Hybrid modeling
revaluing manual action for 3D modeling

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Abstract

3D modeling software uses conventional interface devices like mouse, keyboard and display allowing the designer to model 3D shapes. Due to the complexity of 3D shape data structures, these programs work through a geometrical system and a graphical user interface to input and output data. However, these elements interfere with the conceptual stage of the design process because the software is always asking to be fed with accurate geometries—something hard to do at the beginning of the process. Furthermore, the interface does not recognize all the advantages and skills of the designer's bare hands as a powerful modeling tool.

This paper presents the evaluation of a hybrid modeling technique for conceptual design. The hybrid modeling approach proposes to use both computer and manual tools for 3D modeling at the beginning of the design process. Using 3D scanning and rapid prototyping techniques, the designer is able to go back and forth between digital and manual mode, thus taking advantage of each one. Starting from physical models, the design is then digitalized in order to be treated with special modeling software. Then, the rapid prototyping physical model becomes a matrix or physical 3D template used to explore design intentions with the hands, allowing the proposal of complex shapes, which is difficult to achieve by 3D modeling software alone.

Introduction

The designer uses a language consisting of a variety of representation techniques to communicate during the design process. Each is able to give one type of information which the designer then uses to make design decisions. Sketches, technical drawings, rough mock-ups, elevations, perspectives, 3D computer models and finished scale models, to name few, make up this language, and in recent years the computer has been incorporated to this list. The advent of working on paper in the 16th century developed into drawing as the traditional act of designing. Before that, during the Renaissance, the realization of models led to the architect's understanding and designing of the project.

The computer has been added to these traditional tools and techniques because of its potential to treat information, thus improving the different stages of the design process. It is principally at the end of the process, however, that digital tools show their advantage over their traditional counterparts through increased possibilities in presenting and communicating the project and greater accuracy for late production. This is so because most computer solutions come from other disciplines, where the goal is to improve accuracy and production. Bermúdez and King (1998), in researching representational media, have found that digital media are stronger for design development, whereas manual representations are more suited to the conceptual design phase.

Despite that, the computer has not been integrated with other manual or analog techniques on a regular basis. Several digital design solutions try to simulate or imitate these traditional tools offering their digital equivalent without convincing results. Instead of improving on traditional tools with the capabilities of the system, the digital equivalents force the user to interact only with the computer during the design process.

The computer has become a funnel for most of the representations made during this process. Because of the complexity of the interface, the system requires specialization, forcing the designer to continue using traditional manual tools, particularly early on in the design process when creative activity is most important, and the computer brings more limitations.

We are considering the following approach: taking the information out of the computer system in order for it to be treated by the user's knowledge and skills (Dorta 2005). In this paper, we present and evaluate a new technique of 3D modeling where the designer goes back and forth between manual and digital representations to master modeling complex 3D shapes. We use 3D physical models, 3D scanning, rapid prototyping and 3D computer modeling to better achieve design intentions. We carried out a cognitive and design evaluation of this technique and the results show that shapes are mastered much better with intuitive manual actions and manual feedbacks.

Models and design

In antiquity, a craftsman or artist would build scale models, including interior and exterior details, to design a project and visualize and communicate her/his intentions. This was time-consuming; every step—every conception, development, and modification—necessitated the construction of a new model. Building scale models was a way to communicate with clients and construction (Moon 2005). With advances made in geometry and mathematics, it was only in the Renaissance that drawings appeared as a quicker and more practical media for designing and presenting buildings before their construction. Interested in understanding and representing classical architecture, Filippo Brunelleschi, an enthusiast of models, proposed perspective drawing as another tool for representing buildings and urban landscapes in a realistic way. This approach would define the architect as a profession. Despite some problems with perception due to scale, the advantages and functions of models as physical depictions of design ideas, in conjunction with the possibilities of skilled manual actions, have remained constant over time. Today, Frank Gehry digitalizes his models and the information is transferred to a computer program through which the estimating is done (Moon 2005). For him, this process preserves spontaneity. It is like an alternative to computer modeling tools used to manipulate shapes.

