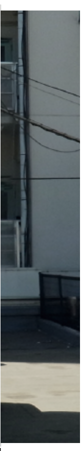
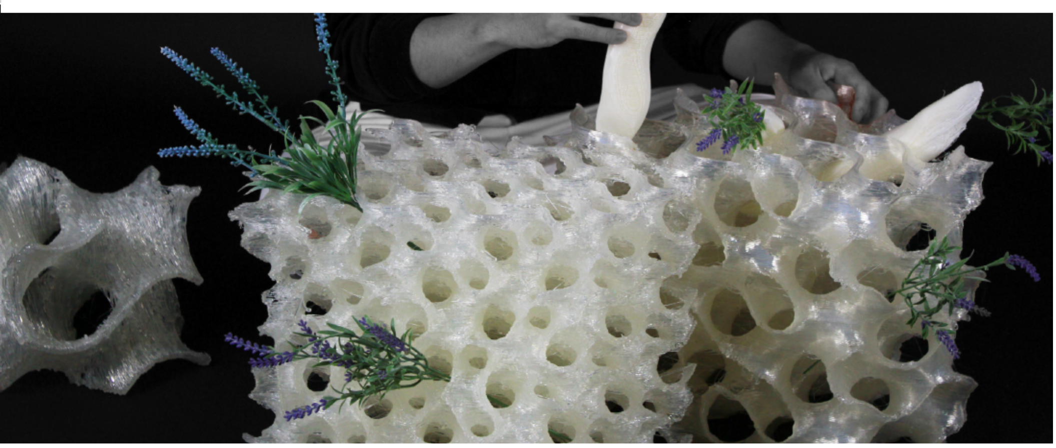
ICDF 2016

2nd International Conference on Digital Fabrication

TOKYO

MARCH 3-5





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ICDF2016

Proceedings of 2nd International Conference on Digital Fabrication

2016 Tokyo, March 3-5

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BEST PAPER AWARD

ofxEpilog: An openFrameworks addon for controlling an Epilog laser cutter. Mutsuhito Ando, Kiyoshi Suganuma, Fumie Takahara, Takayuki Ito, Kazuhiro Jo

BEST POSTER AWARD

Nursing x FAB: Development of Self-Help Tools Through the Use of 3D Printers. Junki Yoshioka, Shoko Miyagawa,　Hiroya Tanaka, Taiki Iwamoto, Kanae Oyama

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OPENNESS APPROACHES of PRODUCT DESIGN in the DIGITAL FABRICATION

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Abstract

In the recent years, the applications of digital fabrication in the small quantity manufacturing have gained significant attention and keep growing. Somehow, the main advantage of digital fabrication are based on the high flexibility of manufacturing mass derivative styles, therefore, the optimisation and convergence of design solutions in the traditional design thinking is losing their necessities. The traditional design process can't react congruously the design needs of digital fabrication. The designer should lead the external needs or design intensions from people to boost designs in the digital fabrication, and the open connection is called as design openness. In this paper, several design approaches will be listed to explain the new role of design openness in the future digital fabrication.

PRACTICAL APPLICATIONS IN MANUFACTURING

Under the effect of crowdfunding and maker movement, the personal fabrication oriented machines became affordable and down sized. Not only making the prototypes, the digital fabrication has been applied on the small quantity and precision manufacturings for decades. In recent years, there are new trends are increasing the occupancy on practical manufacturing as below:

3D Printing Service

These service providers, such as Shapeway Inc or i.Materialise Inc, offer the designers the industrial 3D printing service, the display platform, delivery and payment system. The service covers most business process for designers and attracts them to upload 3D models and set the end price by themselves. The products on the 3D printing service are made when order occurred, and only the digital fabrication can satisfy this mass style, small quantity and irregular orders.

Crowd-funding Product

In this kind of cases, digital fabrication is not only the technology to make the product prototypes, but also the solution of small quantity manufacturing. Due to these product proposals are limited by funding shortage in the beginning stage, so the entrepreneurs apply the digital fabrication as the alternative manufacturing solution to strive for investment until they can obtain enough funding for making mould. The digital fabrication can decrease the funding requirement and failure risk.

Open Source Design

This special design approach shares full manufacturing data in digital files to unspecific people and enable them to produce the same product by the digital fabrication machines, and it's also called as 3D fax. Due to abandon the product monopoly and business profit, the open design usually is a kind of public welfare, social design or experimental project, and could archive the purpose of local production and product evolution by crowd resource. The most famous sample is the RepRap, the open source of low cost 3D printer.

TRADITIONAL DESIGN THINKING IN THE DIGITAL FABRICATION

Although the digital fabrication is attracting attention from above applications now, the most designers are still applying traditional design thinking of mass production on these digital fabrication. In many cases, the designers just applied the digital fabrication as an alternative manufacturing to save the cost of mould making temporarily. The main intension behind these small quantity manufacturings is decreasing risk of the immature mass production, not providing diversity product by digital fabrication.

Single Style of Mass Production

Single design style is a characteristic of mass production, because it's limited by the mould manufacturing technology. The mould manufacturing is an expensive and precise engineering that has been developed for almost a century, and the making process is almost irreversible and unmodifiable. Once the mould is made, it has to contribute thousands pieces of same product until its life end to balance the cost. Therefore, the design thinking of the mass production is focus on how to decide the final style for the mould manufacturing, and the style should be the best choice among the many design solutions generated by designers. That's why the optimisation have played the important role in the modern design process for decades.

