A Study on the Application of Rapid Proto-Typing Technology to Innovations in Product Design

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***Abstract* — In this paper we discuss the features and principles of rapid proto-typing technology. We analyse product conceptual design within the whole process of market survey, function design, principle design and commercial design. This technology can create more humanized and more beautiful product design that can better satisfy consumer demand, and also lead to rapid production and manufacturing. We show that this technology can achieve a coordinated process of production from design drawing and model making to finished product, and has the potential to solve the issues of complex surface modelling and design optimization. It also helps to achieve innovations in several areas: i) product design, ii) processing, iii) material, iv) equipment, v) production organization, vi) management and vii) user innovation.**

Keywords - bias tunnel; Product Innovation Design; Rapid Proto-typing Technology

I. INTRODUCTION

The famous physicist of ethnic Chinese, Chen Ning Yang and German philosopher, Wolfgang Weksch successively think that "the 21st century will be the century of design". The 21st century not only is the century of design, but also a century of competition. Any design will be faced with a rat race. Those designs needed by the society are of competitive edge, rather than any obsolete designs. The concept of advantage design is transformed from the thought of "design for competitive edge". In 1950s, with the promotion of world market competition, those U.S.-led capitalist countries raised the "creative activities" which soon involved former Soviet Union, Japan and European countries. Then, "conventional design" was activated creatively, and kept moving to "creative activities". In its high tide, some products of new technology, new material and new process kept springing up. Conceptual innovation, appearance innovation, structure innovation, material innovation, process innovation and other innovations emerged in endlessly. Therefore, in 1990s, U.S. explicitly raised "design for competitive edge", and design with the market-oriented ideas. Whereupon, speed economy is the inevitable outcome scientific and technological advance to a definite degree, and is the significant turning point for human from realm of necessity to the realm of freedom. At present, knowledge update gradually accelerates. In the period when agricultural economy kept the dominant position, knowledge update rate was about 100 to 150 years; while in the period of industrial economy, the update cycle was about 20 to 30 years; in today's knowledge economy period, its update cycle has been reduced to 3 to 5 years. The famous British technical forecasting specialist, James Martin predicts that human knowledge doubled each 50 years in the 19th century, and doubled each 10 years in the early 20th century. While in 1970s, human knowledge doubled each 5 years, and doubled each 3 years in recent ten years; by 2020, the amount of knowledge will be triple or quadruple of that in predicted year. By 2050, the knowledge will account for about 1% of the amount. In this process, technological innovation keeps on the increase, and market diversifications and personalized demands of customers become more diversified. Therefore, the competitive pressure of enterprise keeps increasing. Technological innovation and design development innovation gradually rise to the highest level of enterprise strategy. The strategic triangle of the three variables including customer, competitor and company takes shape, which also is called as "strategic 3C" (as shown in Figure 1). Under this background, if enterprises can steal a march on some actions like products development, they can move ahead in the market and acquire active position in competitions, so as to get larger living space and developments. In terms of rapid proto-typing technology, since the date of birth, it has been a brand new product development mode. Its essence is to accelerate knowledge circulation by accelerating information flow in the process of product development, so that the development period of products can be shortened and enterprises can achieve rapid, integrated, collateral, crossed and designs by full advantage of all resources, and make adjustments to achieve new product development with combination of the service conditions from customers.

II. CONCEPT, FEATURES AND PROCESS OF RAPID PROTO-TYPING TECHNOLOGY

A. Concept of Rapid Proto-Typing Technology

The rapid proto-typing technology means the generic term of rapid manufacturing of 3D physical entity in any complicated shapes with direct drive of CAD model. The

basic process of rapid proto-typing technology: the designers disperse the designed computer 3D model into a series of ordered units upon the basic requirements of process and definite laws, disperse it upon a certain thickness in the direction of Z (usually called as hierarchy), and transfer the original 3D model into a series of sheets; then input the parameters of processing upon the specific outline information of each sheet for automatic production of numerical control code; finally, develop in a series of sheets with archetype machine (3D printer), and connect them to figure out a specific 3D body. This process is called as rapid proto-typing process (as shown in Figure 2).