Manual media – craftsman and models

Hands, including fingers and all their possible translation axes, are exceptionally relevant as a modeling tool (Dachille et al. 1999). Hand to eye coordination, articulations, skin and muscles let the designer feel the shape evolving right in his hands. The sense of touch is very important to human perception and allows one to truly understand 3D geometry.

Representations in the real world are balanced compared to those in a digital environment. There is a close network between mental images, visual perception, hands and representation (Lasseau 1980). The connection among these elements is strong and permits better control of the representation, in this case a physical model. The interface of digital tools sometimes affects this network, except for direct manipulations. The problems are the structured actions with palettes, menus, default values and system messages that break this balance, leading the designers to make decisions prematurely (Gross et al. 1996). Additionally, the keyboard and the mouse cannot permit the professional designer to completely perceive the shape, even with haptic tools like the *Phantom*™ where the interface is not a glove but a pen-like device.

The main aspects regarding craftsman and manual media are the acquired competences. Being already competent handling certain materials manually, the designer often feels "handcuffed" while performing some task on an interface system. Some modeling actions are hard to achieve because the program is limited by its logic. The manual media allows mastery of 3D modeling using stereoscopic vision and both hands without the intermediary of computer screen images.

Depending on their purpose, models vary in terms of scales, accuracy, and material. They are abstract representations, not replicas of realities (Kvan and Thilakarartne 2003). Physical models, therefore, become models of thought (Schön 1998). Like the sketch, the designer can maintain a conversation with these representations, ensuring that certain questions remain unanswered, leaving a margin of flexibility and giving an explicit visual place for the decisions that remain to be taken (Graves 1977). Rough models can have the same characteristics of sketch representations—abstract, ambiguous, and inaccurate—giving place to the creative flow.

The principal problems of models regard scale. When the scale is too small, the field of view is too deformed to evaluate proportions accurately (Porter 1979). In spite of that, there seems to be no difference between physical and digital models in regards to the sense of proportion (Lin 1999). Moreover, model transformations are hard to obtain because they are time consuming.

Humans are fascinated with models, but when the models are at full-size, like in industrial design, they can become prototypes for the designer, permitting the possibility to make decisions based directly on the mock-up.

Conceptual digital modeling = premature

The use of binary machine language to generate computer images and 3D models makes 3D software require abstract information (Kalay 2004). Based on a particular geometric system to allow arithmetic calculations, the graphic user interface becomes somewhat complex.

In this system, orthogonal, axonometric and perspective views lead into the virtual world. Euclidian geometry and wire-frame views make the user code and decode the representation to understand it. Furthermore, the user must enter the data that the system demands to execute the task. Often this data is accurate, and the interface does not permit ambiguities. In order to carry out a task, the user has to interact with commands on menus and react to validation boxes and default values. These demands interfere with the user's creative flow; s/he is centered on the interface rather than on the design intention (Raskin 2000).

We ran an experiment by making two skilled designers start the ideation of a computer mouse shape using the manual method, one designer sketching, the other making a physical model (Dorta 2005) (Figure 1). Then we had them switch to the digital mode, the first by 3D modeling and the second through 3D scanning.

On one hand, going from sketches to 3D modeling was considered as leading prematurely to a quasi-finished result because some aspects of the geometry were not sufficiently determined in the sketch to feed the modeling program with the needed accuracy. Moreover, the 3D software required premature geometric concerns with the shape while the idea was still ambiguous and abstract for the designer. The sketches, however, permitted the easy exploration of several solutions. On the other hand, going from physical models to the digital realm, despite the primitive nature of the rough mock-up, was a better portrayal of the designer's comprehension of the object's shape, scale and proportion. Transformations were easily accomplished.