Optimisation in the Digital Fabrication

The design optimisation usually means the externalising process of design concept to find the balance under the considering various conditions of engineering and marketing, such as product performance, cost reduction, customer preference and etc. In the practical operation, it is inferring the best solution from mass design parameters for designers or decision maker, meanwhile this process also abandons other valuable solutions based on different considerations.

Somehow, the digital fabrication is a different technology compare to the injection mould manufacturing, so the single style is not the premise for it. Different styles from the same design concept may matches different customer's need and be endowed the value to be produced. Therefore, the optimisation method is not absolutely necessary in the digital fabrication. Instead, the diversity of design concept should be enriched as possible.

Bounded Design System in the Traditional Design

However, the most designs are generated by its designer or limited team members that include few designers and engineers, and such bounded design system is limited by team members' time, human power and information to produce very few and narrow solutions. The design process is almost mono-directional linear, and usually be restarted only when the product or mould lifecycle end. Compare to the flexibility of digital fabrication, this traditional design method can't react congruously. The design process of digital fabrication should be an open, dynamic, automatic and interactive cycle to apply its advantages, and the design openness is the critical factor to solve this need.

DESIGN OPENNESS AND APPROACHES

Before the digitalisation of design in the 90's, the design process was proceed by using sketch, engineering graphics and physical models, and these media are difficult to be exchanged and distributed at that era. After the rise of CAD, this change allowed the design content can be transferred in the digital format, but the design contents can't be modified easily. Under the consideration of mass production and business secret, there is no motivation to make the design content to be opened. The reversible design history function of software is only restricted to inner development members. Besides, different formats and softwares of making content also form the barrier in exchanging files between professional designers or engineers.

Due to the popularisation of digital fabrication and maker movement in the recent years, this trend triggered people's desire in designing and making, and boosted a wave of highly digitalisation and automation of design. More 3D-printing oriented CAD software and mobile Apps are released and aim at makers and non-designers. The programming tool of CAD start the research of design automation, such as Grasshopper for Rhino, Python and Processing. The development of above open tools created the interface and possibility and allowed the external system or unspecific people to access the design process and apply them. Several approaches of design openness are listed as below by the order of open range.

Parametric Model

The concept of parametric model came form the modelling history function of engineering CAD, and it applies the parameters to adjust model features and build geometric relationship between features. This function is favourable for engineer to modify the model iteratively. Now this concept is extracted and embedded into programable CAD software, called as the parametric model. The parametric model can be applied to generate different modelling variations by non-designers, and the modelling process and programming structure are also able to be edited. This approach

Open Design

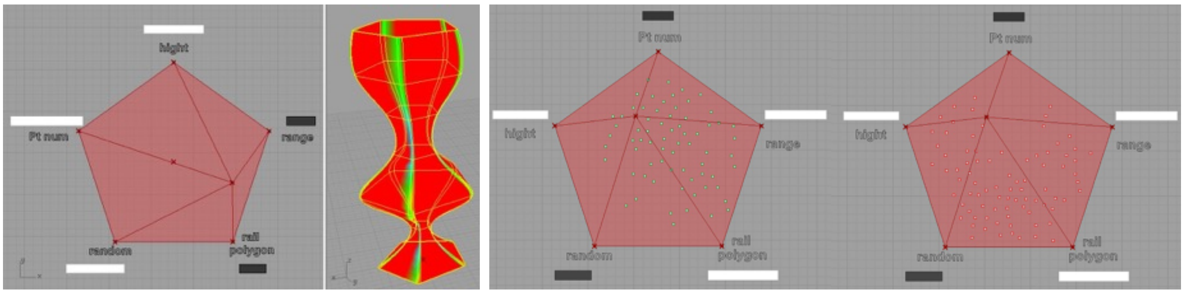
The trend of open source has started from open software of 90's, open hardware and so on. Now corresponding to the digital fabrication, the open source is extended to the product design, and based on the digital fabrication machines as the premise. The open design has two levels, the fist level is sharing fixed design data and step guide for people to produce the same product, if the machines are available there. There are many known on-line platforms provide the service and allow users to share data for free. The second level is updating the design, and that means people who can access the design can contribute improvement on this design by modifying the data. This approach can create various design branch that match different needs.

Customisation

In the personal product sales, many attempts allow customers to edit product configuration from mass modular options to archive product personalisation, such as NikeID. Since the popularisation of programable CAD and digital fabrication, the CAD system can recompose the product model and fabricate a unique style. The customisation service is rising in many business and platforms, because this is an efficient way to collect mass product parameters from objective people. To archive this goal, an on-line parametric system is necessary. From the viewport of openness range, this approach attracts people who are motivated by the concrete need, and involved them into the design process.

Big Data

The practical operation of big data is very common in the search engine and E-business. The software engine or background program collects and analyses the keywords or browsing data to generate recommended options to users. The calculated result is changing dynamically by collecting data, and update the output in realtime. This approach is also theoretically feasible in the customisation service. The customisation system can collect the parameters from valid sales or customers' operation, and conclude the popular setting of product, reversely, the system can attempt cold arrangement to form mutations to adjust the range of parameters. Above figurations show a simple experiment of form evaluation, a multiple-parameters map on the left is applied to present the vase features, and the vases that got positive or negative evaluations are marked on the map. The result can help the system to recommend potential parametric setting to customers.



CONCLUSION

Only few years, the digital fabrication has demonstrated its possibility in the complement of potential market that mass manufacturing can't satisfy. The design thinking of digital fabrication should not stagnate in the ear of mass production. The digital fabrication is not only an alternative option of manufacturing, and it connects the operation of design stage and customer behaviour firmly.