Figure 1. 3C Strategy

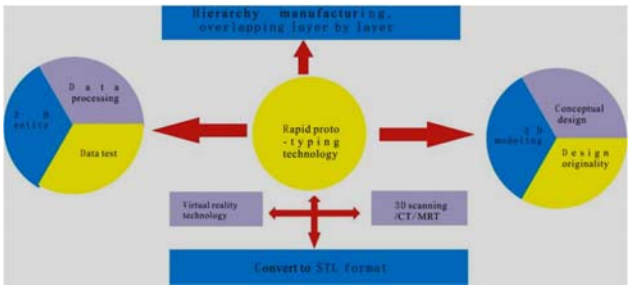


Figure 2. Property of rapid proto-typing technology.

B. Feature of rapid proto-typing technology

Compared with the traditional proto-typing technology, the greatest feature of rapid proto-typing technology is the processing method of "increasing materials", while the traditional molding method is "removing materials". Thus, the traditional processing engine beds and processing molds are not needed in rapid proto-typing technology. Comparatively speaking, this technology can save 70% to 90% materials by comparison with traditional processing method. At the same time, it also can save production costs by 68% to 80%. The rapid proto-typing technology adopts molding equipment, and the fabrication precision can reach 0.01mm with thickness controlled at 0.05-10.5mm and speed at several hours to dozens of hours. The features of rapid proto-typing technology: firstly, direct drive by CAD model. In the process, the digital model information of CAD can be directly transferred to STL information with help of software so as to directly drive the numerical control code of molding machine and complete model production. Secondly, this technology can produce 3D models of any shapes without help of any specialized tools and auxiliary equipment. With this technology, the complicated 3D model information will be dispersed to develop a series of sheets for final 3D entity by overlapping layer by layer. In this process, this technology is completed independently. Thirdly, the applicability of materials is good, and its molding is highly effective. The materials adopted for this technology range from high polymer materials to metallic materials and from organic materials to inorganic materials. At the same time, a 3D model can be produced with this technology in several hours and even less time, which is much faster than traditional technology. Finally, its application area is extensive with good economic benefits. This technology not only can be appropriate for new product development, but also can rapidly manufacture components and parts and be suitable for short run production. At the same time, the irregular components are widely used in complicated 3D model manufacturing, tooling design, toy design, rapid reverse and copy and many other fields; it is east to control the production period and costs for short run production. Producers can firstly do market research and forward design and production upon consumer demands, which can help to greatly reduce unnecessary losses from inventory and cost and greatly increase economic benefits of enterprises.

C. Process of rapid proto-typing technology

Rapid proto-typing technology can be divided into two categories: one is the molding technology based on laser and other light sources: Stereo lithography apparatus (SLA), and the usually used materials include crylic acid, Makrolon and shape deposition manufacturing. The features of SLA present high material costs, expensive equipment and necessary structural support. The workload in earlier stage is large, and thermoset photosensitive resin cannot be melted repeatedly. For the process of laminated object manufacturing (LOM), CO2 laser only needs to incise the outline of model on sheets. The whole section scanning is not necessary but to depend on the size of model and complexity. Besides, the molding is fast, and it is easy to produce large parts without any supports which can reduce workload. The process of selected laser sintering (SLS) is to lay a layer of thin thermoplasticity powder equably on the workbench or cover a layer of plastic material outside metal and other powders to develop powder group, and then heat the powdered material with infrared ray to a certain extent, and control laser beam and seedling burnt lens for laminated manufacturing.

The other one is the molding technology based on jet, mainly including FMD (Fused Deposition Modeling), nylon, ABS, 3DP (3D printing) and MJD (Multiphase jet deposition) materials. The fundamental of FMD is to heat plastics to the molten state, squeeze them out from jet nozzle, and scan them from the bottom up layer by layer upon the instruct of software, and achieve solid state after the molten-state plastics cooling. Then, the effects of laminated

manufacturing and overlapping layer by layer can be achieved. Nylon and ABS material manufacturing process is the effect by melting and spurting them and overlapping layer by layer. 3DP was invented by Professor Emanual Sachs from Massachusetts Institute of Technology in 1993, and its principle is similar to ink-jet printer. In terms of form, it is closest to the concept of "3D Printing". The adopted materials are farinose, such as ceramics, plastics and metal. MJD also is another good method to solve rapid proto-typing technology materials.