Rapid prototyping and ideation

These technologies have been applied to disciplines related to production, time-consuming tasks and engineering processes. When applied to design representations, making a physical model out of its digital description is the main goal of this technique, and these technologies are challenging the design offices as other technological devices did

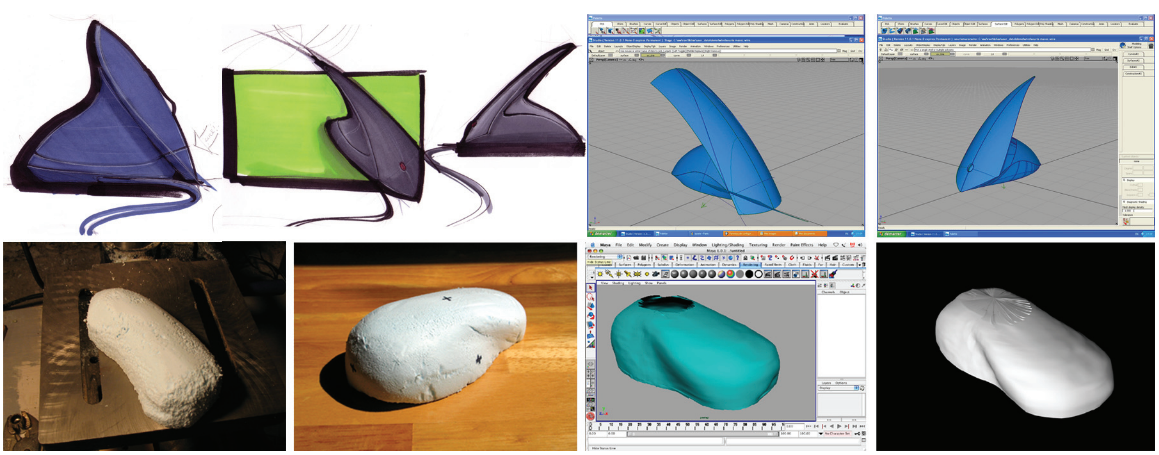

Figure 1. Sketch to 3D modeling | Physical model, 3D scanning and 3D modeling.

in the past (Streich 1996). Nevertheless, these technologies are now too expensive; few professional offices can afford them. In addition, the logic behind using these systems is to produce accurate objects later in the design process, rather than serving the conceptual design.

According to Kvan and Thilakaratne (2003), the systems appear to put illustrative and semantic models at an advantage rather than the design conversation as proposed by Schön (1998). In this study we privilege rapid prototyping (RP) techniques in this way instead of using them for digital fabrication. Here the designer builds physical parts of the project following software shape generators that will afterward be manipulated in the real world (Sass and Oxman 2006).

The approach we give to RP techniques is to use them as matrices or 3D template generators for shape exploration during conceptual design. Instead of waiting until the shape is finished to produce a prototype, we use RP to print rough concepts to manually explore the idea. Rather than producing an accurate prototype, the goal is to create a model that can become a matrix of other physical models to help the designer during the ideation process, giving her/him a physical support for manual modeling exploration.

In this way, taking the model out of the virtual world, the designer can apply her/his acquired competences and intuitively achieve complex shapes and design intentions without the geometric concerns and the interface limitations of actual modeling software. Then, s/he can re-enter the virtual world to take advantage of the digital tools and techniques that the computing 3D modeling offers: Booleans operations, affine transformations, curves generation, etc.

Hybrid Modeling

Hybrid modeling consists in working with the two modes of representation (manual and digital) to modify the 3D model through manual (clay modeling, etc.) and digital (Boolean operations, etc.) processes. It is a cycle of continuous and frequent back and forth iterations between the virtual and the real at the beginning of the design process, especially for ideation. The technique uses 3D scanning and RP in order to benefit from the advantages of manual and digital modes.

To illustrate this approach, let us consider a designer who undertakes the formal modeling of an object. Considering the implications of going from the sketch to 3D modeling, s/he begins the ideation by handling physical materials like a Styrofoam block, which s/he modifies manually to create the first idea. This concept is then digitalized and visualized, and consequently the designer uses techniques suitable to the digital mode to apply transformations and Boolean operations such as subtractions or additions.

