THE USE OF PAPER MODELLING TECHNIQUES IN NEW PRODUCT DEVELOPMENT

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ABSTRACT

Simple and crude prototypes can have a great impact on developing new products, particularly when used in early stages of development processes, because they are quick to build and make use of accessible resources. Rapid and low-cost manufacturing of three-dimensional models promote the interactions between the development team and their future users, and also testing multiple solutions for the product. Nevertheless, even the simplest physical representation of a product or part of it can become a real challenge to make. Recently, methods of building paper prototypes were improved by the use of software tools. Now, using specific computer applications it's possible to create physical artifacts from paper and cardboard materials directly from CAD applications, testing colors, textures and labeling effects.

In the present work, paper modeling techniques are presented as an alternative rapid prototyping (PR) technology for specific stages of the development process. Additionally, a practical workflow methodology is proposed to facilitate the elaboration of paper prototypes, since the early stages of the development process, reflecting on the benefits and transformations of using paper crafting technologies in customer-oriented and user-centered design and development.

INTRODUCTION

Today, the constant increasing of competition in a global market forces companies to develop new, aesthetic, functional products with an increasing quality and according to costumer's requirements, in very short time-to-market. The constant reduction of products life-cycle and the consequent need to speedup the development of new products pushes companies to reduce their time for developing it without compromising the product's market-based performance specifications, forcing them to rethink the overall project management practices.

Therefore, it becomes critical to foresee product characteristics since the early steps of product development, building and testing three-dimensional previews of the final product, especially if subjective factors like look, shape and feel are at stake. The use of physical models should not be delayed to later stages of development, working just as production verification tools or as simple demonstrations of the manufacturability of the design.

Prototyping, in a general sense, can be understood as the creation of a physical model that helps foreseeing a certain product. The prototype is "an artefact that by means of using technology tries to recreate some aspect of the real product that is thought to matter" [1].

There can be greater opportunities on product innovation if physical models are built and tested earlier in the process (Fig. 1). By simulating future product attribute's they open up paths to innovative solutions for functionality problems that emerge along the process, or they can help redefining the product's initial specifications to better match costumer's needs. At an organizational level, they can act as active learning tools, helping interdisciplinary teams to engage around a common working tool that can improve communication and decision making.

Fig. 1 – Teamwork around a full-scaled cardboard model of "MARS" chair by Konstantin Grcic [2].

PAPER MODELLING APPLICATIONS ON PRODUCT DEVELOPMENT

Nowadays, the proliferation of computer virtual visualization tools that can simulate both shape and material looks, defines a trend for the process of product design: to use only physical testing in later stages of development. But strategic investment in physical prototyping technologies has to make a good balance between their cost, their technical capabilities and the questions they help to answer. The key to manage prototyping benefits (virtual or physical) is to understand that prototypes and simulations are means (not ends) for better evaluating the progress of one's work [3]. And by using it carefully and periodically one can avoid the inherent uncertainty that usually surrounds the development of a new product, and improve the project's directions through a desired goal. Prototyping tools may not change the meaning of the project itself, but they will surely change how teams organize themselves to develop a product. Prototypes facilitate communication among developers, costumers and users, providing a propitious environment for instant error checking and feedback [4].

Paper concept prototypes can be used in the various stages of a new product development process (Fig. 2).

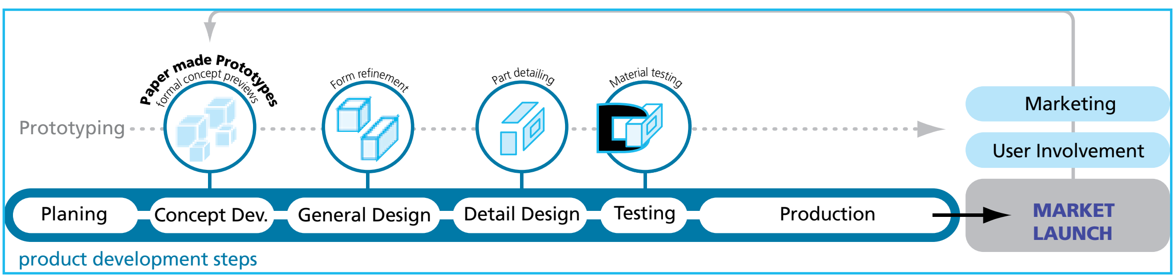

Fig. 2 – Use of paper made prototypes in product development

In the initial conceptual stages of DP, when multiple initial solutions are presented, it can be hard to allocate resources to build and test physical prototypes for each solution [5]. Commonly used Rapid Prototyping technologies (RP) can be expensive or time consuming for quick concept testing. Usually, investments in RP or other physical prototyping technologies are made when the product attributes reach a more consistent and acceptable level of definition.

