REMOTE COMPUTER GENERATED PHYSICAL PROTOTYPING BASED DESIGN

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ABSTRACT

This research explores some of the opportunities offered by the field of computer aided design. It differs from much of the research in the field in the sense that it extends beyond the boundaries of the computer screen by building and testing a computational and communication design environment made of computers, computer peripherals and digital communication devices.

From our observation of the designer's interaction with the computer generated physical prototyping systems we were able to confirm the unique haptic feedback and understanding of complex three-dimensional geometry. We also found limitations of the environment in relation to evolutionary design.

It was clear from those experiments with algorithmically generated design alternatives that potentially terrific opportunities lies in their combination with computer generated physical prototypes and manufacturing systems.

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Introduction

This research explores some of the opportunities offered by the field of computer aided design. It differs from much of the research in this field (Mitchell, 1998) in the sense that it extends beyond the boundaries of the computer – what is commonly referred as “getting out of the box” – by building and testing a computation and communication design environment made of computers, computer peripherals and digital communication devices.[1]

In this research we created a computer-based environment and observed a range of volunteer designers, in the early stages of their design process. The focus of our observation was how these designers interacted with the environment with the aim of exploring the environment’s advantages and limitations and found that it raised novel questions about research in Computer Based Environments. This ongoing research focuses on the exploration of the field of design for manufacturing using mass-customisation systems.

This paper describes (1) the computation and communication based environments, (2) the methodology used to conduct the experiments, (3) its advantages and limitations and (4) further possible research questions. The paper focuses especially on unexpected outcomes.

Two computation and communication based environment

The designers produced a three-dimensional computer model and then used Rapid Prototyping[2] systems to produce three-dimensional physical objects. The three-dimensional computer models where produced using both traditional software, including AutoCAD, Rhino3D, Alias, as well as algorithmically-generated design alternatives (Duarte and Simondetti, 1997), including rule based parametric methods and genetic algorithms. The Rapid Prototyping systems used were Fused Deposition Manufacturing (FDM) and Stereo-lithography (SLA), both available at the Industrial Centre in the Hong Kong Polytechnic University.

To enhance communication, the research team installed a series of video conferencing systems over the Local Area Network (LAN) using Classpoint Software for multi-point continuous (24 hours a day) connections between the designer’s workstation, the RP workshop and the observer’s workstation. We

[1] The computers used were: PC Pentium II, 300Mhz, SGI Indy, PC Pentium 166 Mhz. The computer peripherals were: FDM2000 by StrataSys, SLA 3500 by 3D Systems. The digital communication devices used were: PC Pentium II, 300Mhz NT Server for Class Point multi-point videoconference, PictureTel LIVE 200, Intel Proshare. LAN used was 100 baseT Networking system (UTP 100Mb/s).

[2] Rapid prototyping systems build three-dimensional objects according to the data provided by a three-dimensional computer model by depositing or solidifying various materials layer by layer.

wanted to simulate the studio environment in which the designer concurrently sketches and produces physical models, while being observed by the principal investigator. The designer made use of this set up for experiments that where conducted in the School of Design.

For experiments conducted outside School of Design, we used email. The designer would send three-dimensional computer files as email attachments, and then three-dimensional physical models were produced in University's Industrial Centre. Photographic images of the models were than sent back to the designer also as email attachments. The observation was limited to personal comments sent back and fourth over email; only in one case was the physical model sent back to the designer in Australia.

It is worth mentioning that we always respected each designer's inclination to use one traditional software or algorithm rather then forcing the designer to use those specific systems that better interfaces[3] with current Rapid Prototyping (RP) systems. Our choice resulted in all designers producing surface models as oppose to solid models generally considered more appropriate for RP technologies. The same attitude made some of the experiments unique from a strictly technical point of view. The resulting experimental data about open and closed surface modelling and its implication in rapid prototyping systems will be the subject of another paper, by the project research assistant, Mr. Chak Chan Lewis.

The methodology used to conduct the experiments

To explore the limits of this fast evolving field of research and to secure immediate result we conducted a series of case studies that seen together give a sense of the range of possible interaction with this technology and opens questions for further discussion.