The design diversity and needs are generated in unimaginable speed and in everywhere. The openness is an approach to afford design service by digital agent for anyone who can access, and break the bounded mode of traditional design. These approaches are recommended to the designers who concentrate on applying digital fabrication and build the design access for external objective.

REFERENCES

1. Neil Gershenfeld, FAB-The Coming Revolution on Your Desktop, **2005**.
2. H. Tanaka. Fablife, 2013.
3. Barry Schwartz. The Paradox of Choice, US: Harper Perennial, **2004**.
4. Krishnapillai Anandasivam and Elivio Bonllo. A Generative Design Strategy for Product Design. Conference of Design Cognition and Computation, **2006**.
5. JY.Li. The Open Innovation Collecting Platform Based on the Mass Customization and Generative Design Technology, Conference of Mass Customisation and Personalization Conference, **2011**.

Implementation of a Course with 3D Printing for Cultivating Creativity in Non-Art Major Students

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Abstract
We designed and implemented a course for cultivating students' creativity using three-dimensional (3D) printing as a main tool. We set various exercises requiring students to create 3D objects to represent their conceptual ideas. Some students reported that they became aware of several important aspects of a creation process, as they executing various assignments repeatedly. At the same time, observing students' outcomes and behaviors, we found that many students do not show the progress as we expected. After seeing this result, we strongly felt the need of modification of the course design at some aspects. This article reports our experience of implementing the course and observations. We also report our plan to improve the curriculum by reflecting upon class experiences accumulated to date.

Keywords: Course Design, 3D Printer

INTRODUCTION
As three-dimensional (3D) printers are becoming cheaper and easier to use, many universities are adopting them as tools for education. 3D printers are reportedly successful in raising students' creativity in crafting objects [1,2]. Thus, we decided to conduct a class using 3D printers to achieve two major objectives: first, for students to learn the 3D printing technique so that they would be able to use it as a tool for making necessary parts of their own creation; second, to increase students' awareness of the importance of imagining the user experience in designing objects for a given theme. These objectives were set because we consider these skills as beneficial in the creation of interactive media contents, which were among the major themes that students undertake as graduation study topics. Learning these topics with the use of a new tool was expected to inspire creativity in students.

We started a class and had been running it for the last two years. Before the class started, we expected that it would automatically boost students' motivation and help them formulate various ideas independently by solely employing 3D printers. The expectation was based on the reported success of this procedure. However, an unexpected outcome was that most students were not able to conceive new ideas. They rather thought of common gadgets, such as a smartphone cover, or simple parts, such as rectangular and circular cylinders. We concluded that the students were curious about using 3D printer in general as a new technology but they did not have concrete ideas of the purposes of their imagined gadgets. It would be easier if the course's objective was to teach the use of a 3D printer. However, cultivating creativity presents a difficult task as this is not a matter of passing knowledge on to students. Moreover, most students were not trained in artistic creation nor accustomed to create objects from scratch based on their ideas. As such, the course design was modified to make the course more effective for achieving the course's original objectives. In this article, we report our experience of implementation of the class, including the observation of its outcomes and reflection of its effects. We then propose modifications for the course.

INITIAL COURSE DESIGN

Our initial attempt was to install another course of digital fabrication at our university. We also tried to emphasize the aspects of creation of ideas. This course was prepared for second- and third-year students. We received up to 24 students each semester. There were 15 classes in one semester and were held three hours a week. We prepared 3D printers and allocated one for every two students (see Fig. 1). The courses had the working definition of creativity as “an ability to conceive various ideas.” Therefore, several tasks were assigned to students. Each of the tasks required them to conceive of unique designs. We expected that giving short-term assignments repeatedly would accustom the students to the creation process.

Fig. 1. Students at work (left), 3D printers (right)

Table 1 shows the current syllabus of the course. We decided not to proceed with using 3D printer and digital tools from the beginning. Clay and paper materials were used first to let the students be more explicitly aware of creation and idea conception. Students were trained in four to five weeks on the how of 3D printers and digital modeling software as almost no student had experience in the use of these tools. After the students learned to use a 3D printer, they began to work on various assigned tasks to conceive ideas and materialize them as 3D objects.

Table 1. Course Syllabus

Week	Description
1, 2	Design workshop using clay and paper
3, 4	Use of 3D printer
5, 6	Modeling tool variation
7, 8	Materialize an abstract concept
9, 10, 11	Create a “movement”
12, 13, 15	Create a “play” (final assignment)
15	Presentation and discussion

RESULTS AND OBSERVATION

As the last of the task sequences, we set an assignment that required a creation of objects to be produced as “play.” The students were permitted to create anything they want as long as it inspires “play,” but it would be better if they could produce something new. Figure 2 (left) shows a work of various parts that are similar in shape to the Japanese *kana* characters. The parts had magnets at their endpoints so that they could be mutually connected. One can create a character-like figure by combining multiple parts freely. Combinations could even create character-like figures with a 3D structure, a feature not offered by flat, 2D written text. This work offered the fun of freely creating combinations and discovering unexpected figures. Figure 2 (right) shows rollers that can produce various marks by rolling them on sand. Different rollers would produce different marks, such as an imitation of a dog's or a human's footprints and various textures on sand surface. We rated these works highly because they succeeded in offering fun with their object's design itself but not making objects as the parts of a game and rely on a game design for offering a fun.

