TOUCH AND DESIGN

TEST CASE EVALUATION REPORT

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Abstract
This document summarizes the activities related to the T'nD system testing and evaluation performed in the last six months of the project.

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1. Executive Summary

The aim of WP7 was to test and evaluate the T’nD system. In order to do that, PsyCLE has proposed a methodology based on the assessment of the system usefulness and usability, as compared with more classical modelling practices and tools. First, these two types of ergonomic principles have been defined, and then they have been applied for T’nD system evaluation. Some test cases have been defined with the contribution of the project end users, and then implemented. Thirty master students from PoliMI and UdG participated in the experiments. Three groups were organised; each group was asked to use specific modelling tools for accomplishing the tasks: physical modelling, CAD modelling and T’nD modelling. Two modelling tasks were assigned to users: create a representation of a given laptop cover, and create a free model of a computer mouse.

The results have been analysed considering two main aspects: quality of the model created and usability of the T’nD system. The description and the results of the testing sessions are presented in this report. On the basis of the analysis of the testing results some considerations and suggestions for system improvements are made. The analysis of results pointed out usability problems, partially related to some technical problems that the system still have, as well as related to the necessity of having a longer training in order to be able to fully deploy the system functionality and proposed way of working. In addition, some interviews have been made to T’nD end users in order to understand what they think about the developed system, their participation to the project and the deriving possible benefits.

A conclusion is that T’nD is not merely a computerized scraper or digital sandpaper. It is a brand new tool, requiring new skills. In our evaluation test, participants were given an exceedingly short, and actually insufficient training prior to using T’nD. Comparing T’nD outputs with the outputs of two other techniques, in which the testers were thoroughly trained, was rather unfair towards T’nD.

We may conclude with the following consideration. The T’nD project started with the intention to mimic some physical manual activities in order to exploit the existing skill of modellers and designers. The system we have implemented has actually some weaknesses but an intrinsic higher potential than simply mimicking a real tool. This has raised major problems since we "limited" our self in the testing use cases to the simple reproduction of the traditional manual operations, and only on this basis we have evaluated the quality of results. The potential of the system should be further exploited.

2. Introduction

WP4 deliverable *D6 – Definition of Scenario and test cases* defined a potential scenario and set the test cases to be run at the end of the project in order to validate and evaluate the T’nD system. At that time the IT partners’ point of view concerning shape modelling and haptics technology, was carefully considered in order to drive the end users requirements along a realistic implementation path.
On the basis of their input in fact, a set of feasible functionalities and technological solutions were identified. These were supposed to be satisfied by the T’nD system prototype within the Project timeframe. The aim of TnD was to facilitate users’ interaction with virtual models in order to modify and feel shapes by means of the haptic tools conceived in the project.
Basically, the consortium intention was to study modellers’ activities in order to identify significant actions referable to the physical modelling work. The priority was to enable the use of haptics to translate design intents into sculptural actions: the interaction between user and tools rather than the interface with the virtual space was judged essential in order to capture modellers’ intents through motion and let the system automatically realize the desired contours.
The consortium deemed that among other, sweeping techniques would have played an important role in shape modification within the project frame. The technique was not new but its utilization in quality shape modelling was still imperfect due to:

- difficulty to define actions which convey to desirable shapes.
- mathematical complexity to express the result of the sweep in a way that can be reused in downstream treatment.

To support the above difficulties, psychophysical research activities have been launched since the beginning of the project in order to find out jointly with the users’ possible breakthrough solutions.

2.1. End user expectation and requirements

The main expectation was to get a tool that on one side aids the designer to translate with greater facility and immediacy their design intent; on the other side, that the mathematical output returned by the system was used in real-time within the process.
In other words, end users wanted to understand whether the haptic technology could be used to create models of top quality surfaces through a natural interaction by using the T’nD system.
They wished to use the system within the digital flow of the design process, thus decreasing the number of physical models that are required today. One possibility for instance, is related to the transition from 2D to 3D phases throughout styling definition: the challenge for the novel system is to become a real alternative to the clay model.
An additional request was related to the possibility to re-use data for iteration and evaluation loops: surfaces resulted from T’nD work sessions should represent high-quality and manageable outcomes to be passed to the other phases of the process chain for subsequent design activities.
At last, the possibility to implement innovative work-flows was guessed too: the desire was to link companies’ know-how to experts’ manual ability in order to optimize standard developing methods and procedures adopting the new interfaces.
In order to measure the achievability of project objectives and validate the technology, end users provided the consortium with some test cases (i.e. handled vacuum cleaner, automotive “C” pillar) which were modelled with standard manual methods and were supposed to be remodelled at the of the program with the achieved prototype.

2.2. Implementation of the testing sessions

Since the beginning of the project it was clear that the potentialities offered by the novel modelling system might have lead industrial partners to improve and fasten their product development workflows.

It is a general feeling that the developed system still keeps the expectations conveyed in the project proposal. Evidently, it shows some problems related to the fact that the technology is really at an early stage, and therefore not yet usable for daily activities. Actually, the goal of a research project developing new technologies and processes is first of all to prove the proposed concepts and feasibility in order to start up an industrial exploitation targeted to reaching the full functionality and cost/performance values of a product that allows industrial partners to stay and win in the marketplace.

The prototype developed is characterised by the capability of producing surfaces having very good quality, and by supporting a very natural and friendly force feedback.

We may affirm that the major problems of the T'nD system are related to ergonomics issues. In fact, the system cannot be considered satisfactory because of the following criticalities:

a) views changing: the virtual tool goes out of perspective when rotating the model thus making the work troublesome;
b) very low perception of the scraping tool position in the 3D workspace;
c) lack of precision due to device instability and initial inertia when in converting designer gesture into model modification;
d) limited motion possibilities of the haptic tool in the working space.

The above items a) and b) impact the system usability perception. These problems could be easily removed by improving the graphical user interface and adopting stereo viewing. Unfortunately, it was not possible to implement appropriate improvements mainly because they would have had heavy impact on the software architecture of the system, and on the underlying basic decisions taken in order to facilitate and deploy the industrial exploitation. In fact, one of the basic architectural choice that was made for deploying an early exploitation of the modelling techniques being developed concerned working directly on the think3 software environment instead of building a self-contained T'nD prototype. On one side, this choice demonstrated to be a great advantage for reducing the effort and favouring the exploitation of the modelling technologies developed; in fact, some of the results have already been integrated into the current commercial version of think3 products. Conversely, the drawback related to this choice was the impossibility of modifying the architecture, and the consequent necessity of working with the degrees of freedom provided by the current version of the graphical user interface (GUI). Actually, it must be reminded that the main target of the T'nD project was to develop haptic devices to add to a CAD system that already has complete and sophisticated graphic and rendering functionalities. As a matter of fact the Consortium underestimated the influence and issues of visual and haptic integration, mainly froma usability point of view. The architecture of think3 GUI, which was not conceived for the introduction and integration of haptic devices, did not allow us to easily and properly integrate some functionalities available (stereo viewing, shading of objects, etc.) in a manner that was necessary for getting an easier and more user-friendly user interface for the T'nD prototype. The results of the study concerning the GUI are part of think3 exploitation plan, and in fact the GUI of think3 new released products are based on them.

The above items c) and d) reflect a similar situation related to the haptic devices used. The choice of using two HapticMaster systems for getting a more powerful platform for the development of the new devices (more DOFs) generated the intrinsic technical problem of dealing with two devices. Each device has its own control and does not know to be physically connected to a second one. This solution is the origin of the intrinsic instability of the system that could not be fully eliminated during the development of the T'nD prototype. The comprehension and results of the study of these problems are part of FCS exploitation and consist of a new product under construction and of a new system with improved mechanical characteristics and a unique control.

3. Ergonomic evaluation principles and their application

Ergonomics deal with the adaptation of tool systems to users' characteristics. The system must fit as close as possible human physical skills. Furthermore, since the use of technological devices is always driven by cognitive processes, the system must also closely match cognitive skills and processes of the users. Such requirements are necessary in order to reach a system with a high level of performance regarding both the usefulness and the usability.

Usefulness is determined by the fact that the system allows the users to perform the tasks it was designed for. A useful new system should be, at least, as efficient as existing tools for performing the same tasks or it should offer new functionalities as compared with existing tools. In accordance with industrial practices, the T'nD performances were compared with classical situations of physical modelling and CAD (Computer Aided Design) modelling. The quality of the resulting shapes is another parameter to consider. For what concerns the comparison of the quality of the results obtained, it can be performed at various levels: we may consider the final shape of the object, and also the mathematical quality of the created surfaces.

Usability refers to easiness in using the system and, especially, it aims at determining whether the use of the tool is handy, comfortable and easy to learn.

3.1. Usefulness

The T'nD project aims at developing a new 3D modelling tool intended for designers. Accordingly the T'nD prototype should allow designers to model as efficiently as already existing modelling methods do, i.e. physical modelling and CAD modelling.
The modelling efficiency can be measured with regard to two main criteria:

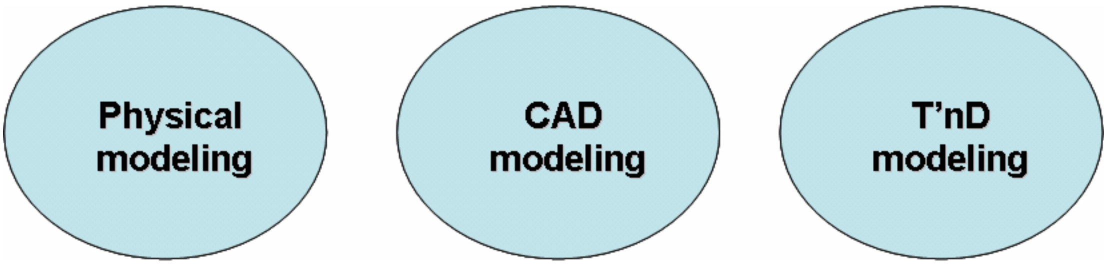
- the overall time needed for the modelling activity;
- the quality of the models produced by designers.