For example, to optimise the range of the experiments, the test group included designers geographically distributed in Hong Kong, India and Australia. Designers ranged from highly educated practitioners to first year degree students and even included a computer graphics programmer.

The aim of this broad methodology is to compare what designers do during the early stages of their design process, before and after the introduction of new technology. We then attempted to evaluate if and how their design process had improved by presenting the results to a panel of experts.

Description of case studies

The following case studies are listed according to: the designer's level of experience and education, the stage of design development and the level of access to the in-house environment.

Micheal Cheng is a second year student in the BA(Hons) course in the School of Design. His knowledge of CAD software is above average within his class, although limited to the use of software for 3D visualizations. Michael interacted

[3] For Example ProEngineer by Parametric Technologies, Unigraphics etc… In some cases designers used AutoCAD surface modeling and 3D Studio, in other cases the designers used Rhino3D instead of using solid modeling module or software.

with the in-house environment at a later stage in his conceptual design, when most of his decisions had already been made. Michael was able to fully and repetitively experiment with the in-house environment.

Manit Rastogi practices and teaches Architecture in New Delhi, and has previously carried out research in design and computation (Frazer, Rastogi, Graham, 1995). Manit has an expert understanding of CAD, CAD programming and architecture. He did not interact with the in-house environment. He emailed the design to the principal investigator who generated a physical model and emailed an image of it back to him. Manit produced a Genetic Algorithm code in AutoLISP for AutoCAD to generate the design. He generated a three-dimensional cellular automata (CA) using closely packed spheres (Frazer, 1995). The designer used a mapping algorithm that generates surfaces through the points of the CA. The complexity of the surface is controlled by the complexity of the rules of the CA generated using genetic algorithms that in this case evolves for increasing complexity. The designer has frozen one instance of the evolutionary data space and produced a physical prototype.

The code generated a surface model of the design with intersecting surfaces. The AutoCAD software couldn't export the .stl file necessary to prototype the design. A utility software, downloaded from the WEB[4], was used to generate the .stl file.

Michelle Flowry, Grant Dunlop and Gregory Duncan are first year students in the Master of Architecture course in Deakin University, Australia. Their designs were produced for a course offered by Prof. Mark Burry, which is aimed at teaching "programming for enhanced CAAD productivity and design capability." [5] The students sent their files by e-mail and received images of their physical prototypes.

Benny Leung is a senior industrial currently teaching at School of Design. His three-dimensional computer model was created by his assistant, Benny did not interact with the in-house environment because he did not personally use the computer. His design was already partially developed. When Benny received the physical prototype this was his first reaction: "If we look at the drawing is not that thin, when you made the prototype something must have happened…". He added: "I do appreciate the slightly translucent white colour." The designer's reaction suggests that he is getting new types of feedback from the 3D prototype.

Chan Kwai Hung received graduate education in Computer Science. He is currently conducting research in the field tools for algorithmically-generated

[4] Most common 3D software, including AutoCAD, allow the user to export 3D solid geometry in STL format used by Rapid Prototyping systems. We used a freeware found on the Internet called STL_Util to export closed surfaces in STL format. As for open surfaces we manually applied a minimum thickness to be able to export in STL format. STL_Util 2.1, written by Benoit Michel, Rue de Sendrogne 100, 4141 Sprimont, BELGIUM, 1994, e-mail: 2:293/2202.12@FIDONET.ORG

[5] Advanced Computer Application in Building and Architecture, src421, http://www.ab.deakin.edu.au/src421/

designs in School of Design. Hung was mostly concerned about his process of developing a generative design tool. Therefore the design instance that was prototyped did not represent a memorable step in his process and did not produce the kind of feedback that is necessary for his work. Prof. Frazer, the leader in Hung's research, commented that the physical static prototype represented a trivialisation of his evolutionary design, intended to be experienced over time, or in the fourth dimension.

Advantages and Limitations of the environment

The following comments are in addition to the results of previous research conducted in a similar environment by the author (Simondetti, 1998). In that earlier study major advantages to the designer offered by Rapid Prototyping Systems were identified in: haptic feedback, feedback on designs in motion and feedback on complex free-form designs.