Fig. 2. Character-like shapes (left), and rollers to leave trails on sand (right)

At the beginning of the course, however, the students were slightly confused by the unfamiliar tasks. With the task of conceiving an idea to a concept represented by onomatopoeic words like "boom" or "bang," they could not imagine a shape from what they felt about the word. They thought of attempting to make models of concrete objects that cause the situation the words represent rather than molding figures directly borne out of their feelings. Further, the students tended to create something they already knew rather than try to conceive new ideas. When asked to create something "interesting," they tended to create something similar to the things they thought were interesting without being consciously aware that they were borrowing others' ideas. Figure 3 shows such examples. The works shown in the left of Figure 3 are taken after Japanese traditional toy "Kendama (cup and ball)", and the work in the right is just another puzzle game. These works are only recreation of existing toys and no new idea is observed. Moreover, the students were not well aware of the type of models a 3D printer can produce. They used the printers to create objects like a simple circular cylinder or a plane panel, which could be easily prepared by any other means. We believed that an explicit instruction is necessary for the students to avoid such tendency.

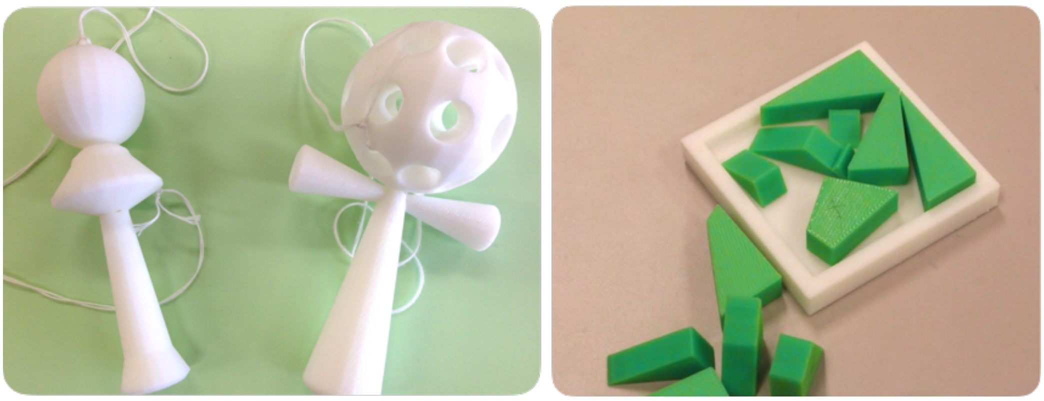

Fig. 3. Students' works taking after traditional toys

MODIFICATIONS

After conducting the course several times, we modified certain task contents. By observing the students' works, we attempted to elicit student creativity by applying certain constraints to a task rather than giving students freedom in deciding what to make. When they were asked to create anything they want, they spent most of their time deciding mainly what to make before they start to ponder or develop their own designs. This prevented them from conceiving new ideas and led them to create things similar to already existing items or common objects. We redesigned the tasks so that they define in more detail what the students need to create. By presenting a goal with a narrower scope, students can concentrate directly on developing their own ideas as they can skip the stage of thinking about what to make.

Another aspect we modified was the variation of modeling tools introduced to the students. At first, we taught them with only one standard CAD tool, which constructs a figure by composing and transforming primitive geometries. The representation was limited with only one approach; not so many variations were observed in the outcomes. Currently, we introduced several tools of different approaches to give them a wider modeling selection. We regarded the variation of tools as important to let students have ideas more freely without worrying how to materialize them.

EVALUATION

We obtained the students' responses to the course from their reports on their assignments. According to their responses, they became aware of certain important processes for being creative. Such awareness was learned not from the instructors but by going through multiple tasks themselves and comparing their work and processes among one another. As regards the task to materialize abstract concepts or onomatopoeic words, certain students described in weekly reports that they found the differences of their modeled figures interesting; such a variation stemmed from the identical concept or target. They noted that this process taught them how they were trapped by a fixed image, seeking the correct answer rather than conceiving original ideas. They also commented that this made them aware of the importance of having multiple viewpoints when brainstorming. Another student commented on the importance of repetitive improvements for molding an idea and producing a better result. We regarded this as an extremely important process for students to become aware, as the students tend not to change their designs as they hold onto their first idea, even when instructed to develop their design. We appreciate that certain students became aware of it through the tasks.

PROPOSAL FOR FURTHER IMPROVEMENT

The current syllabus is not yet suitable and effective for our students. We are aware of the need for further improvements on certain aspects other than the problems and modifications mentioned earlier. One such aspect is that the course is currently packed with too many tasks. We believe that undertaking various problems repeatedly to learn the creative process is an effective approach. However, a tight schedule seemingly prevents the students from having sufficient time to reflect on their experiences. We would like to propose certain amendments on course design as discussed in the following.

First, it is difficult to have an appropriate evaluation of student performance [3]. At present, we evaluate students by the quality of their works, weekly reports, and presentation and demonstration, which serve as their final assignment. There is a need to emphasize the elaboration of developing and improving one's idea. To achieve this, the final assignment should be set in threefold: allow the students to create a starter idea and further develop such idea two more times. This change requires a reduction in the number of tasks currently assigned to the students or allowing them to work on their project outside of class hours. In either way, we will be able to score a student's performance by evaluating the progress of the work rather than by the quality of the final work. Apart from the evaluation issue, the students must be made aware of the importance of changing and evolving ideas repeatedly, which should be reflected in their created figures.

Second, we currently spend a large part of the course in teaching the use of the tools, which seems to be a waste of time better spent by the students in creating tasks. This problem can be resolved by establishing a permanent workshop laboratory where students can learn the use of the tools and use them freely. We need this facility to lessen the time consumed for teaching the use of the tools during regular class hours. We do not mean it would be better to substitute the class with such a laboratory. Indeed, the complementary use of a class and laboratory is expected to offer a wide range of benefits. We also expect that having a permanent workshop laboratory will help in the issue of maintenance for the printers, which are frequently out of order.