With regard to these three situations, which we considered relevant in an industrial context, a test-case was set up and performed, within a rather stringent and systematic experimental comparison.

Three experimental conditions were defined, with respect to modelling tools: physical modelling, modelling with CAD and modelling with T'nD.

Three groups of participants were constituted on this basis, assigned to the performance of the same modelling tasks while using different tools:

- a classical physical modelling tool (group 1)
- a classical CAD software (group 2)
- the T'nD prototype (group 3)



T'nD was to be evaluated by comparing the modelling process (in terms of overall time needed for performing the tasks and quality of model) of the same objects according to each of these three conditions.

Each group of testers was assigned two modelling tasks:

1. the first modelling task consisted in copying the 3D model of a laptop cover from 3-view industrial drawings.
2. the second task aimed at testing T’nD potential for creativity, by asking participants in every group to design a selected object: a computer mouse.

3.2. Usability

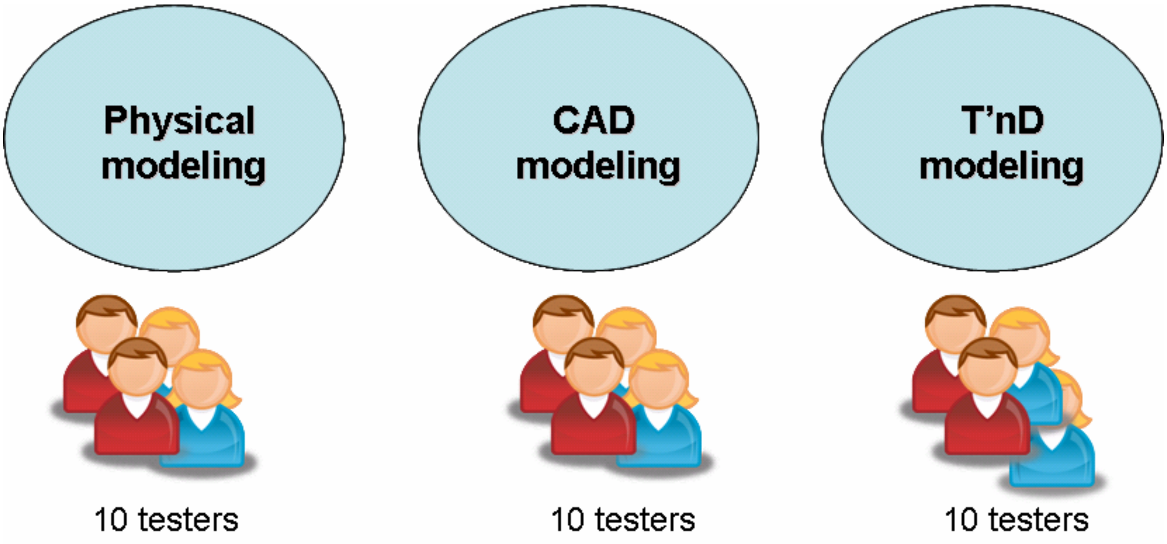
In order to assess the usability of the T’nD system, the activities of the designers in the 3 groups were video-recorded. These recordings and the consecutive analyses allow us to make an accurate description of the activities peculiar to each type of tool. Especially, the analyses aim at showing which aspects of the modelling process are critical in terms of time spent and number of actions required for performing the design tasks.
On these bases, the benefits and drawbacks of each modelling technique were compared in order to assess the T’nD usability. These results are useful for suggesting how to improve T’nD functionalities.

4. Test-cases

This section describes how test cases have been organized and performed. We describe the kinds of participants we have involved, the tasks and instructions assigned to them, and the tools and material at their disposal for performing the tasks.

4.1. Participants

Thirty master students in design participated in the experiment. Half of them came from the industrial design faculty of the Politecnico di Milano (PoliMI, Italy) and the other half from the industrial design department of the Universitat de Girona (UdG, Spain).
Participants were randomly assigned to one of the three experimental groups. Each group comprised ten participants: five students from PoliMI, and five students from UdG.
All these students were assumed to have the same expertise level and skill in classical modelling practices: physical modelling and CAD modelling.



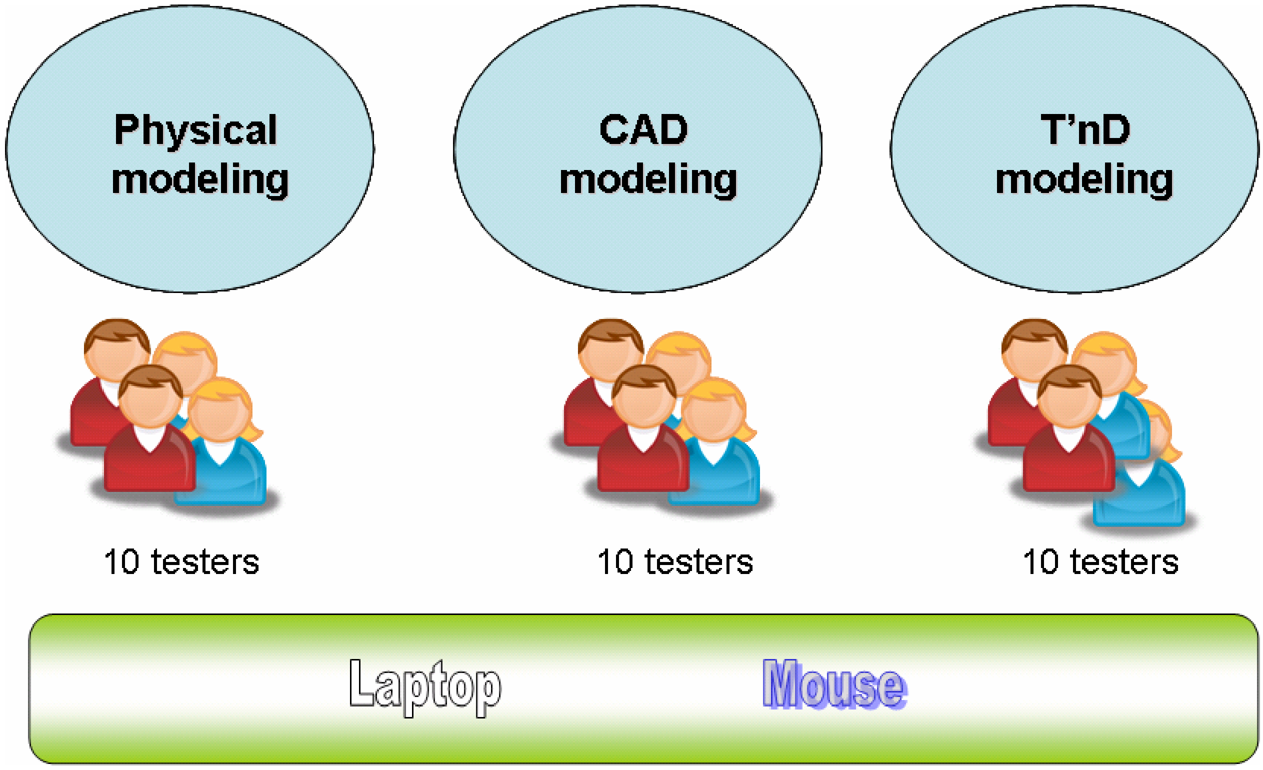
4.2. Tasks and instructions

Two modelling tasks were assigned to each participant.

- In the first task, the participants were asked to produce a 3D representation of a laptop cover using the modelling tool corresponding to their group. All of them were provided with 6 pictures showing the model of a laptop cover (see Annex I) produced by an expert designer from Alessi. They were asked to match the original model as close as possible.
- In the second task, the participants were asked to produce a free 3D solid model of a computer mouse. During this task, the participants were also allowed to sketch on paper before performing the modelling task itself.

The tasks and instructions were the same for each group. All the instructions were given in English. Participants could ask any questions they wished, both before and during the experiment.

The time allocated to each of these tasks was 30 minutes separated by a 5 minutes pause.



4.3. Tools and Material

4.3.1. Physical modeling

Participants in the first group were asked to perform the two modelling tasks using foam material. They were provided with standard craft tools to work on foam blocks: hotwire, electric saw, cutter, sand paper (strong, mild and soft), scissors, adhesive tape, pen and ruler. Some pictures of students making physical prototypes are shown in the following.

4.3.2. CAD modeling

Participants in the second group were asked to perform the two modelling tasks using CAD systems (some used SolidWorks, others used Rhinoceros), depending on the training they previously had. These two tools offer the same ability for performing the two experimental modelling tasks, even if they do not support sweeping techniques as provided by T’nD. They were provided with powerful PCs settled with 3200 MHz processor, 800 MHz bus and RAM 2048 MB. Each computer was powerful enough to avoid lags during modelling tasks.