III. CAD/CAE/CAM/PDM AND OTHER 3D MODELING TECHNOLOGIES

In the late 1950s, CAD technology began to develop. By the 1960s, it became a reality that drawing techniques could be operated on the computer and continued to be improved ; after the 1980s, 32-bit microcomputer workstation and microcomputer had been popularized and developed, which greatly promoting the development of CAD technology. CAD technology has entered the practical stage, which has been widely used in the overall design, style design, structural design, process design and other aspects of electronics, machinery, aerospace, textile, construction and other products. CAD technology has experienced several major changes, from its generation to drawings by hand and then the more "intelligent" part of designer's professional knowledge. The computer technology has seen tremendous development (as shown in Fig. 3).

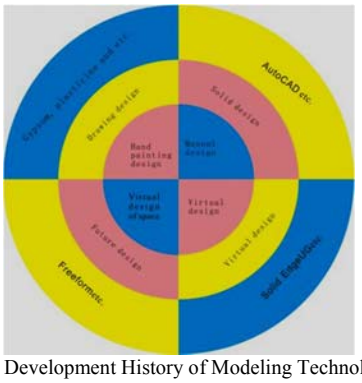


Figure 3. Development History of Modeling Technology

A. 2D Drawing software

The commonly used two-dimensional drawing software in the product design is AutoCAD software, which is an interactive drawing software developed by American Autodesk company for microcomputers. It is mainly used for 2D engineering drawing, and has the function of drawing and editing. In the meanwhile, it is also provided with the function of three-dimensional modeling. Autodesk launched the first vision V1.0 in 1982, and then a series of classical versions, such as V2.6, R9...R2000, AutoCAD2004, AutoCAD2007, AutoCAD2010 and the AutoCAD2015 version commonly used nowadays. AutoCAD is compatible with STL format, and also supports Pro/E, 3Dmax, Rhino and other software. In the meantime, its good compatibility allows it to save files in dwg format and have functions when used with other software.

B. 3D Modeling Software

The commonly used 3D modeling software in rapid prototyping technology is Solidorks, Pro/Engineer, Unigraphics, 3Dmax, Maya, Rhino and etc. Solidorks is the 3D modeling software developed by American company Solidorks, which applies to parametric modeling. The company is mainly engaged in the development, design and marketing of the software used in three-dimensional mechanical design, engineering analysis and product data management. Pro/Engineer is a 3D modeling software developed by American company PTC, and its main feature is also parametric modeling. Among them, three-dimensional model can generate two-dimensional document, and at the same time, surface function is so powerful that it can generate NC code. It is the software developed by the famous company in the field of CAD/CAE/CAM. Unigraphics was originated from McDonnell Douglas Aircraft Company, which joined the world's largest software company EDS in 1991, then developed Unigraphics software with Unigraphics Solutions Company. Thereafter, UGS has become world's famous supplier of CAD/CAE/CAM technology and been mainly used in automobile, aerospace aviation and machine design field. It is the modeling software provided with reverse engineering module and capable of docking ANSYS interface and outputting STL format. 3Dmax and Maya are also the commonly used three-dimensional modeling software and widely applied in architectural design, animation design, product design and other fields. Their main feature is also parametric modeling. Rhino is the powerful and professional 3D modeling software used in PC and developed by Robert McNeel & Assoc. It is compatible with modeling function part of 3DS Max and Softimage. In the meantime, it works very well for fine and complex 3D NURBS models. Furthermore, it also can output obj, DXF, IGES, STL, 3dm and other different formats. It is provided with both the flexibility of NURBS and accuracy of CAD, and it is applicable to the field of industrial design, CAM 3D animation, and etc.

C. Freeform Modeling Software

The technology of parametric modeling has become gradually mature since 1990s, and especially the Pro/E of PTC. From the mid 1990s, the hybrid modeling methods combining traditional methods with parametric methods emerged at the right moment, which was represented by UGv11 and CADKEY'97. Such hybrid modeling not only presented the extraordinary foresight in the modeling methods, but also made the designs more natural and more in

line with the design habits. Since the virtual freeform design was born, it has been provided with some of the advantages of the previous software. Furthermore, 3D Touch technology has been registered by it as a patent. Its birth further enriched and developed the modeling method in virtual design. It had the features of wireframe modeling, surface modeling, solid modeling and parameter modeling.