CONCLUSIONS

We designed and implemented a course aimed at cultivating students' creativity by introducing digital fabrication as a tool. We believed that it could be ideal to allow the students create anything they have conceived without constraints, as in the case at MIT [1]. However, designing a more compact practice set within our limited resources and time is necessary. Moreover, the skill level of our students is almost elementary in terms of the use of the tools and creating original ideas. Even the course is performed under these conditions, we observed a change in students' recognition in the mode of creating ideas. Although a small achievement, it would be an excellent outcome considering that the course is a new attempt and has only started. Digital fabrication and the related tools can stimulate the students' interests. This process helps them understand that various approaches exist during the creation stage. It also helps them understand that there are fun and achievement obtained through thinking more freely.

REFERENCES

1. N. GERSHENFELD, *Fab: The Coming Revolution on Your Desktop–from Personal Computers to Personal Fabrication*. Basic Books, 2007.

2. T. L. HEMSATH, Searching for innovation through teaching digital fabrication. In *28th eCAADe Conference Proceedings*, 2010, 21–30.

3. J. LARMER, How can we teach and assess creativity and innovation in pbl? http://bie.org/blog/how_can_we_teach_and_assess_creativity_and_innovation_in_pblcan, February, 2014.

Memory of Things (MoT)
Interactive memory product design

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Abstract
The things in our daily life, which contain a rich "memory of life," should already be familiar to the senior. With these things, as well as enhancements in emotion, memory, and narration, this study intends to design the interactive memory products with better adaptation for the senior. The project “Memory of Things (MoT) –Interactive old things memory system” for the senior's Reminiscence activity is proposed.

INTRODUCTION

Most home-based technology-aided products that are currently available on the market are designed for the needs of seniors. The design emphasis is often on the technology itself, instead of its ease of use, thus leading to poor acceptance by users. More attention should be given to the interaction between "people" and "things" and the product’s usability. In recent years, Ecological approach and Affordance, proposed by the psychologist Gibson, for the design of technology-based interactive products have gradually received more attention in Computer-Human Interface design (Gibson, 1999; Murphy, 1999). Moreover, emotions may be generated because of engagement, usage or events between people and people, people and things, and people and space. Memory is eventually generated when time is factored in. The well-known psychologists Mihaly Csikszentmihalyi and Eugene Rochberg-Halton (1981) note in their book The Meaning of Things, that people like certain things in their life because of their connection to their memory. The authors reach this conclusion using a theory of Psychology and analytical tools that are used in sociology. A special story gives a thing a significant meaning, thus making it emotionally attractive, triggering one's sentiment to the past, to make connection to memorize.

"Home" is the origin of human memory. "Things" in life become the carrier of memories throughout life. Unfortunately, most of the technology-aided design cases still put too much emphasis on technology and not enough on the more human aspects, such as emotion and memory. In fact, the "memory of life" has stronger and special significance for seniors because physiologically speaking, seniors’ short-term memory weakens gradually over time while their long-term memory grows stronger by comparison. Psychologically speaking, seniors develop a sense of loss because they have an awareness of the end of life and thus lose interest and faith in the future. As a result, they begin to voluntarily remember their life stories and arouse their sentiment for the past. As a promoter of narrative research, American researcher McAdam believes that each senior’s "story of life" is an important unfolding memory that the individual experiences and is an interpretation of such an experience. If the senior is given the opportunity to narrate their own life story, the caregiver can easily and clearly understand the needs of the senior and provide better assistance and care.

In conclusion, several questions should be considered in elderly design: (1) how should the technology-aid interactive product be designed to enable the senior to accept and adapt to the product? and (2) what requirements should the interactive product design meet to cope with the seniors’ habits for interaction and cognition in daily life? With these questions in mind, this study intends to emphasize seniors' interactions with people, things, and the environment on the basis of the above-mentioned psychological theory. The things in daily life, which contain a rich "memory of life," should already be familiar to the senior. With these things, as well as enhancements in emotion, memory, and narration, an interactive product design with better adaptation for the senior can then be provided with the help of the Internet and technology.

RESEARCH METHOD

Based on the Research-through-design approach (John Zimmerman, 2007), a product design approach is proposed that is better adapted to seniors. Meanwhile, subjects, such as the enhancement of the memory of life through old things, are studied to help establish an emotional relationship between the senior and other people and between the senior and their family.

Step 1. Data Analysis: Thirty seniors between the age 50 and 90 were surveyed and interviewed for the collection of (old) things of life and relevant stories that triggered the senior's emotion for "home." In this step, children or grandchildren of the senior interviewed the senior and recorded the results. Habits developed over time and cognition of daily life were understood through the insight gained from close involvement with the senior's life. It is particularly important to allow the senior tell their story of the old things or their own memories. The recordings were then organized in the format required by the questionnaire. In addition to text, sound and photos were also recorded.

Step 2. Design Concept: This step began by taking materials from the interview data and background stories and continued the development of design guidelines, design ideas, interaction scenarios, and drafting. The development of design guideline included the effort of organizing and choosing old things in Step 1, plus adding technology-aided functionality, interaction mechanisms, and so on. Once done, the collection of relevant old things then began in preparation of prototyping interactive design in Step 3.

Step 3. Information Framework: Based on the information framework "Body-Cerebellar-Brain"[note 1] and the WhizCARPET sensor pad as activity sensors, both developed by the Gerontechnology Research Center, Yuan Ze University, the customized interaction design may be achieved through an APP with user-adaptable parameters. In the meantime, social network sites such as Facebook are included the interaction platform.