The return to the manual mode is done via RP. The object created by RP is relatively malleable and can easily be modified, carved by subtraction (cutting, drilling, sandpapering, etc.) or addition (clay, paperboard, Styrofoam, etc.). Subtractions seem easier to accomplish than additions. Furthermore, the model can be produced as a mold, thus becoming a matrix to reproduce other models that will work as 3D templates for shape exploration. Here, the designer can explore several alternatives of the same shape using malleable materials while respecting and controlling the proportions of the shape being produced by the matrix. Once back in the digital mode, instead of using orthogonal images or sketches as background templates for 3D modeling, the scanned rough model is used intuitively as a 3D template.

The importance of working in both modes, this time applied to tectonics, was described by Jaby (2004). Jaby relates to the work of Fowler and Mueller: "Going back and forth between digital and analog media has the advantage of revealing more quickly and more clearly weaknesses in a project as well as inconsistencies" (Fowler and Muller 2002). Returning to the manual, or analog, mode only at the end of the design process can neither allow these discoveries early in the process, nor permit the application of all the benefits of manual actions. The goal of this approach is to benefit from the advantages brought by digital and manual modes by allowing the designer to choose the method that s/he considers most suitable for a particular action. Finally, it is easier to explore complex geometries on the analog mode than on the computer because of the complexity and "heaviness" of the software.

Cognitive and design evaluation

Thirty pairs of second-year industrial design students participated in this study. The hybrid modeling experience was based on the design of a computer mouse shape as an advanced modeling exercise for an undergraduate computer graphics course in industrial design.

The iteration stages made by each team were:

- Rough physical model making (manual)
- 3D intuitive modeling (digital)
- RP model transformations (manual)
- Detailed 3D modeling (digital)

Every group started with the manual mode, making a rough Styrofoam physical model (Figure 2, a). After 3D scanning, they modified their design using the intuitive HyperNURBS 3D modeling technique of *Cinema 4D*™ software. The rough scanned model was used as a 3D template for modeling with HyperNURBS (b), which operates with a subdivision surface algorithm that interactively rounds basic shapes as a cube. The new shape was built according to the scanned 3D template, which was an irregular, incomplete mesh surface, hard to modify due to the available 3D scanning technique (InSpeck™). The

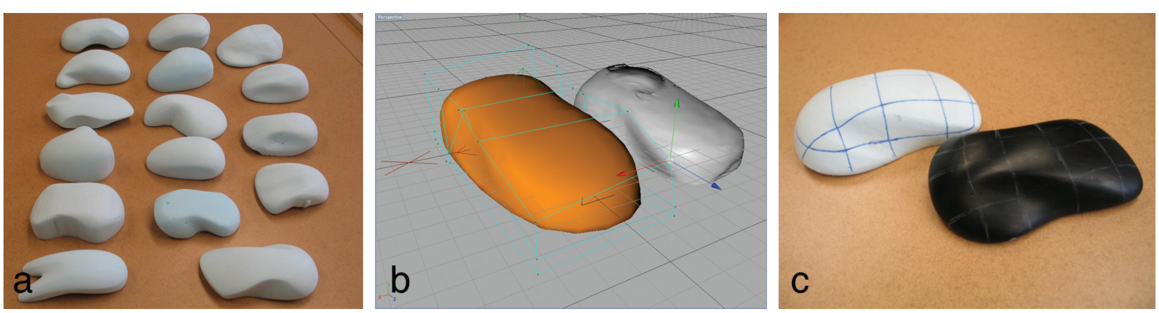

Figure 2. Physical models | Scanned model as 3D template | RP model modified.

RP model produced using a FDM plastic ABS technique was made to return to the manual mode. This model was modified, carved by subtraction or addition (c).

The second iteration in digital mode was accomplished using 3D detail modeling (Figure 3). Here again, the students used the scanned model as a 3D template. This time, they created the character shape curves on the model, and then closed the surfaces. Finally, they used the HyperNURBS technique to round the form. The student took this approach to be like detailed 3D modeling, for they had mastered the proportions and the exact shape, meeting their design expectations (Figure 4).

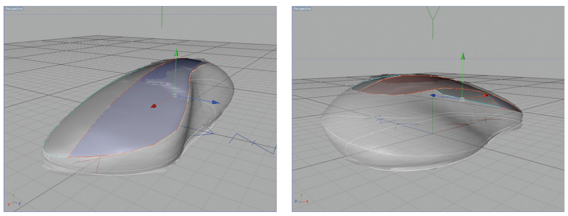

Figure 3. Detailed 3D modeling with character shape curves on the 3D template.