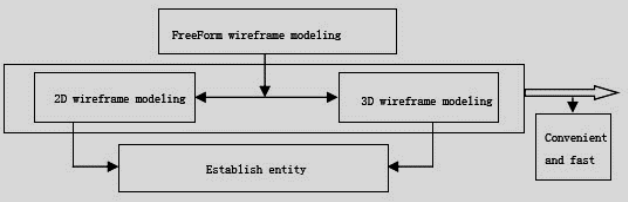


Figure 4. FreeForm Wireframe Modeling

As to the wireframe modeling, the most important feature is to signify the outline of form and structure with points and lines and change the size and shape of the form and structure through the constitution of points and lines. In other words, virtual model is barely the wire frame of shape, and its corresponding mathematical descriptions are curvilinear equation, lists of point coordinates and the connection information of the points and lines. The connection information herein can identify the points, lines and the endpoints between lines. When lines signify the form and structure, the data size is small and the definition is simple. It is very quick to edit them and in line with people's production habit. In the process of producing more complicated form and structure, people are used to draw the outline and then portray the details. However, when it comes to the production of the form and structure that are extremely complex, such modeling method is provided with fuzzification and ambiguity (as shown in Fig. 4).

Currently, there is a large number of surface modeling methods represented by parameterized surface modeling method and spline modeling method. Herein, the parameterized surface modeling method is realized by multi-surface modeling method. Another method is NURBS (Non-Uniform Rational B-Splines) put forward by Versprille in his doctor degree dissertation, which is part of the standard widely applied by the industry. NURBS can better control the curvature of curves than mesh modeling does, so that it can create better and more real surface modeling (as shown in Fig.5).

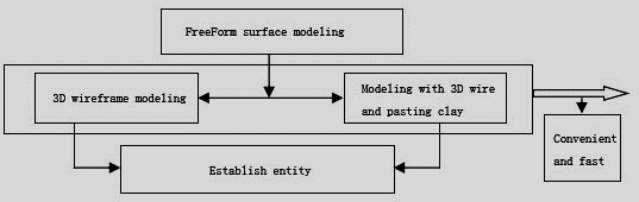


Figure 5. FreeForm surface modeling.

The virtual clay modeling technology FreeForm is provided with above-mentioned advantages during the solid modeling process. Thus, its modeling methods are divided into two parts. One is the voxel modeling (namely the formal modeling); the other one is surface modeling. The geometric modeling methods are the functions that previous software already has, while the free-form surface modeling is the most prominent characteristic of FreeForm (as shown in Fig. 6). Both methods will be elaborated as follows:

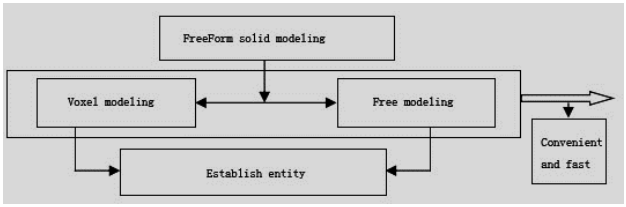


Figure 6. FreeForm solid modeling.

IV. EXAMPLES OF VIRTUAL CLAY MODELLING TECHNOLOGY FOR FREEFORM IN PRODUCT INNOVATIVE DESIGN

A. The Constitution of Virtual Clay Modeling Technology Freeform System

Virtual reality technology mainly has three essential characteristics: imagination, immersion and interaction (as shown in Fig. 2-1). Among them, immersion is the most noticeable one, in which case, together with good interaction, it will give people great imaginary space so as to help people develop their creative thinking. The imagination herein means that the object's behavior is "autonomous" in virtual design environment and automatically completed by procedures under people's operation. In this case, users think it to be "autonomous" and "organized", which is in line with physical laws. The so-called interaction refers to the fact that the operator, in the virtual environment, can operate on the objects in the system, and this operation can be accurately and veritably perceived by the operator. The so-called immersion sense refers to the fact that the operator can feel the internal stimulation in the virtual environment. The strength of the immersion is inseparable with the accuracy, level of detail and validity of virtual representation. The three "I" characteristics reflect the key characteristics in virtual reality technology and present the good interaction between technology and people (as shown in Fig.7).