Step 4. Design Prototype: Digital fabrication techniques, such as 3D printing, laser cutting, 3D scanning, and CNC milling, are employed for the customized repair of the old things of life and replacing damaged parts. Further, with the addition of interactive devices, such as control chips, sensors, and so on, not only can the objects function according to their original purposes but also provide adaptive technology-aided interactive functions.

Note 1: The system "Body-Cerebellar-Brain" consists of hardware (Body), a controller (Cerebellar) and a mobile device (Brain). The mobile application is the "Brain," providing users with various features for data entry and displaying information; the interaction device that employs a micro-processor as its controller is the "Cerebellar", which handles the operation of algorithm and basic I/O signal control and is responsible for motor control and signal feedback. The device itself is the hardware, which is named the "Body."

DESIGN PRINCIPLES

This study proposes that the project be named "Memory of Things (MoT) –Interactive memory product" for the senior's Reminiscence activity. This memory system design guideline is as follows:

1. **Do not re-design a new thing, but repair the old things in home**. First repair the old or damaged things that the senior is familiar with. Then, add to the repaired object technology-aided interaction functions. Adhere to the principle of "bringing an old thing to new life," but avoid damage to the original features of the old things.

2. **Choose the things that belong to the "home" and leave unforgettable memories or those that are rich in the story of life**. Things in this category include magnets on the refrigerator, photo albums, clip book (newspaper clippings, ticket stubs), diary, letters, jewelry box, gift ornaments, souvenir (from travel), first purchased objects (for wedding, new-born), old sofa, old electric fan, old TV, sewing machine, phonograph, radio, old cars, and so on.

3. Understand the background story of the senior and **provide customized product design**.

4. **Provide a carrier of memory**. The collection and organization of emotional attachment between the senior and their children ach is achieved through the interactive product and the social network (Facebook) that aims to bring intimacy. An individualized family "story network" is established with the hope of facilitating a cross-generation communication that is rooted in "showing concern for others in daily life". The product that contains sentiment for the past thus becomes a memory carrier.

5. **Provide an interaction mechanism for "Environment, Things, and People**." Design an interactive product that links the environment, the things and the senior in daily home activity.

DESIGN PROTYPES

This study collected the damaged vintage fan and old lamp from seniors and has been completely repaired by the aid of digital fabrication techniques. We reproduced parts on these old staff by scanning, modelling and then 3D printing. Some damaged parts were replaced by 3D printed parts and laser cut elements (Figure 1). Meanwhile, we embedded the Micro-controller (Arduino YUN), input devices (sensors, storage module), and output devices (speakers, motors, LEDs) on these old staff. Later we completed the electronic circuit and programing (Figure 2). Finally, the vintage fan and old lamp connected to the internet via WIFI, to send and retrieve data. We did a lot of try and errors in the process of fabricating, circuit mounting and programing. Figure 3 shows the completed vintage fan and old lamp, it remains the same appearance but the functions already enhanced to adapt the seniors' daily life and extend to become an interactive memory system with the help of the Internet and technology.