Computer Generated Physical Prototyping[6] Based Design environments evidently appear limited in providing the feedback necessary to help the designer proceed when confronted with a design, as in Manit's and Hung's case, that is an instance of an evolving data space. In a limited number of generations, these designs begin to show complex interpenetrated surfaces. From a technical point of view, interpenetrated surfaces proved challenging for the slicing software that prepares the files for rapid prototyping.
The computer generated physical model made using FDM (fused deposition manufacturing) processes, proved to be hard to read because of their opaque and static qualities as opposed to the dynamic translucent visualisation offered by a rendering software. The SLA (solidified resin) prototype, with its translucent material, proved to be more readable then the opaque FDM one.

An interesting discussion also occurred around the issue of scale. In the virtual world designs evolving on the screen are scale-less. In the transition process from bits to atoms, the designer must specify a scale at which the design will be produced. By doing so, the visualisation offered by the computer generated physical models drastically limits its effectiveness to the designer. It was discovered that it is easy to imagine one self walking inside the data space when is dynamically evolving on the screen, but once it was prototyped with an overall size of 20x20x20 centimetres, that design did not appear to offer the same inspiration to the designer. The haptic feedback offered by the ability to hold the design, in these particular examples, appeared to be information of no use.

Global Virtual Design Environments, similar to the one recently set-up at School of Design, was suggested as a possible solution to the problem raised above. With its supercomputer for real-time multi-piping rendering and real-time design generation and its semicircular walk-in screen and 3D glasses, this environment promises to offer the designer the necessary four-dimensional interaction and feedback.

[6] This notation of what may be commonly referred to as Rapid Prototyping was found by the author, for the first time in William J. Mitchell, "Change, Time and Speed", Thresholds no. 16, Dept. of Architecture, MIT, 1998.

However, when the designer is developing the design of an object that is meant to be touched, as in Michael's design for a hand held pin collector, it was noted by professor Frazer, that "[…]none will dispute that having something in your hands and being able to turn it around, it makes it somehow very much easier to appreciate even than very dynamic images. There is something about its three-dimensionality and its tactile qualities that is more communicative to the brain."[7]

The success of Michael experiment is also related to the fact that the prototype of Michael's design, was produced at full scale as opposed to a scaled representation, generally used for interior and architectural designs that tends to turn a building into an object, sometimes a toy.

Further research

It is clear from these experiments with algorithmically generated design alternatives that potentially terrific opportunities lies in their combination with computer generated physical models systems. My current research project in Design for Mass Customisation Manufacturing Processes is exploring these opportunities offered when a designer develops a series of parametric algorithms to generates families of designs that share selected parameters and differ one another according to some others.

From some of the comments by the panel of experts on the result of the experiments, it appears clear that designs algorithmically generated, as in the case of Manit's and Hung's, were perceived as much more appealing when represented as dynamic images on the screen if compared with their physical prototype. It was noted that screen representation offers a distorted view of the real design, and that may have made some designs look more interesting than what they actually would be, when prototyped.
However this only an hypothetical observation, and a systematic testing that compares all sorts of representations, including dynamic rendering is necessary.

Computer generated physical models, as this research reinforces, are imposing themselves as an alternative representation for designers. Together with the development of Walk-In Three-Dimensional Virtual Design Environments, or CAVE, it seems that there is an opportunity to extend the research towards building a matrix of comparison with an historical perspective. The matrix may list design representations, including for example: pre-perspective, projected geometry, early computer aided design systems, early solid modelling, generative systems, Virtual Design Environments, Computer generated physical models and compares them according to criteria of appreciation including: tactile qualities, intelligibility, robustness and cost.

This possible development of the research will have a practical use, because it will offer guidelines to the inexperienced designer on which representation may be most appropriate to his/her necessity. It may also cast light on the too

[7] Notes from the panel of experts discussion conducted at School of Design, HKPU, January 1999.

often hidden relation between the representation used during the design process and final result of the design.

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