4.3.3. T'nD modeling

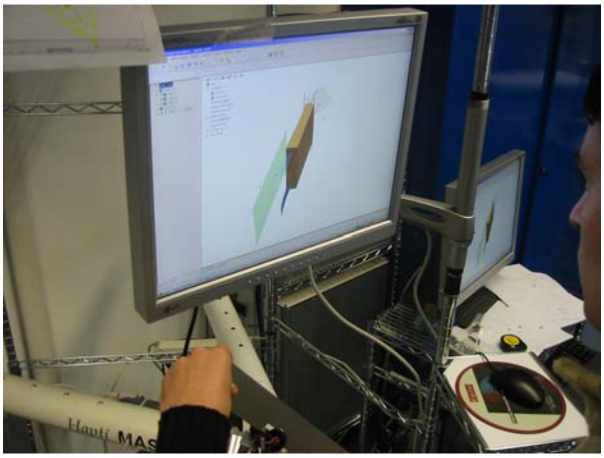
Participants in this third group were provided with the T’nD prototype to perform the two modelling tasks. Though the use of this prototype is intended to be based on abilities developed for physical modelling (especially some gestures) and developed for CAD modelling (e.g., the use of commands), using T’nD was new to them. Therefore, our objective was to determine to which extent the use of T’nD is intuitive for participants having no actual training in the use of this system, while being extensively trained in classical modelling methods.

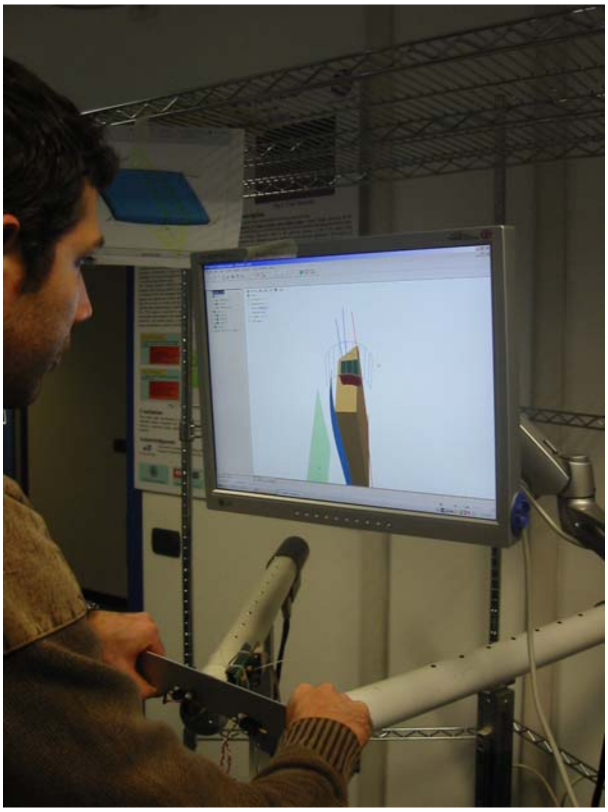
4.4. Data acquisition

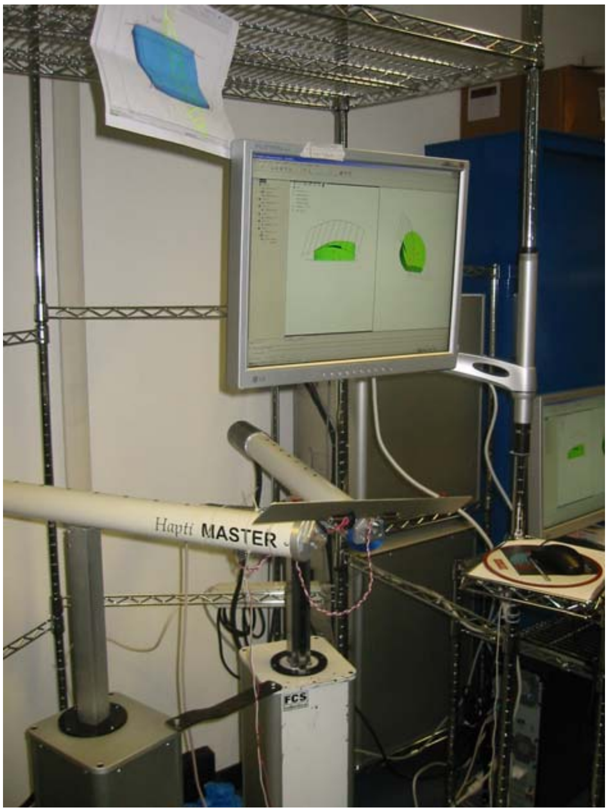
Data concerning the experiments have been video recorded, as well as comments made by the testers during the tests have been recorded. These data have been then carefully analysed by PsyCLE researchers, in order to provide an evaluation of the T’nD system. In particular, the following parameters have been observed and measured in the videos acquired:

- duration of actions and tasks
- number of errors performed by users (necessity to perform undo operations)
- snapshots of created models in order to evaluate quality of the shape

The following pictures show some testers using the T’nD system for creating the laptop.







5. Results

This section analyses the results obtained in the testing sessions. The results are analysed considering the following aspects:

- Quality of the models created
- Usability of T'nD system

The comparison of the shapes created can be done at various levels:

- Completeness of the final shape
- Quality (in mathematical sense) of the obtained surfaces.

From the analysis of the created shapes, we can affirm that, in general, the results obtained with T'nD are characterized by much better mathematical quality of the surfaces, but are not completed. This is mainly due to the fact that the filleting operator is not available in T'nD (and it did not mean to be). Actually, it has to be noticed that filleting is a typical activity that is done in a procedural way by using a CAD system, and can be seen as a post processing activity.

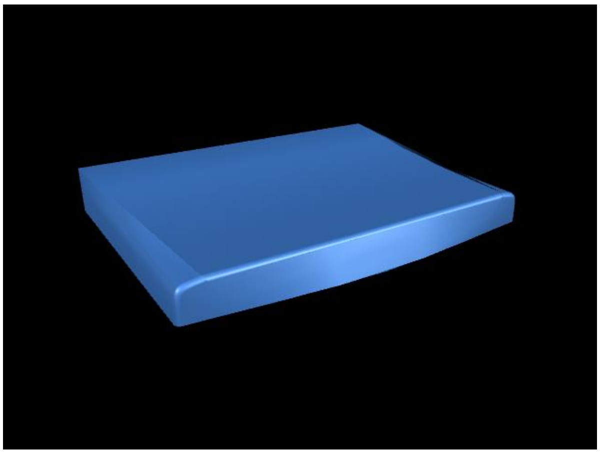
5.1. Models quality

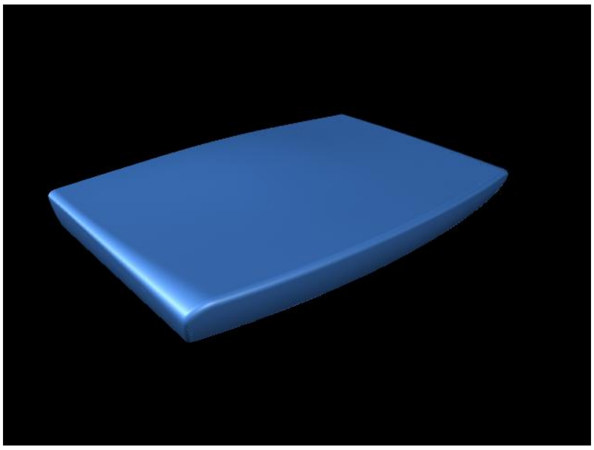
The first observations result from a comparison of the models produced in the three situations, for the two modeling tasks: laptop and mouse. The following sections report some pictures of the created models.