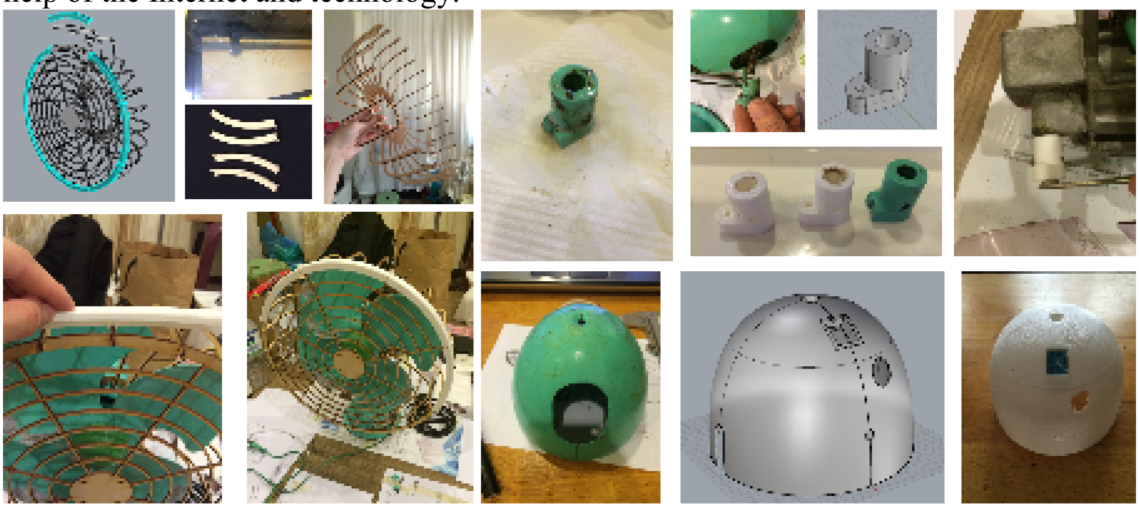

Fig. 1. Repairing process aided by digital fabrication techniques

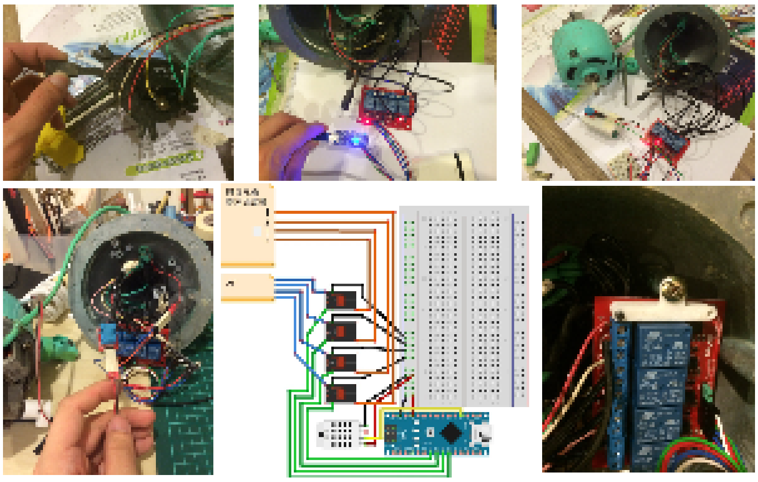

Fig. 2. Embedded the micro-controller, circuit mounting and programing

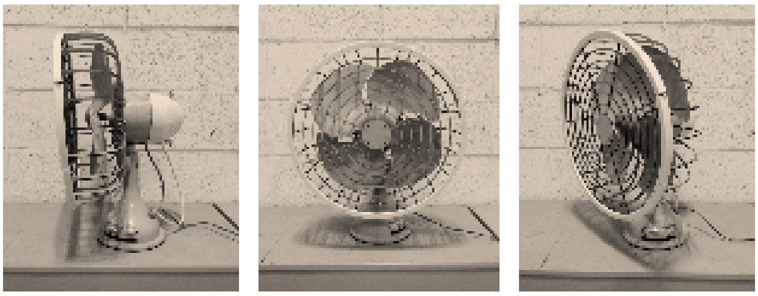

Fig. 3. The completed vintage fan

CONCLUSIONS

The prototype of the interactive fan and lamp are completed in this study. It is hoped that the interaction mechanisms of "Environment, Things, and People" for individualized MoT may be applied to more things that trigger sentiment for the past, link more "memories of life", and allow the senior to recall, with the aid of technology, a richer and more full story of their life. Furthermore, this study concludes The MoT interactive mechanism information framework as shown in Figure 8. User test will be the next step of our research aim, and we will test these interactive old things in the living lab of Gerontechnology Research Center in Yuan Ze University.

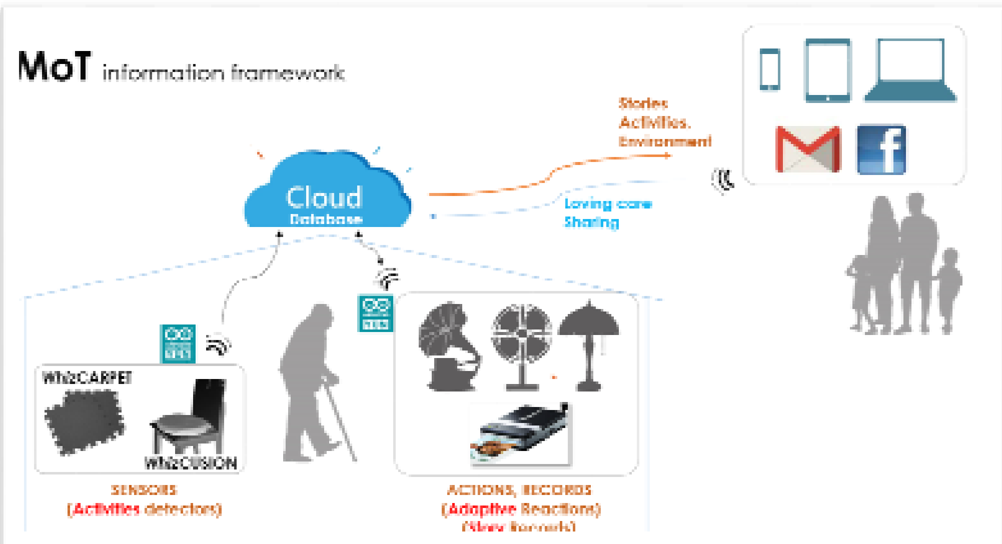

Fig. 8. The MoT information structure

REFERENCES

1. Csikszentmihalyi, M. and Rochberg-Halton, E. (1981). The meaning of things – Domestic symbols and the self. Cambridge University Press.
2. Gibson, J. J., (1977). The Theory of Affordances, in R. E. Shaw and J. Bransford (eds.), Perceiving, Acting, and Knowing: Toward An Ecological Psychology. Lawrence Erlbaum Associates, Hillsdale, NJ, 67-82
3. McAdams, D. (1993). The Stories We Live by： Personal Myths and the Making of the Self. New York: Morrow.
4. Murphy, R.R. (1999). Case Studies of Applying Gibson's Ecological Approach to Mobile Robots, IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 29(1), 105-111.

An Interactive Fabrication System that Allows Users to Edit a 3D Model during 3D Printing

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INTRODUCTION

Digital fabrication (including 3D printing) is becoming increasingly common, and is having a significant impact on current manufacturing methods. 3D printers that can form high-precision 3D objects are being utilized in a wide variety of applications, from personal fabrication projects to commercial product prototyping.

However, in current 3D printing process, 3D printers are utilized in the final stage of printing to produce the completed 3D model. The 3D models are designed with modeling software during the pre-printing stage (as shown in Figure 1, top). Currently, 3D printers are not used in the initial design stage, because 3D models are typically incomplete at this stage owing to lack of clear goal. In addition, it is often necessary to use trial and error (i.e., modifying the 3D model) to improve a design after an object is printed; in this case, users must remove already printed objects from the printer platform and reconfigure printing parameters.