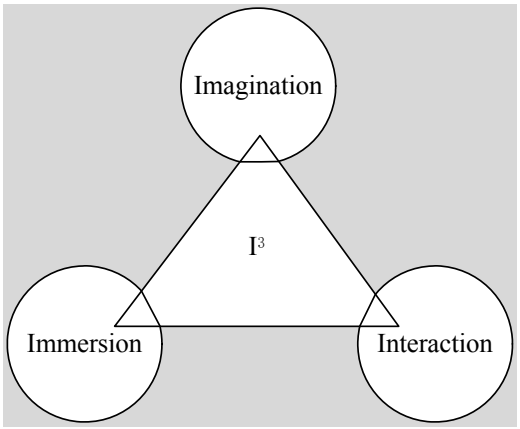


Figure 7. 3-I Figure of Virtual Reality.

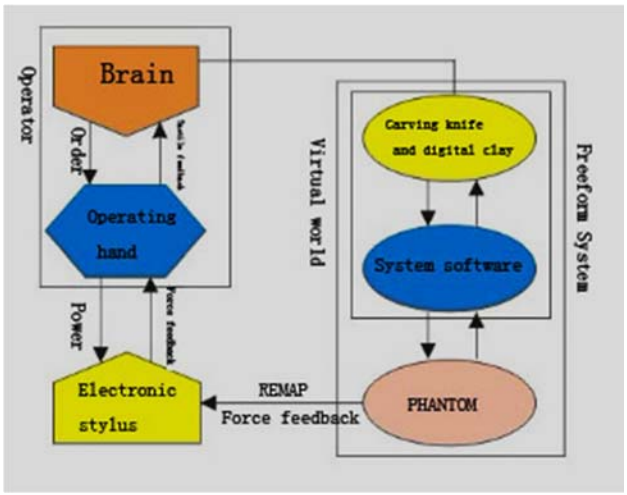
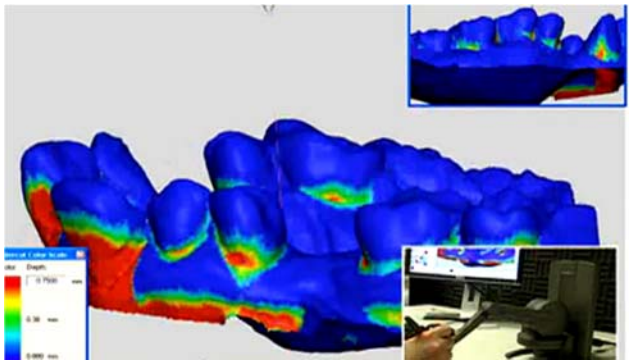


Figure 8. Constitution Diagram of Free Sculpture System

The entire design system is divided into two parts, software and hardware, which are based on PC platform. The Freeform modeling system applies 3D Touch technology PHANTOM, a hardware interface. With its small, exquisite, ash black and simple arm-like electronic stylus and operating system, it utilizes some scalper tools for digital clay. Besides, GHOST, a software system, is like a "Touch Engine", which should be the core of this technology. Clay, namely "digital clay" or "virtual clay", is the real clay on computer screen. In the meanwhile, electronic stylus can be used to engrave it. This technology is applied in desktop computer. It has three component elements. The most major advantage of Freeform is the feedback of force. During the sculpture process, you will get a feedback of force. In the meantime, it will make a sizzling sound. The freeform has good compatibility. It can input pds, ai, obj, ply, stl, step, iges, bmp, jpg, ai and other formats, and at the same time, it can output stl, iges, step, bmp, zcp, ply and other formats.

B. Application Examples in Virtual Clay Modelling Technology Freeform

3D modeling of denture teeth. Create a plane where X axis, Y axis and Z axis are parallel. And then use Edit Plane to translate and adjust the plane's position. Use Copy Profile tool to draw the plan, elevation and top view. Combined with Wire Cut Clay tool and Loft Clay tool, the overall outline of denture teeth can be drew. Then utilize Tug tool and Tug Area tool to adjust the size of model. Paint and airbrush color (as shown in Fig.9-1). Utilize Tug tool and Tug Area tool to portray the details of denture teeth model. The effect is shown in Fig. 9-1.