5.1.1. Laptop covers

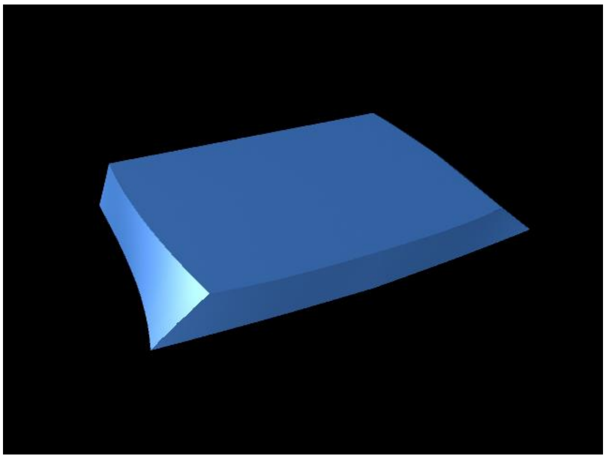
Laptop obtained with physical modeling

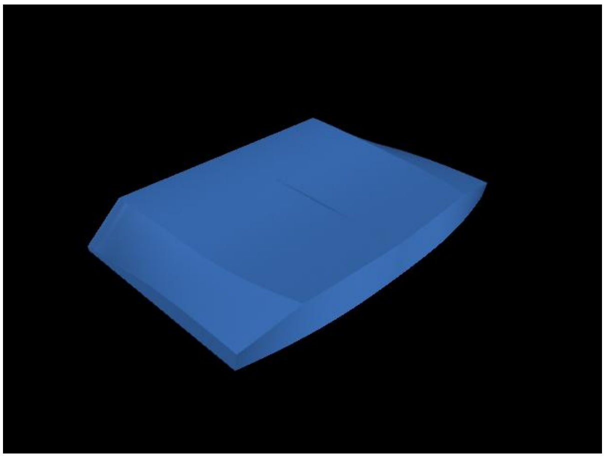
Laptop obtained with CAD modeling





Laptop obtained with T'nD





5.1.2. Discussion about laptop modeling results

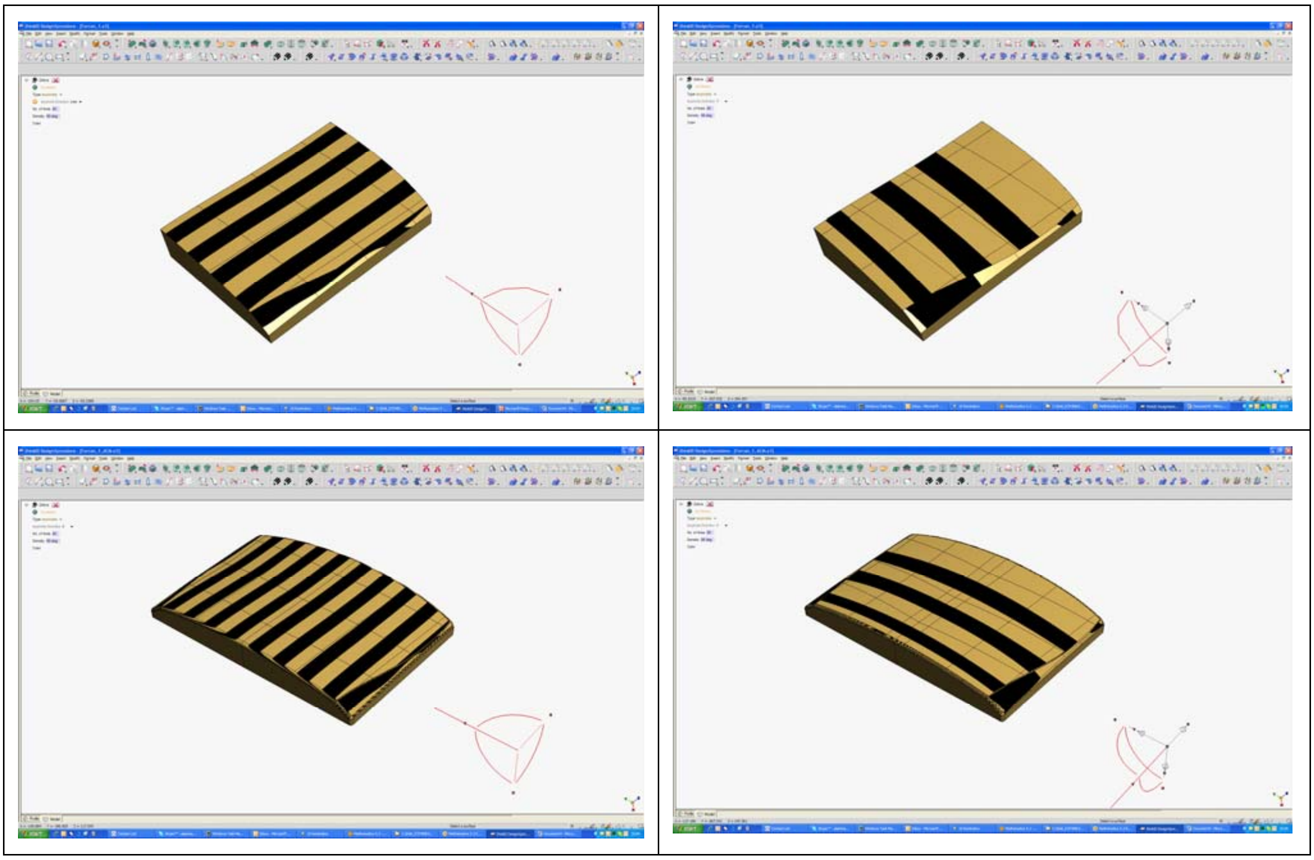
At a first glance the quality of the models made with T'nD is far lower than the quality of models made with CAD or physical modeling. T'nD models are very rough with sharp angles and are only remotely similar to the suggested laptop model (Annex 1).
In the laptop cover design task, the students had at their disposal haptic guides that helped them to compensate somehow the difficulty encountered while handling the T'nD prototype.

The following results, which were obtained in a free design task (without any guide) emphasizes the quality (evaluated visually) gap between models made with T'nD and the classical means of modeling.

Actually, a more careful and in depth analysis of the quality of the surface, performed using reflection lines functionality applied to the models created using a CAD tool (Rhinoceros) and the T'nD system has shown that the models created by the students with the T'nD system have in general a better quality in terms of surface curvature continuity and surface light reflection. The following pictures demonstrate these results.

Reflection lines applied to a model of the laptop cover created using a CAD tool.

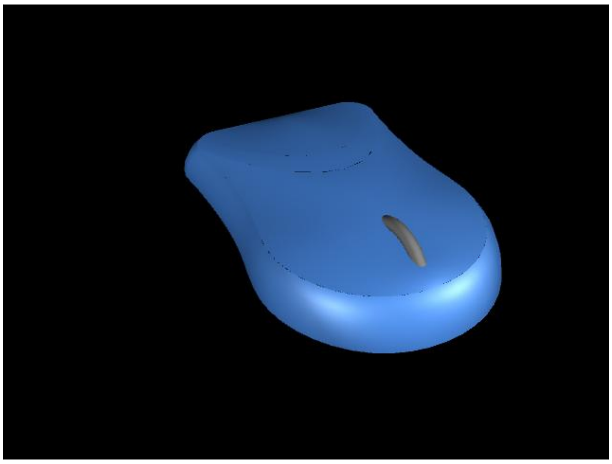
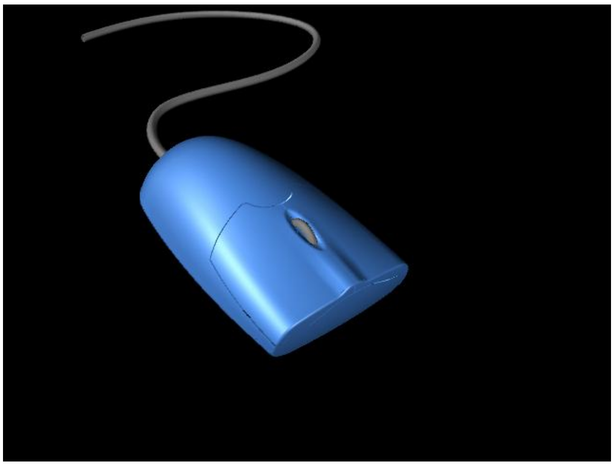
Reflection lines applied to a model of the laptop cover created using the T'nD system.



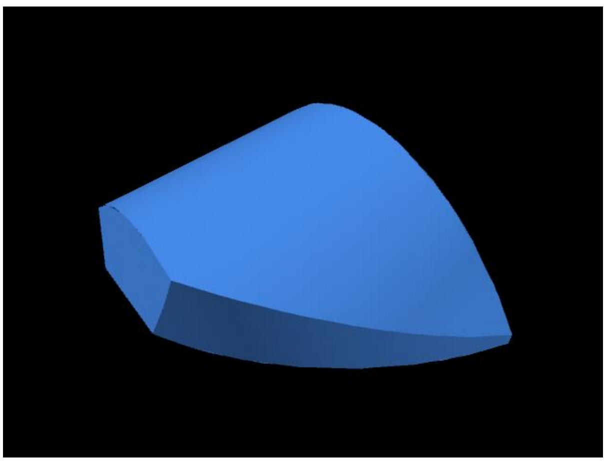
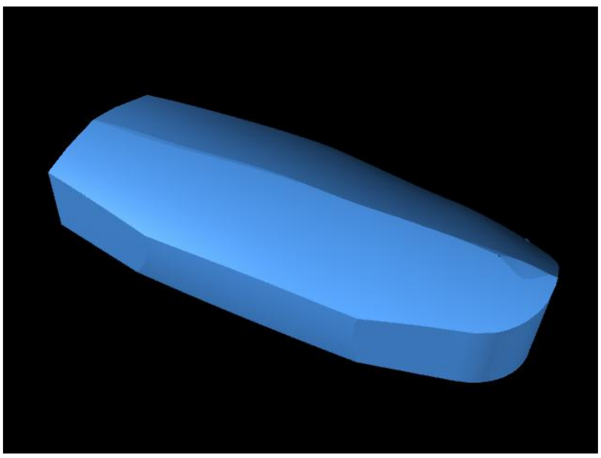
5.1.3. Computer mice

Computer mice obtained with physical modelling


Computer mice obtained with CAD modelling

Computer mice obtained with T'nD

5.1.4. Discussion about mouse modeling results

In the mouse task it appears that the participants were unable to model an object with a computer mouse appearance using the T’nD system. The resulting models are, again, very rough. Very few sweeps were made in the 30 minute sessions. It would be pointless to undertake any fine analysis concerning the quality of the models since the production level of T’nD is clearly below the classical modelling techniques.

However, there is little doubt about the usefulness of the T’nD system:

- T’nD offers a rather unique example of the alliance of computer technology accuracy and speed of operation with the vivid experience of manual work,
- such a combination of computer technology and manual operation offers the opportunity to take advantage of the professional experience of designers together with the aesthetical value inherent to their patiently acquired manual skills.

Therefore, in order to determine difficulties encountered by T'nD users in this user test, we analyzed usability issues that may constitute the major causes of the lack of quality of models produced with T’nD.

5.2. Usability analysis

From the analysis of video recording of the testing sessions we have identified three categories of usability issues, which are detailed in the following subsections: view control, haptic tool control and user interface navigation. Each of these usability issues result from a comparison of observations made in the three modeling situations.

