed for time to be considered in the analysis, which is very important for a study on the adoption of new tools and practices.

But, if on one hand surveys enable large amounts of data to be collected, usually without great effort if compared to other methods, on the other hand, in certain circumstances the collected data is not enough to allow researchers to deepen the analysis, demanding other tools to be used for conclusions to be taken. As data collection for this study restricted itself to the two surveys, not having been complemented by other techniques, we are probably faced with the paper's major limitation, but also a rich source of ideas for future work.

The choice of a time interval of 3 years between the two surveys had the purpose of checking if the expectations of the participants, captured in 2003/2004 had converted into action. Some of the questions in the survey, particularly those dealt with in Figures 4 to 6, included the possibility of the respondent to tell if the company intended to use a tool, practice or technique within the next 3 years, in case it still didn't do so. The authors of this paper were particularly curious about the evolution of the scenario with respect to the "intentions for the future", considering that intending to do something doesn't imply having to commit resources for that to happen, which makes it much easier to foresee future actions than actually performing them. There was an expectation that at least part of the companies' intentions didn't become reality. However, the analysis of the collected data contradicted that expectation, in many cases.

There were, indeed, a few situations for which the responses of 2003/2004 were optimistic with respect to the future use of the surveyed issues, but that was not the rule. In other cases, the adoption of new tools happened at a faster pace than anticipated, as happened with the use of virtual prototyping.

Several issues were raised along the analysis as requiring further research and not allowing for conclusions based just on the evidence that was collected. Each of those issues can be individually further explored, by means of case studies or interviews with specific respondents, in order to achieve better understanding of the situations.

The authors consider that the results obtained in this study represent good evidence of the evolution of the use of the Internet and other IT for design purposes by manufacturers in Brazil, although far from reaching its full potential, especially in the case of smaller companies.

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