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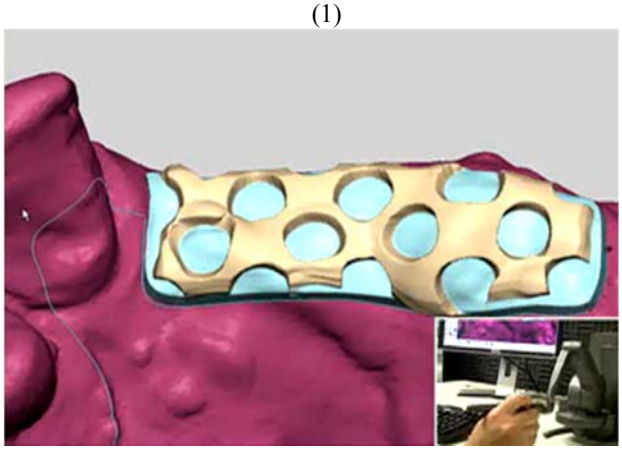
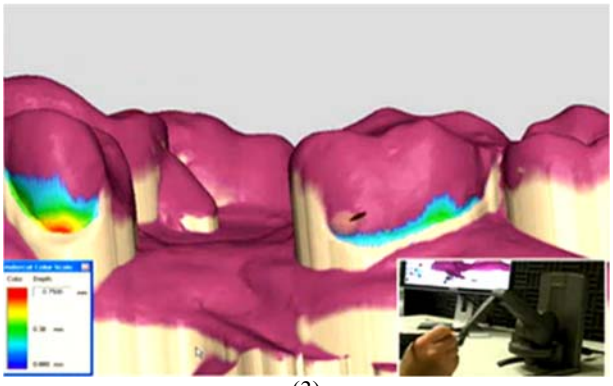


(2)

Figure 9. 3D modeling design process of dental steel bracket (source: Sensable)

Detail design of false teeth of denture teeth. The 3D design of the dental crown of false teeth still requires Paint tool and Airbrush tool to paint colors on the detailed part. The area of painting parts is almost equivalent to the parts needing to be portrayed, which can be added or reduced as needed. Tug tool and Tug Area tool can be used for adjustment, and sculpturing tool can be used for sculpture (as shown in Fig. 9-3). With the aid of Edit Ref. Piece Selection tool and Edit Ref. Piece with Curve Loop tool, the selected part can be converted to clay (as shown in Fig. 9-4).



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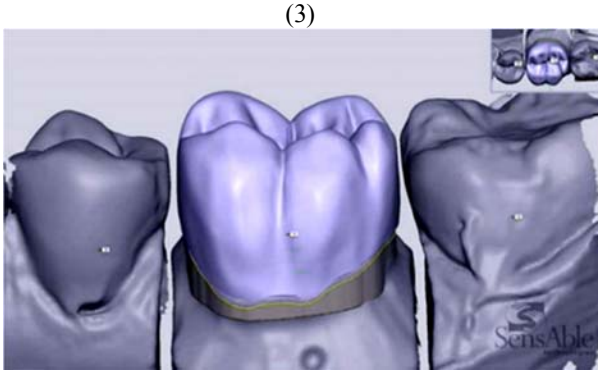
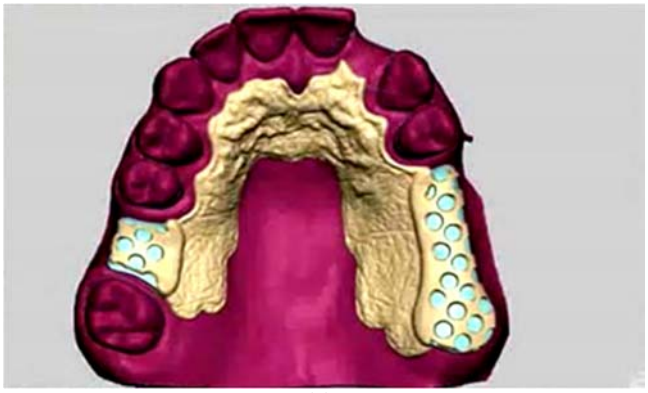


(4)

Figure 9. 3D modeling design process of dental steel bracket (source: Sensable).

Overall design of dental steel bracket. Divide the designed dental steel bracket into three parts: teeth, lower jawbone and tongue and mark them with different colors for detailing of each part (shown as 9-5). Finally, make the model production based on designed teeth and then start mass production.



(5)

(6)

Figure 9. 3D modeling design process of dental steel bracket (source: Sensable).