We made the cognitive and design evaluation of the hybrid modeling technique itself as a new way to make ideation using physical models. Nevertheless, this technique has not been compared to physical or digital modeling techniques alone. The goal was to evaluate its usability in conceptual design.

The evaluations were done by filling out a questionnaire at the end of every stage. The formulation of the questionnaire was based on the NASA Task Load Index (TLX) (Vidulich and Tsang 1985) system.

Figure 4. Exact shape following design expectations (Goulet-Thomas; Giroux-Dupont).

The subjects gave estimates on the six subscales using bipolar descriptors (from high to low). Three dimensions relate to the demands imposed on the subject (mental, physical, and temporal demands) and three to the interactions of a subject with the task (performance, effort and frustration).

Other design aspects were evaluated as: design expectations, efficiency of the prototype, understanding of the shape, error detection and correction, and verification of the scale. As well, some questions regarded the execution of the technique: skill level of the modeling technique after the first and second 3D digitalization, difficulty of the modifications made to the design, and the time invested in each task.

Results

The time invested in manual work with the mock-up and the RP model was less than the time invested for the creation of the 3D models. Some of the mock-ups were finished in 40 minutes. These did not need to have a finished surface. This could have contributed to faster work. The overall workload between the first 3D model and the final design was almost equal. The six categories measured dealing with the demands imposed and the interactions gave very similar results. Figure 5 shows the results where the mental demand was less in the two stages of manual work. The activities related to the mental demand such as evaluation and identification were done more easily.

The level of frustration with the physical models was less than with the digital 3D models. The evaluations and modifications were made at the same time as the mock-up was being shaped, while the digital 3D model needed to be modified through commands and re-evaluated with functions like « zoom and rotation ». Figure 6 shows the results of the frustration in the four stages of the hybrid modeling technique.

The results were outstanding for the evaluation of the details, ergonomic evaluation, verification of the scale and error detection (Figure 7, a). Also, the design modifications that were done to the RP model show that the students explored more design options, and the results were high regarding the understanding of the form and correction of errors (b). The efficiency of the RP model was better as a physical 3D template than as reliable source of information (c).

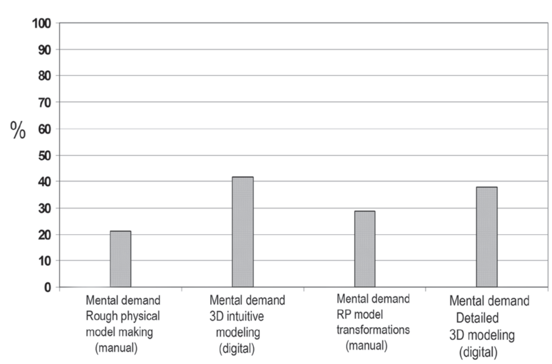

Figure 5. Mental demand.

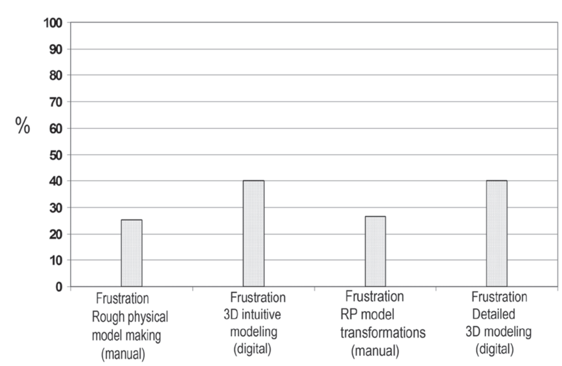

Figure 6. Frustration.