5.2.1. View control

Figure 1 shows the proportion of view switching for each task (laptop or mouse), in each modeling situation (CAD, physical or T’nD modeling), with regard to the total duration of the participants’ global activities.

In the physical modeling situation, changing one’s point of view on the model represents only 3% of the total activity time. The designers can freely move around the model or move it with their hands. Thus, view switches are almost instantaneous or simultaneous to other modeling actions.

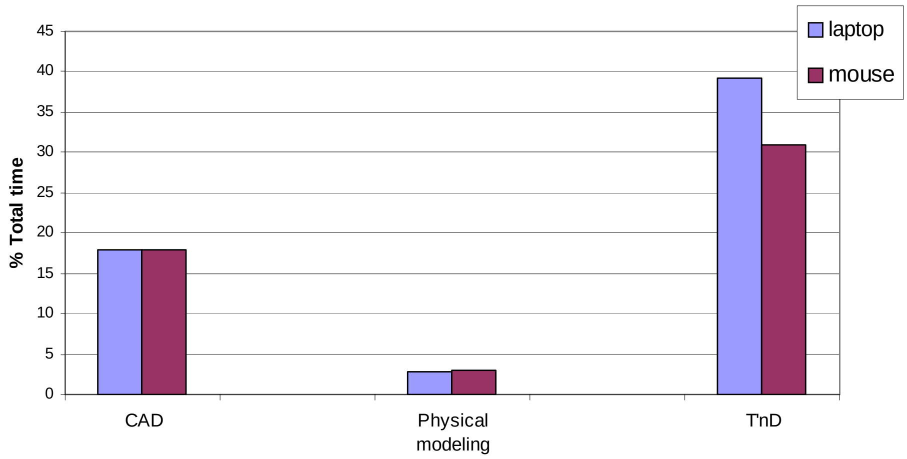


Figure 1: Proportion of view switching according to the modeling situations and the tasks to perform.

Both in CAD and T'nD modeling situations, participants use a computer screen display for representing the models. Changing of views in these conditions appears to be more time consuming and less intuitive than in physical modeling situations, since the users have to manipulate a computer mouse in order to rotate the model on the screen.

View changes with T'nD requires about twice as much time as performing the same action with a CAD software (from 18% with CAD to 39.2% with T'nD while modeling the laptop). This was unexpected since CAD and T'nD systems use the same visualization method.
The analysis of the recorded data shows that the problem is related to the fact that when the user rotates in T'nD the view using the mouse, as it would be the case with a standard CAD software, the virtual representation of the haptic tool rotates too. As a consequence the tool moves out of the user's perspective. Therefore, the user has to perform some additional operations in order to align the virtual tool and virtual object. That is, he has to rotate the view back in its initial position and use a set of non intuitive commands to rotate the view along X, Y and Z axes in order to keep the virtual tool in perspective.

Consequences also appear on the mean time required, for each view switch (see Figure 2).

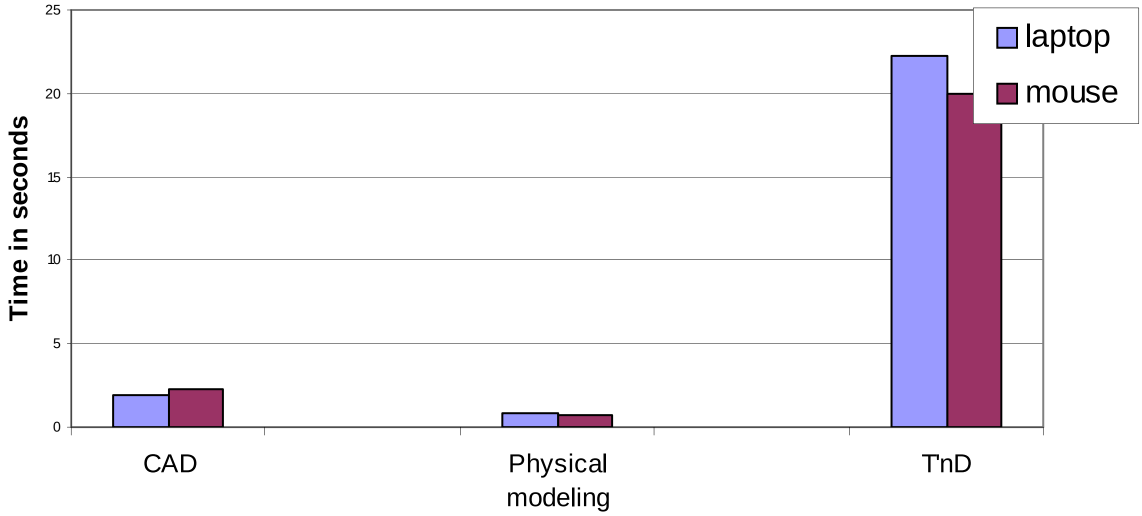


Figure 2: Average time for each view switch according to the modeling situations and to the tasks.

Suggestions for improvements

On the basis of these results, we suggest some improvements for the future release of T'nD prototype:

- A first improvement would consists in the virtual tool staying in perspective, whatever change of view the user wishes to make. This would bring T'nD performances close to CAD performances.
- A second improvement would result from using the haptic tool as a metaphoric camera in order to switch views. An intuitive use of a 6 DOF device for freely looking around the virtual model could bring T'nD performances above CAD concerning view changes.

5.2.2. Haptic tool control

During the experiments, we observed that the users were somehow uncomfortable with the use of the haptic tool. They spent a large amount of time trying to figure out the exact position of the tool in the 3D workspace (see Figure 3).

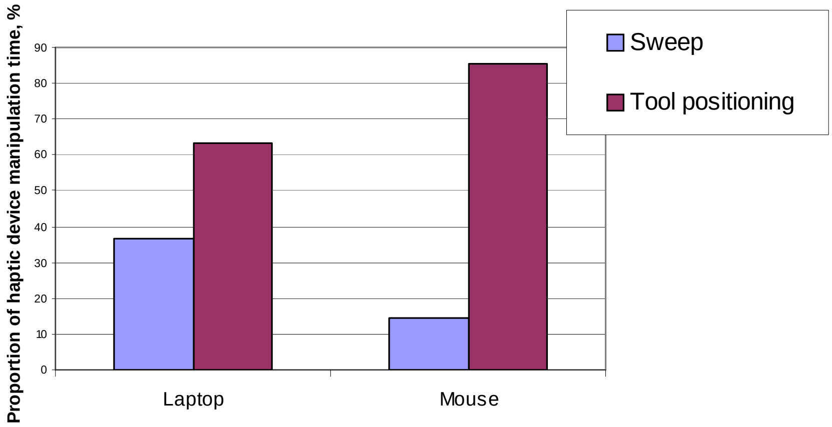


Figure 3: Proportion of sweeps and tool positioning with regard to haptic device manipulation time

These results show that the main proportion of the time is used in positioning the haptic tool, rather than in removing material. This is especially the case in the mouse design task (85.6% of positioning) since the users had no guide to help them positioning the tool. In physical modeling conditions, tool positioning is extremely fast and can be considered as instantaneous.

The cause of this problem might lay in the use of a 2D screen to represent a 3D haptic workspace: T’nD users seem unable to clearly understand where the tool stands, regarding the solid to be sculpted.

In addition to this problem, the haptic tool suffered frequent instability problems that caused it to shake, especially when getting close to the surface of the model.
As shown on Figure 4, the shakiness and the lack of perception of the tool position make T’nD error prone in the first instants of material removal.

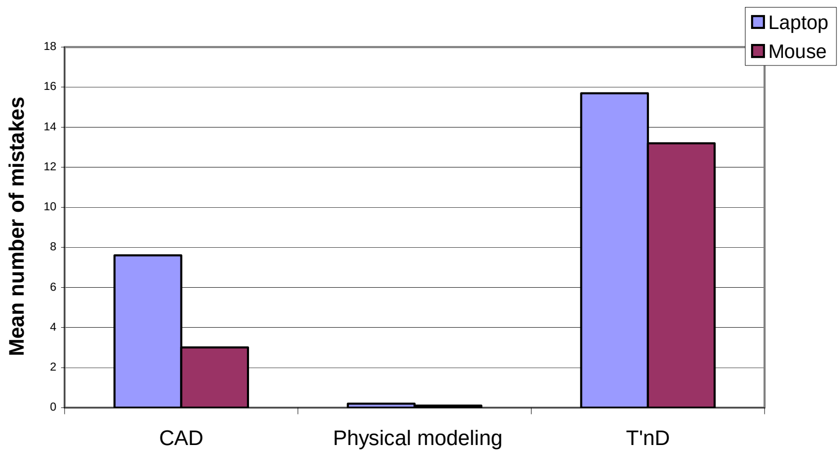


Figure 4: Mean number of mistakes immediately followed by "undo" actions according to the modeling situations.

Suggestions for improvements

Participants in the physical modeling condition worked on foam material. This material hardly allows correction of mistakes, which is why very few corrections were observed during our experimentation for this group.
CAD and T’nD share the same error correction method: the use of an "undo" command allowing the users to step back in their modeling process. However, errors while attempting to modify the solid occurred twice as much with T’nD than with CAD. Since the correction method is the same for both tools, this shows how much errors are made while trying to control the tool motion.
This problem could be solved by eliminating the shake bugs, and, possibly, by using stereoscopic viewing in order to give to the user an understandable representation of the tool position.

Another possibility could consist in providing T'nD users with a referential, which would show schematically the position of the tool relative to the object being sculpted (see Figure 5). This might help the user in deciding where the tool is and how to move it with respect to the object.