Three-dimensional (3D) paper-built concepts can be used as a quick and economic solution for initial concept testing. Paper modelling is better known as a handicraft (a manual technique for creating physical three-dimensional representations) or as "paper toy art" usually done by kids to craft their own toys. By cutting, folding, bending and gluing pieces of paper, it is possible to create objects with simplified geometry and surface colour decoration. Paper made prototypes simulate by simplification the outline surface geometry of a product, as well as its colours and graphical information.

As the importance of shape and its proportions to the overall concept is a critical factor for product design and styling, paper modelling can be an easy and potential way of building small and medium scale prototypes. Therefore, by its characteristics they can be a helpful tool for quick testing product's geometry and proportions since initial phases of product development phases.

This approximation problem poses several challenges like:

- Constructing intuitive and easy way to assemble small paper pieces;
- Minimizing the number of patches;
- Reducing distortion in the boundaries between paper parts;
- Minimizing errors between the original surface and its approximation for paper construction.

Nevertheless, for industrial designers the geometric simplification of conceptual forms, necessary for paper prototyping, helps in better understanding the geometric implicit structure and inner volumes that define its aesthetic values.

By doing so, further geometric development (on a chosen concept) is done trying to maintain those values/characteristics unchanged.

The life-cycle of paper prototypes is not limited to initial stages of concept testing. Usually, paper models are also built for alternative testing objectives. Marketing has long made use of physical prototypes for market tests, by evaluating product models within its users and costumers. Market surveys are always a possible secondary use for prototypes that initially were made for internal testing.

Fig. 3 – Example of paper models for advertising purposes in an auto show.

In the case of paper built models, not intended for utility testing, their use can be extended for advertising efforts (Fig. 3).

On another perspective, marketing initiatives also can take advantage of user's paper manufacturing capabilities [6]. A paper model of some product can always be built in almost every place (home, office, etc.) by almost every one with a printer, some scissors and glue. Some companies already spread their brand by making paper representations of their leading products available for internet downloading. By doing this, companies seed user's identification with the brand, incrementing the user's intention in acquiring the real product of that specific brand – creating the so called evangelist users.

Marketing and advertising campaigns using paper made prototypes are now common practice of some companies to achieve and increase their link to consumers. When not: some potential consumers (that can't buy the product, by geographic or economic constraints) tend to recreate their own interpretation of the product in paper. Doing so to evaluate before buy, or simply for collecting a paper approximation of the wanted product (Fig. 4).

Fig. 4 – Aplle's IPhone recriated in paper model

Exploiting these user characteristics of self-motivating co-developers, companies could improve their link to the market needs and wants. Sharing some mid-developed concepts through the form of downloadable paper models, companies could survey some results in order to catch up the most recent user will's.

PAPER MODELLING ADVANTAGES AND DISADVANTAGES

Some of the main benefits of paper made prototypes are highlighted below:

- Paper model construction is characterized mainly by the extremely **low costs** involved, which do not compromise the overall budgets of product development. They are relatively quick to design with the aid of specific computer applications and **easy to build and assemble** with office-like tools and intuitive manual techniques. Gluing paper parts can be done with cellulosic and acrylic not harmful mixtures.

- Paper-made prototypes are useful for building a **high range of model scales:** hand-scaled models to body-scale or bigger models – adapting paper thickness and density to the size of the model – choosing from light and thin paper to structured cardboard.
- On other hand, paper based modelling presented in this article is just an initial method of building three-dimensional prototypes by assembling flattened patches. The methodology is possible to apply to (or in conjunction with) other planar materials, like thin plastic sheets, etc. Operations involved in prototyping in paper resembles some final production technologies used to transform other similar planar materials such as metal and plastic sheets, like laser cutting, machining, hot bending and welding. As so, paper is best suit for producing physical prototypes for this specific kind of manufacturing technologies. Due to the same physical limitations of building metal or plastic sheet parts, papercrafting can be an excellent alternative prototyping solution for **rapid concept testing for these similar technologies**.