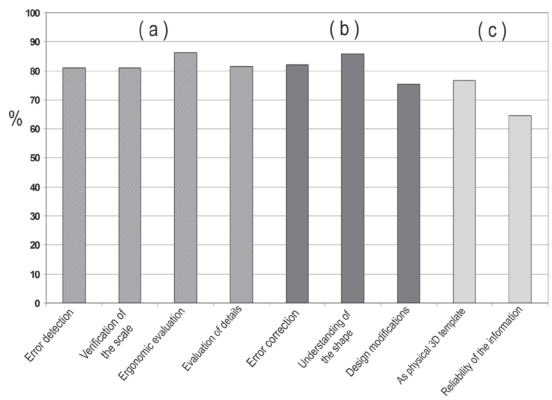

Figure 7. RP model evaluation.

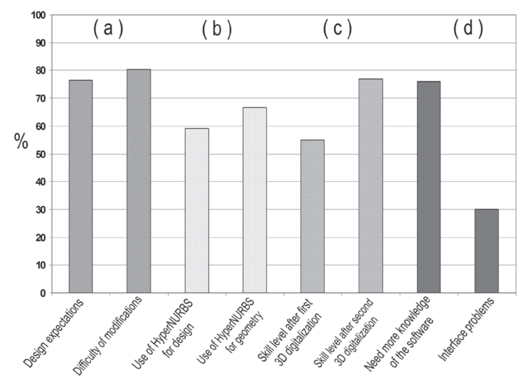

Figure 8. Detailed 3D modeling evaluation.

The design expectations were high during the final stage. The modifications had a high level of complexity as a result of the feedback from every stage (Figure 8, a). The students were concentrated on mastering the HyperNURBS technique to develop the wished geometry rather than in the design itself (b). Nevertheless, there was a quite significant increase in the mastery of the modeling technique between the first 3D digitalization and the second one (c). Most students agreed that they need more knowledge of the software in order to make better designs. However, because of the intuitiveness of the *Cinema 4D* interface, the students were not affected by interface problems (d).

Discussion

The stages where the work was done manually obtained better results regarding time, mental demand and frustration. The modifications were directly done by hand. The RP model was suitable when used as a 3D physical template, but the material (plastic ABS) made changes more difficult. Using softer materials from RP techniques like ZCorp™ would have simplified modifications on the template. This could have influenced the design decisions that were done to the RP model in the process of modifications. Nevertheless, the information was transmitted to the computer thanks to the digitalization of the RP model, using it as a 3D template, thus allowing the modifications to go on until the desired form was obtained.

The design expectations were achieved at a very good level. The exchange of information between the four stages (manual and digital) gave more opportunities for changes (hybrid). Nevertheless, some of the RP models did not correspond to students' expectations because some of them created the 3D model at the wrong scale, which made modifications difficult.

Even with the intuitiveness of the HyperNURBS technique, some students found it difficult to shape their 3D models. They were focused on the tool rather than on the design. Another reason could have been the rough quality of the 3D templates due to the limitations of the available 3D scanning technology.

Conclusions

The computer is integrated in the design process without understanding exactly where it is really effective. 3D models and RP are part of the process to validate functional and technical aspects (precision and speed), but not for design reasons. These techniques were not created to support ideation or conceptualization tasks. In addition, these techniques are used mainly during the last steps of the process to communicate the idea to clients. The designer should not see the two modes (digital and analog) as being distinct; the limitations of each approach are thus reduced—the interface or the complexity of modeling in the case of the digital, and the time consumption and dimension errors in the case of analog. Thus, the 3D representation of a project would be carried out by design criteria and not by production criteria.

It is necessary to stop making *refined* solutions from the very start of the process. Instead, we are searching for form, just like sculpting or painting, through a series of empirical and successive stages of improvement, like the "New Modeling" proposed by Weinand (2004).

The designer himself, without fear of imperfection, should process the data. Thus, the computer should not be seen as an essential instrument used for generating concepts: revaluing manual action is suggested.

The hybrid modeling technique was evaluated as an interface in order to measure the workload and other cognitive aspects related to the design goals for modeling complex shapes. The results show the value of manual action for 3D modeling, especially at the beginning of the process when ideas are abstract and ambiguous, and when the software asks for premature geometrical decisions. This approach targets the gap in computer tools for conceptual design, and shows that new computer interfaces and tools, well adapted for designers, are needed.

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