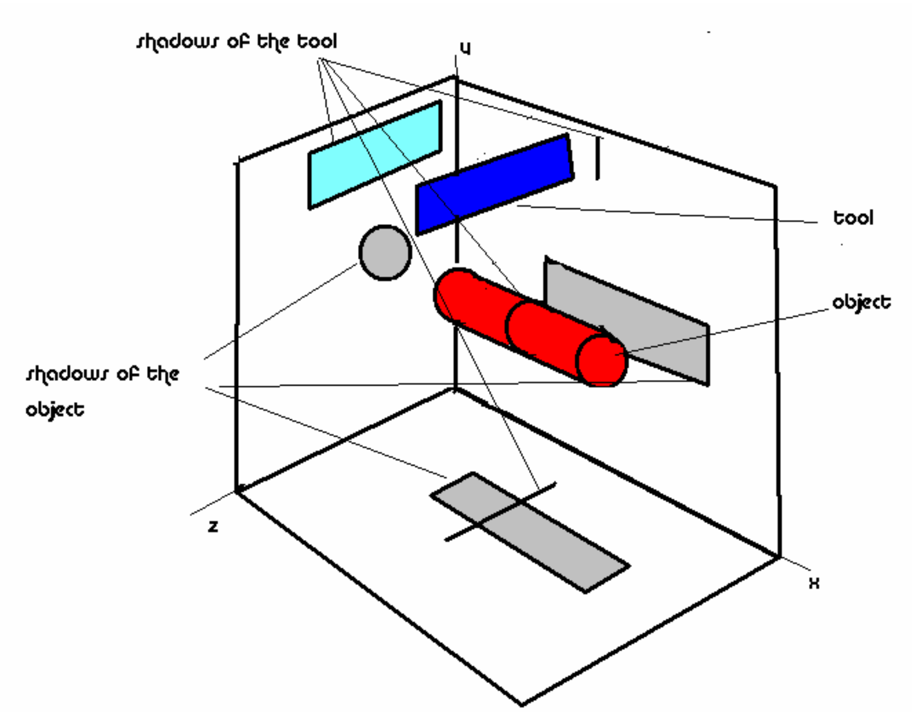


Figure 5: Schema of a position referential.

5.2.3. User interface

"User interface" is used here to designate the tools designers can use for their modelling activities. For instance, in the physical modelling situation, the user interface includes the workbench and all the sculpting tools. In the CAD and T’nD situations, the user interface is mainly composed of the menus and options, offered by the software used, to select virtual tools or type of actions.

As shown in figure 6, the amount of time used to set up the right tool is extremely dependant on the user interface type.

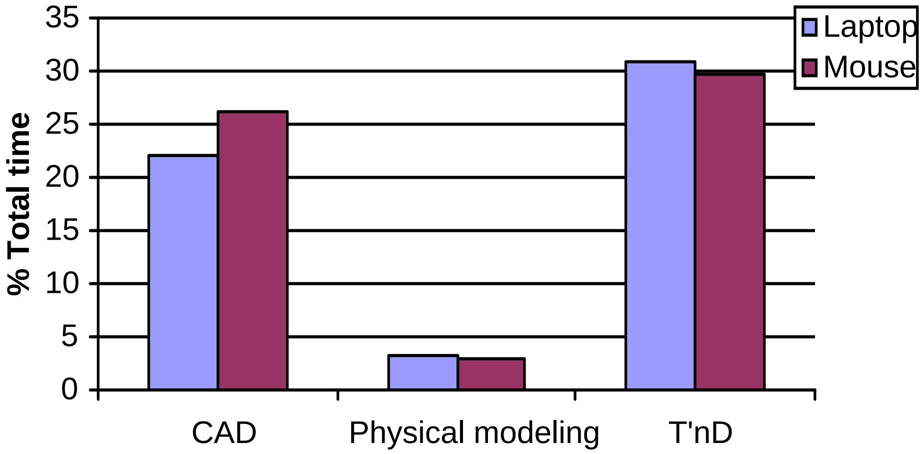


Figure 6: Proportion of menu navigation or tool changes with regard to the global activity duration.

The action of changing tools is far more time consuming with CAD and T'nD systems than with physical modeling tools. This can be easily explained since, with CAD and T'nD systems, the user has to go through various sets of menus rather than just picking a tool on the workspace in physical modeling situations.

However, T'nD users spent 25% more time for choosing menus than CAD users. This was not expected since, in our test case, the T'nD device offered a restrained set of classical CAD commands. Therefore, we analysed in details the use of menus made by T'nD users.

Based on our observations of the T'nD testing sessions, it seemed that the users spent a large amount of time selecting and activating haptic constraints. In order to test this hypothesis, we subdivided data related to the menu navigation into two sub-categories (see Figure 7):

- menu navigation used to select haptic constraints.
- menu navigation concerning every other aspect of the modelling activity.

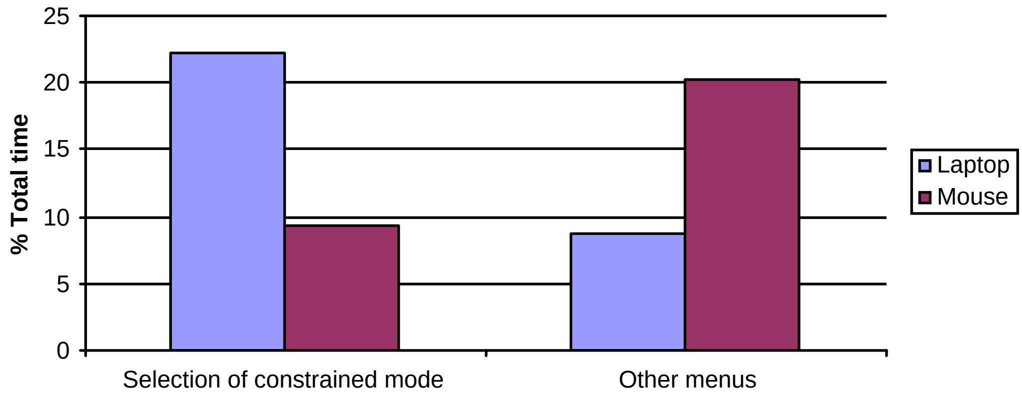


Figure 7: Navigation time with regard to T'nD menus and according to the tasks.

Concerning the laptop modeling task:

The participants were provided with curves and planes, loaded in the workspace, to be used as haptic guidance in order to help them in designing the laptop.
Setting up the constrained modes of T'nD (G0, G0-G0 or G1) in order to actually make use of these guides took more than 22% of the total activity time. This is due to the selection method. For instance, to select G0-G0 the user has to select:

1. sculpt mode,
2. G0-G0 mode,
3. the solid,
4. the first curve,
5. the second curve,
6. apply and finally unlock the haptic device.

Thus, many steps are required for a common action. Moreover, this process has to be done each time the user wishes to change constrained mode or wants to save his/her last sweep.

Concerning the computer mouse modeling task:

For this free task, participants were provided with no haptic guide. Since the haptic device is not easily handled, the participants, for most part, wished to make their own haptic guide for designing the mouse. This explains why they spent 20% of their time using other menus of the T'nD software.

Suggestions for improvements

To solve the above mentioned problems, the selection of constrained modes should be improved to a more intuitive process. For instance, the software could infer by itself the constrained mode that the users wish to use depending on the type of haptic guides selected.
Another possibility to investigate would be the use of vocal commands for selecting the desired constrained mode.

6. Interviews to T’nD end users

An interview has been made to T’nD end users with the aim of knowing how each of them evaluates the developed system, their participation to the project and the deriving possible benefits.
In particular, we were interested to know how they evaluate the achieved results:

- modeling functionalities
- haptic interfaces for scraping, sanding and exploring virtual clay
- integrated system
- new vision for shape modeling based on haptics

in respect to products and/or process typical of their company, considering these aspects today, tomorrow and at long term.
In the following, the comments given by the three end users Alessi, Eiger and Pininfarina are reported.

6.1. Alessi’s interview

This interview has been made to Cristiano Colosio from Alessi.

Participating to the T’nD project has allowed Alessi to consider for the first time a practice based on modeling through the use of the hands for directly interacting with the virtual object, which is the dream of all CAS operators. In fact, it always happens that since the first moment when any designer learns how to use a CAS tool, works and becomes experienced in it, he always dreams to be able to interact with the forms as if he would model them with his own hands. This is confirmed by the fact that a user who works together with other people (usually designers), is used to use gesticulation for explaining and making explicit how some forms have to be built or modified. In addition, he would like to touch what he has done digitally.

Nevertheless, during the three years of T’nD project, and in occasion of the various tests performed using the integrated system, Alessi’s people have often met some operational difficulties that make difficult to think of using the system on a daily base. However, the experience was indeed very useful in order to become aware of the limits of a system as T’nD, and consequently of the areas of possible improvement, but also of the potential of the haptic technology.

The first approach with the T’nD system, which occurred at the end of 2004 as soon as the first prototype was ready, immediately made us understand which was the possible product domain for its use, in terms of formal definition of a product. In fact, it was immediately clear to us that our initial desire to be able to model our test case "vacuum cleaner" using the T’nD system could not be satisfied because of the continuous variation of the section of the object. The T’nD system can still be used where the profile to be moved can be considered constant. Despite this limit the user can define a large set of completely different shapes having different “moods” and sections.
Considering our initial test case, this may appear to be a limit. Anyway, it becomes a plus whereas the shape quality is looked for, in terms of definition of the surface, and where it is allowed by the topology. In fact, the sweep surface obtained in T’nD by imposing some drive constraints, guarantees a very good quality result, in terms of reflection lines. Therefore, we may state that T’nD system finds its primary use where the object is obtained by means of sweep surfaces.