V. RAPID PROTO-TYPING TECHNOLOGY IS BENEFICIAL FOR INNOVATION OF THE NEW PRODUCT

A. Design Innovation

It is easy for designers to learn and apply, they can simply handle it through ordinary training because of its simple and convenient design procedure, while good human-computer interaction interface will offer designer with vivid experience and it is helpful for design. During the traditional design process, the process is very hard and designers can only send blunt command through the computer mouse and keyboard, in this way, FreeForm is popular among designers with its good man machine interface as well as free surface. The designers may feel like in real designing in the process under the help of real simulation and the good interface, which is good for them to implement long-existing design ideas and methods.

B. Product Innovation

Designers can be able to master the whole design flow and take each link such as conceptual design, sketch design, functional design as well as new product development and design into consideration. Besides, they may respond to market rapidly and make adjustment based on application situation. During the process, due to that whole design process is taken together so that any change in the design can be adjusted in time.

C. Equipment Innovation

The new product development process means rapid proto-typing technology combined with virtual sludge technology freeform. Differ from traditional forming technology of “subtraction”, the rapid proto-typing technology adopts “method flop-in”. Therefore, it is good for saving material and reducing production cost. Meanwhile, introduction of new design technique not only inspires creativity of designer but also quickly makes reaction based on consumers’ use condition.

D. Process Innovation

Introduction of virtual sludge technology has changed simple and single way of traditional product designing and improved application process of modern software like CAD\CAM, comprehensive three-dimensional modeling technology and force feedback technology enable people sense the whole designing process. The design process is reversible and design drawings can be directly imported into rapid molding machine, and different materials and processes can be applied according to the different needs of consumers.

E. Market Innovation

When making character design with virtual sludge technology, it takes emphasized spot, alternative part and concentrated form into consideration. In addition, it uses unique imagination to describe or extend some certain part or form with concentrated form and to fully display or performance a topic. The method of "Great to see small" or incomplete to complete will bring design with infinite imagination and flexibility. Meanwhile, it varies from consumers' different reactions. What's more, it meets novel demand of consumers and highlights the age feeling. Therefore, it will explore market from such aspects and reach market innovation.

F. Material Innovation

The quality of material will directly influence production process and forming precision. Rapid proto-typing technology accepts new material and technology rapidly and sensitively at the same time continuous innovation of new material and technology require such kind of technology to fit the development of new materials.

G. Iteration Innovation

Virtual sludge technology of FreeForm takes customer demand as priority in the design of customer value and customer satisfaction so that every link in the design almost gets rid of the traditional design in terms of manufacturing and implementation. The users are final consumers of products, therefore, they all have the right to participate. In this process, the system can absorb various opinions, form strategic design with analysis, judgment and decision, it is good for improve the efficiency of design iteration rapid prototyping and effectively enter into next iteration.

H. Production Organization and Management Innovation

Since the born of virtual sludge technology, it plays large role from concept of product design to product market research, selection of features, determination of principle as well as concept plan design, rapid prototype manufacturing equipment and rapidly manufacture. As a link, it not only organizes manufacturing resources in flexible way but also disperse those at different regions and enterprises for production, design and management. It exceeds the space constraint and achieves remote design, manufacture and management by Internet. Furthermore, it reacts to the market in high efficiency and speed by making full use of resources.

I. User Innovation

Traditional forming technology cannot react well to the consumers' service condition in the process of production, organization and management. While rapid proto-typing technology is a design and production theory which combines them together and takes designers design inspiration and consumer satisfaction as center and reacts quickly to the market.

VI. CONCLUSIONS

The paper introduces concept, characteristic, process and materials of rapid proto-typing technology and compares it with traditional rapid prototyping technology, it turns out that such technology is good for raw material saving and production cost reduction.

It introduces two and three dimensional modeling technology as well as virtual sludge technology and makes comparison towards them. It turns out virtual sludge technology is helpful to stimulate designers' inspiration and to react market well. Therefore, it introduces 2D modeling and 3D modeling of such technology also with its transformation and compatibility problems, it is good for design creation combined with other three-dimension techniques.

Combined with 3D modeling process of dental steel bracket as well as its rough model design, portray subsection and final effect, it states the superiority of combination of such technology and rapid proto-typing technology.

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