Paper made prototypes also have some less valuable characteristics that can represent some disadvantages for their application in PD:

- **Paper mechanical strength** – paper is a fragile anisothropic material not suited for functional tests. Its mechanical and chemical resistance is weak. However they are not usually built to last. Reinforcement can be made, structuring the paper with other materials such as wood, plastic or metal parts, at a premium cost.
- **Handcrafted assemblage** – the techniques involved in manual paper modelling (manual part cutting, bending and gluing) can compromise the final look of the prototype and therefore, misguide its evaluation and understanding.
- **Lack of shape smoothness** – paper representations can hardly replicate complex shapes accurately because they are built manually and by adding parts incrementally – shape distortions can increase in complex models that usually need to be divided in a large number of parts. Also, paper prototype's final quality is extremely dependent of modeller's skills and experience, especially when they're done by manual development (surface subdivision and flattening) and manual fabrication (cut, bend and glue)

STEPS FOR PROTOTYPING THREE-DIMENSIONAL PRODUCTS IN PAPER

With the aid of computer applications, the development of paper prototypes can reach higher levels of detail and complexity suitable for representing any kind of geometry, not just for the manufacturing technologies mentioned before. Paper representations of more organic shapes are always simplified approximations of the designed geometry, maintaining just the main proportions and some formal aspects of the virtual shape.

As with any other prototyping technology, some sequential steps are necessary to accomplish a paper model of the product. To build an accurate prototype with paper materials it's proposed the following workflow (Fig. 5):

1 – Concept sketching and modeling

With the aid of a CAD application, the external surface of the product or part of it can be built virtually. As with other prototyping technologies aided by computer, the first step must be the creation of three-dimensional model in a CAD application. Is also possible to recreate even some of the visual attributes of the product – for example the pieces are decorated to simulate the appearance of metallic surface.

2 – Surface simplification (tessellatio)

This operation involves converting the initial surface data in a polygonal mesh – a simplified geometry set of triangles or rectangles. Manually, this can be a complex and long process that involves technical drawing capabilities and some descriptive geometry knowledge. In some cases, it may be necessary to use automated systems for the development of paper models. Currently, it is possible to use computer applications (some dedicated exclusively to the paper modelling) to assist the planning of three-dimensional objects of high complexity in minutes.

3 – Flattening the three-dimensional model

When the CAD model is defined, transfer the information on its way to a dedicated that breaks down the shape vertices in cuts, planned with the representation of zones for paper stress and collage.

Normally this is a lengthy process, but using computer applications, like PePaKuRa Designer®, improve great the speed of implementation.

4 – Part printing

The flattened model can be saved into a sharable computer file, like PDF (Adobe's *Portable File Format*), organizing the model parts for printing.

Then, the file can be transferred to an appropriate scale and printed through a desktop inkjet or laser printer onto the selected paper type.

Fig. 5 – Proposed Workflow Steps

5 – Paper parts cut and stress

Normally this operation is done by using some conventional tools like *x-acto*'s cutting knifes or some scissors. But, it can be possible to go further beyond the manual process.

Currently, it is also possible to automate the cutting and stressing processes of pieces of paper for the construction of models by using computer controlled machines (Fig. 6) designed for paper manufacturing.

Equipment such as exemplified, can cut and stress planar sheets of paper or cardboard with different thicknesses and consistencies.

However these machines are not easy to find, some print-houses have them for package or exhibition-stands production and can provide paper cutting services. Thus, the sequence of prototyping ends with the pre-assembly of parts of its assembly until then complete the final prototype.

6 – Parts assembling

Parts are assembled by manually bending and gluing them together in a specific order. This phase involves lots of manual work, depending on the complexity of the paper model.

The process of modelling products in paper is by far not limited to simple shaped and coloured artefacts. With the aid of computerized applications like the one presented in this paper, and with the possible use of CNC paper cutting machines, the possibilities are endless.

Fig. 6 – Example of CNC machine (and tools) for paper cutting and stressing [7]

The previous workflow is relatively simple, but the time needed to perform this operation depends on the capability of the modeler, the complexity of the model and/or the number of parts required to build the prototype.

CONCLUSIONS

Paper models reveal their potential for cheap and effective representation of fundamental aesthetic values of the product's conceptual shapes since the initial steps of the development process. On the other hand, paper models can become increasingly important to marketing researches for user oriented testing done early in DP.

Although the art of prototyping physical models in paper relies mainly on hand work, the process for developing it has improved buy using tools capable of translating complex shapes to flattened parts in minutes. Therefore using the presented prototyping workflow and potential with the aid of computer applications, it is possible to accomplish even more complex geometries in a paper crafted prototype.

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