During the various tests carried out at PoliMI we experienced some usability problems. In fact, we realized that it is quite difficult to work with the T’nD system where the haptic tool, mainly due to space problems, is positioned exactly in front of the operator, while the video is in a higher position. This configuration causes a skew among the gesture done for moving the haptic tool and the operator’s sight. It is a little bit like you are writing but in the meanwhile you are looking to something different from the sheet where you are writing on.

The users consider very pleasant the feeling of working on a "real" object. After the haptic system and the software have been integrated, we have to recognize the notable sensibility in rendering the strengths both of few grams that of superior entity.

We think that a more detailed evaluation of the system may be done separating three aspects of the T'nD system:

1. Geometric modeling of the surfaces
2. Haptic system for scraping and sanding
3. Integrated system

For what concerns the various components of the system, we can say that some of them are ready to be industrially used, while others need further research and/or development in order to become suitable for an effective use in an industrial environment.

Geometric modeling of the surfaces
T'nD has introduced a new way for creating some surfaces through sweeping operations starting from a section (which is the T'nD scraping tool) which can be freely moved in space or supported on some guide curves. This is surely interesting and still nonexistent as method for the generation of sweep surfaces in most CAS/CAD application. The surfaces created inside the CAD system thinkdesign used in T'nD are of extremely high quality, and appropriate for the modelling of objects where the creation is mainly based on sweep surfaces, which is especially typical in the cars sector. It is obvious that the result is tightly tied up to the quality of the curves of support and to the section, and to the types of ties to the section during the translation on the guides (G0-G0, G0-G1). In the case in which everything is compatible, the result is assured. In a lot of cases, this method resolves the problems of quality. The result is a surface of class A, where the curves of reflection are of extremely high quality. Since Alessi uses thinkdesign we already have available inside the system this new environment of modelling through sweep. The added advantage that we may think of obtaining by using this practice based on the T'nD system is the possibility to move the section, in line with the imposed ties (scraping tool) exploiting the designer's own sensibility, and therefore guiding the generation of the surface through movements made by the user with his hands.

Haptic system for scraping and sanding
We believe that the haptic system for the scraping has been well studied and implemented. It is notable the sensibility and the precision with which you can interact with the virtual model and the wide range of materials the system is able to simulate and render. In fact, using the buttons to increase or to decrease the hardness of the material and therefore its resistance to the removal, one can really appreciate the way the system reacts in a real manner to these changes. The scraping tool can be used in very natural and intuitive way.
The main defects that limit the system use in real modeling activities are the limited dimensions and the limited possibility of movements.
Concerning the sanding tool (used to explore the surfaces) we were very positively impressed when we tried it. Due to some hardware limitation (the dimension of the surface is almost the same as a human hand) we were not able to feel small details of the model (like a sharp hedge or a little hole), but we were indeed be able to feel big variation in curvature among the surfaces (or within the same surface). The graphic feedback of the position of the tool is very nice and intuitive, as well as the graphic feedback provided of the curvature variation. Unlike the scraping tool we did not have any problem in finding the position, and we never lost our position in the 3D space. It seems that the user and the model are in a "closer connection". Probably the contact with the object is more intuitive and direct rather than when using the scraping tool. We think that the state of the art of this tool is a little bit more advanced compared to the scraping tool, also in terms of its industrial use. We imagine a scenario where some people have to decide about the new shape of a car (since, as said before, this tool may be useful for a big radius of curvature surface typical of large surfaces like in the automotive field) but the range of curvature that can be reproduced is not suited with the kind of small objects Alessi deals with: they may interact with it, maybe modifying the shape directly by inflating or deflating it through the use of the sanding device.

Integrated system

The integration of the various components has been made in unexceptionable way, and this is perceived on how the haptics can be governed in the movements and on the quality of the produced surfaces. However, there are many doubts for what concerns T’nD professional use, and consequently about a whole industrialization of the T’nD system.

In first place, as it was said before, the system set up is not ergonomically satisfactory, due to different working locations of hands and eyes. There are then other limits that penalize the effectiveness of the system. One of these is related to the continuous use of both hands for handling and manipulating the scraping tool, and the consequent impossibility of using the mouse, unless one abandons the scraping tool. Some of these limits are resolved through the use of the vocal interface.

Another limit that can restrict the system use is that it is undoubtedly based on the knowledge of the CAD system on top of which it is built, and therefore it is not a system that can be used by everyone (CAS operators or modelers). We could say that the current system interface allows the use of the system to an operator with experience on the use of CAS/CAD tools, but surely not to a modeler alone, since a relevant part of the activities concerning the preparation of the curves of support must be done before starting with the sweeping actions.

We also tried the sanding tool in the modality for inflating or deflating a part of a model. Honestly the feeling was not as good as like as exploration tool. We found it hard to use and the modification is not so natural (especially inflating, where for adding material one has to apply a pressure on the tool). With inflating or deflating we understood that the modification of the surface can be done almost locally by identifying an area and make pressure inside this area. It is very hard to control the surface modification. Usually, in the physical hand made modelling, in order to make uniform a surface we are used to pass the sandpaper also outside the local area (in order to get a uniform curvature). Another problem is that the sanding tool in this configuration must be used with the help of another person.

Conclusions

The experience that Alessi has made participating to the T’nD project has made us aware that we may work with modeling environments through the use of haptic devices. Indeed, the system should reach a better integration, in terms of ergonomic aspects, among haptic, video, use of the mouse, etc. From this point of view, we think that the T’nD integrated systems is quite primitive at the moment, in the sense that it proofs a concept and demonstrates the feasibility of integrating multiple interfaces, but needs non marginal development and tuning activities before reaching the level of a product.

We feel that in the next future this kind of system may be used in some phases of the product development process, as a support to current CAS/CAD systems, where the direct interaction with the object is demanded.

We can imagine areas where you can quickly feel the shape and modify it directly, where the tactile sensation of the forms is considered necessary and, why not, where the ergonomic aspects of an object during its phase of study can be tried. Probably, T’nD is more suited to the second step of the design process, when the user needs to interact and feel the object shape, and possibly also apply some modifications, rather than during the shape creation phase. This is mainly related to the easiness of the sanding tool in terms of usability during the interaction with a defined model, and the good feeling of the space around provided. Instead, build a new concept from the sketch to the final result directly with T’nD is quite difficult.

6.2. Eiger's interview

This interview has been made to Joseph Tresserras and Francisco Espinach from Eiger.

EIGER and Universidad de Girona have had an internal roundtable discussing about the experience with the T'nD system.

Modeling functionalities
We agreed on the fact that the T'nD system offers little functionality at the moment, but anyway enough for testing the basic idea behind the system and the scenario. Most of people who tested the system are more used to tools like sand paper rather than rakes, mainly due to the kind of hard materials we are using. They agreed on the fact that with more training they will be capable of modeling more complex shapes. It is perceived that the learning curve is long, but once the capacity is created it is re-usable for modeling more complex shapes. Some functionalities are difficult to understand, especially the functions based in more information like path, limits, etc. Anyhow, we think it is a problem of training.

Haptic interfaces for scraping and sanding virtual clay
We think that the basic concept of the T'nD haptic interface is brilliant. Our users are used to work in the workshop with their hands and tools. The way of working proposed by T'nD is more capabilities enabler compared to the mouse approach. Users have model building capabilities developed, and T'nD system enables them to exploit these capabilities.
Despite the fact that the two tools, scraping and sanding tools, are well simulated, the testers' first impressions were "What's that monster?", "Is it dangerous?", "Does it work as a design tool?".
So, at the moment the integrated T'nD system is too cumbersome and does not well explain and present itself. The Phantom device, which we have had the opportunity to try at Euromold exhibition, is better at that point, even if it clearly not a device that can be effectively used in the industrial design sector.

Integrated system
The testers did not like using two interfaces at the same time: the mouse and the haptic interface. They prefer to use one single interface or a more integrated approach. They agreed on the fact that the system could be improved considering the following:

- Make the system more friendly (a matter of perception)
- Search ways to accelerate training
- Integrate the haptic interface with other CAS systems.

New vision for shape modeling based on haptics
The testers have appreciated the natural way for modeling shapes offered by the T'nD system. They have not used haptic interfaces before (at least to create shapes), and now they are more interested to the technology. The prototype has created some expectation, and we may consider that as an indicator that the proposed approach is good. They suppose that if it is difficult today creating shapes using current CAS systems, systems like T'nD may offer possibilities for creating shapes easily and in less time.

Vision about future developments
Our users saw the system as a new paradigm in product design at long term (5÷10 years time). They consider that today there are tools like the Phantom that approach the idea, but are not good for product design. We also think that if the T'nD system would be fully integrated and well operating, would provide more user friendly interaction modalities, and also integrate 3D real-time visualization systems (like holograms); it could be a winning product.
Due to the products we design (small objects), and the skill we have (foams modeling), we think that the sanding tool would be more useful for us. Anyway, the scraping tool, with some changes (for example the possibility of using it with one hand) will be useful for us as well. Nowadays, the mouse is the common tool currently used, but the haptic approach will be getting more space.

Points of interest from project presentations

We have presented the system to a variety of locations and professionals. We can say that the system has been well received and we have had a lot of talks about that after the presentations at the coffee-break, and a lot of questions (some without a clear answer from me).

6.3. Pininfarina's interview

This interview has been made to Filippo Cappadona from Pininfarina.

PININFARINA has always been interested in optimizing his own product workflow in order to introduce innovation and reduce development costs. Early in the seventies in fact, a CAD Center was established in order to fasten the design process using digital tools.

It is in this frame that Pininfarina accepted to participate in Touch & Design Research Program carrying on a scientific research path started long time ago and reinforced with his recent participation in the FIORES' programs[1].

Since the beginning, the project has revealed itself to be very promising: it was clear in fact, that the potentialities offered by the novel modeling system would have lead industrial partner to improve and fasten their product development workflows.

The potential extents of the technological innovation were comparable to the introduction of the initial CAD system and so, the team was suddenly forced to rethink part of their standard process activities.

The possibility to use gesture without restraint and manipulate a virtual material to generate whatever desirable shape has something extraordinary in it: no more NURBS or Bezier experts, no more enlarged team to realized freeform models.

We firmly believe that in a near future the system may be used in different phases of the product development to support current CAx systems.

We might imagine a scenario where a company management has to decide about the new product and in particular investigate the quality of its proportion. Different responsible attending the meeting may have the possibility to interact and draft real time a shape on a technical package. In another phase of the process chain, surfacing operators will have the possibility to refine locally the model to obtain quality surfaces by sanding, inflating or deflating the model shape.

We have to consider furthermore, that in respect with reality the system offers the possibility to zoom in and out into specific areas of the virtual model. This gives us enormous advantages when we have to work on small objects (i.e. domestic appliance) or refine tiny patches.

For this reasons, Pininfarina put high expectations in TND results trusting also in Know-how recovery from his modelers gestures as this was actually the workplan objective.

The integrated system carried on so far keeps the promises conveyed by the project proposal. Evidently, it shows some problems related to the fact that the tool is really at an early stage and therefore not yet utilizable for daily activities. Even so, the outcomes achieved up to now clearly demonstrate the potentiality of its innovative and breaking through technology.

The integration of the various components has been successfully done and it's ready to be engineered: the haptic tools return realistically both strength sensations and sensitivity on physical parameters. It is remarkable in example, the variety of materials the system is able to simulate just using a couple of buttons to increase or to decrease the hardness of the material and therefore its resistance when scraping.

Concerning the sanding tool, we have been positively impressed by the possibility to feel surfaces variation in curvature. The graphic feedback of the tool position moreover is very intuitive.

[1] http://www.fiores.com/

From an ergonomic point of view however, the system is not completely satisfactory. The main areas of possible improvement are listed here below:

- views changing: the virtual tool goes out of perspective when rotating the model thus making the work troublesome;
- very low perception of the scraping tool position in the 3D workspace;
- lack of precision due to device instability and initial inertia when in converting designer gesture into model modification;
- limited motion possibilities;
- the usability of the system is definitely based on CAD system environment both for modelling tools (see i.e. the “constrained mode”) and GUI (Keyboard and mouse).

To conclude, the T’nD system surely needs a further and indispensable development to reach the reliability of a marketable product. Nonetheless at present, it proofs that our original objectives have been reasonable and demonstrates the feasibility of multimodal interfaces integration.

Thus, Pininfarina believes that haptic might be a right opportunity to infer commands to the system conveying by gestures the original design intent. We’re therefore open to continue any research in this field and suggest focusing future research programs on the attainment of a virtual environment realistic visualisation and on know-how retrieving from modellers’ gestures.

7. Conclusions

The experiment conducted allowed us to point out usability problems, for which we suggested solutions. In addition, some limits of the experiment can be pointed out. Especially, the participants were students at PoliMI and at the Universitat de Girona. They had no experience with the T’nD system prior to the experimentation and they were allowed only for 30 minutes of training in order to handle the system. Even though the T’nD system is built in order to take advantage of the users' knowledge regarding CAD and physical modelling, the application of that knowledge might not be as intuitive as expected. Thus, 30 minutes of training was probably too short time in order for the users to adapt their knowledge to a new environment. This could have been even more difficult for students than for experienced designers, since students' knowledge is relatively recent and is dependent on the context of initial learning: it might be difficult for a student to transfer her/his hand motion skills, learned in a workshop, in a virtual environment.

To conclude our evaluation, the following points should be stressed:

1. The testing procedure which T’nD has been submitted to is extremely demanding, if not exceedingly severe. It should be noted that very often, evaluation of a new tool consists of the appreciations formulated by a selected group of experienced users.
2. Such was not the case in the present evaluation: participants in the testing were graduate students, with certainly a good training in the design, some limited training in the modeling techniques, but no extended experience in the modeling trade.
3. Modelling is usually not the designer’s job, but the modellers’. Furthermore, while many modellers use foam modelling, few use clay modelling, and those few are very often former modellers promoted to the design studio.
4. Why then build a modellers’ computer assisted tool for the designers?
   • Former studies evidenced a strong longing among designers for manual tools, calling for strong physical and bodily involvement[2].
   • Actual clay modelling is an exceedingly long process. Computer assistance and virtual clay makes modelling a lot more rapid.
   • The output of computer assisted virtual clay modelling provides immediately with a digital model, and dispenses with the lengthy process of digitalizing a solid clay model.
5. T’nD is not merely a computerized scraper or digital sandpaper. It is a brand new tool, requiring new skills. In our evaluation test, participants were given an exceedingly short, and actually insufficient training prior to using T’nD. Comparing T’nD outputs with the outputs of two other techniques, in which the testers were thoroughly trained, was rather unfair towards T’nD.
6. We are confident that T’nD has a high creative potential. However, this potential has still to be explored and evaluated. It was rather brutal to expect design graduates, however brilliant and well trained, to reveal immediately the creativity potential of a radically new tool.
7. Thus T’nD relatively poor results are only in part to blame upon the tool itself or the students. It is rather the result of our overestimation of the prototype potential for evaluating the final product.

To conclude, the T’nD system surely needs a further and indispensable development to reach the reliability of a marketable product. Nonetheless at present, it proofs that our original objectives have been reasonable and demonstrates the feasibility of multimodal interfaces integration. T’nD does exist.

[2] To quote but one designer: “I want to do it with my hands really, instead than just the mouse. I want to sort of modeling with my hands, standing maybe in front of a big screen, instead of sitting; sitting is too little involving the whole body; making shape is sort of acting, it’s like a dance almost. Like in a workshop, you use different tools…and your hands, and your body, and your spirit. You can lose that feeling working with a computer because the amount of movement here does not collaborate with the actual big changes on the screen”. That’s all what T’nD is about.

It does operate in real time, providing the operator with the sensations and perception of actually working with a scraper or a sand paper on a piece of material, whose consistency, resistance and resilience are convincingly experienced. This is no trivial feat.

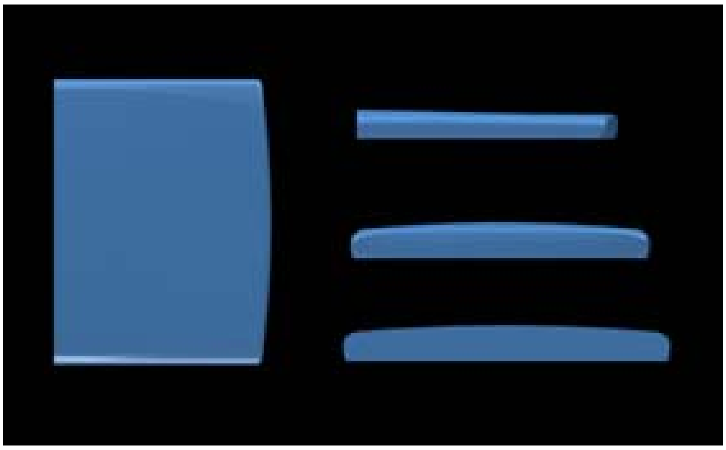
The original decision taken at the beginning of the T'nD project was to reproduce virtually all the physical actions of modelling clay material in order to exploit existing skills. The use cases performed during the last period of the project have demonstrated that actions required for "gross" scraping are performed very well with the T'nD prototype and the feeling is well in line with the physical experience (thus exploiting existing skills). Conversely, the operations regarding the finishing of the work – like filleting- require in the real clay modelling very long and tedious manual work and are very badly performed with the T'nD device, but can be easily done in the procedural digital modality offered by CAS/CAD tool. So, our final consideration is that the right way to consider, use and exploit the T'nD technology is through the integration of the haptic technology with the digital modelling tools. The right approach seems to be not a merely tentative to reproduce all the manual modelling operations but is a new hybrid procedure that tries to optimally integrate the most efficient procedures provided by the two approaches, also satisfying the target to minimizing the impact in changing the operators' usual procedures. Looking at the problem from this perspective, the evaluation process should consequently define and measure a hybrid way of working that is completely new.

We may conclude with the following consideration. The T'nD project started with the intention to mimic some physical manual activities in order to exploit the existing skill of modellers and designers. The system we have implemented has actually some weaknesses but an intrinsic higher potential than simply mimicking a real tool. This has raised major problems since we "limited" our self in the testing use cases to the simple reproduction of the traditional manual operations, and only on this basis we have evaluated the quality of results. The potential of the system should be further exploited.

Annex 1: Views showing the model of the laptop cover

This section shows various views of the laptop model provided by Alessi.

Four orthogonal views of the laptop (top, side, face and back)



Two isometric views showing different perspectives