In this paper, we present an interactive fabrication system that allows users to edit a 3D model during the printing (Figure 1, bottom). Our technique allows users to edit non-printed areas of a 3D model during printing by intervening in the communications between the 3D printer and the host application controlling the printer (Figure 2). This system provides a new fabrication environment that integrates printing with 3D modeling; it not only speeds up the trial and error process, but also allows users to create 3D models during printing. We describe the mechanism in our system in detail and discuss the capability of this technique.

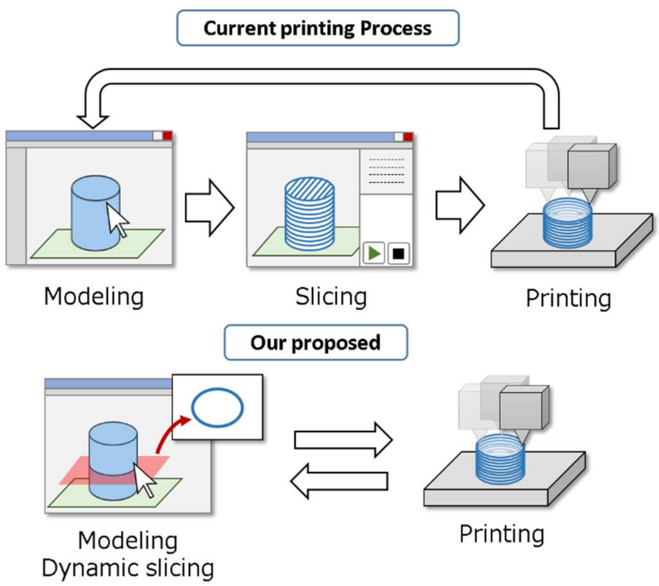

Figure 1. Comparison between current 3D printing process and our proposed.

Figure 2. Editing during printing

RELATED WORK

Willis et al. [1] use the term *Interactive Fabrication* to describe a fabrication environment that allows users to edit the design of object while it is being printed. *Interactive Fabrication* is characterize by the capability to accommodate real-time input/output from user; this allows users to interact directly with the material via fabrication machines, similar to the manner in which brushes or chisels are used to paint or sculpt. Therefore, users can establish a closer relationship with materials and reflect their creativity while printing objects. Willis et al. present a series of prototype devices that accept real-time input/output to fabricate physical forms, and investigate the capability of *Interactive Fabrication* [2]. In a similar vein, *Interactive Construction* [3] can interactively control a laser cutter. Using a laser pointer, users directly create cutting instructions for materials placed on a laser cutter platform. Traditional 3D printers do not have this interactivity, and each part of the process is separate; 3D models must be modified before/after printing. Our technique allows trial and error during printing, and uses a 3D printer as a part of an interactive system for early stages of design.

In the field of human-computer interaction, there is a significant amount of research on the 3D printing speed. Muller et al. studied the feasibility of increasing 3D printing speed and reducing printing time by lowering the fidelity of 3D models [4]; this system reduces the 3D printing area by replacing a portion of the 3D model with bricks or acrylic material cut by a laser cutter. Our technique does not aim to reduce printing time; however, if users can effectively edit a 3D model during printing (to modify a modeling error, for example) it is possible to reduce overall processing time, including the time required for trial and error.

SYSTEM

In this section, we describe the mechanism used by our technique, and discuss the prototype system we implemented to demonstrate it. This system is implemented as a host application to control 3D printers. We employ the visual language vvvv[1] to implement our system, and we practically apply this to ATOM[2], a 3D printer based on fused deposition modeling.

Methods that allow 3D model to be edited during printing

A host application converts inputted 3D model data (i.e., an STL file) into commands by slicing models into print head movement path layers. These commands are written in *Gcode*, which is the most widely used numerical control programming language. Gcode is used mainly in computer-aided manufacturing to control automated machine tools. A host application sends the code to 3D printers sequentially, and printing is completed step by step. We leverage this mechanism to allow 3D models to be edited in the middle of printing.

However, in a general host application, we cannot access a 3D model or Gcode when printing begins, because 3D models are converted into Gcode all at once. In contrast, our system writes each printed layer as a partial 3D model; only the parts required for printing are sliced into Gcode.

Process Pipeline

The pipeline of our technique is shown in Figure 3. First, the system calculates the points where the 3D model intersects with two plates: a lower plate placed at the current printed position, and an upper plate positioned one layer above the lower plate. A partial 3D

[1] http://vvvv.org/

[2] http://genkei.jp/atom2/

model is generated from these intersection points and written to the specified STL file. This process is repeated from the lowest to the highest point of the 3D model (where no additional intersection points exist).
Next, the system converts the partial 3D model in the STL file into Gcode. For this process, we used CuraEngine[3], which is open-source slicing software operated by our system (via command line execution). CuraEngine can import a configuration file containing runtime arguments; through this file, we can specify parameters such as printed layer height, internal structure configurations, and printer head speed. Users can modify this configuration file as needed; for example, the top and bottom layer defined by the Gcode can be changed to solid (to achieve a structure density of 100%). We removed the start and end codes returned by CuraEngine from the Gcode. These codes are useful for regular printing, but caused layer-shifting errors in our system. We also added a movement command to the end of the Gcode. This movement prevented printed objects from being melted by the heat of the printer head.

Finally, the system sends this Gcode to the 3D printer sequentially, and the 3D printer begins printing. When the printing of a layer is complete, the system generates and slices the next layer, increasing the height of the two plates. In the middle of this printing process, the system allows users to edit 3D model areas above the printed layers, which avoids interference with the printing process.

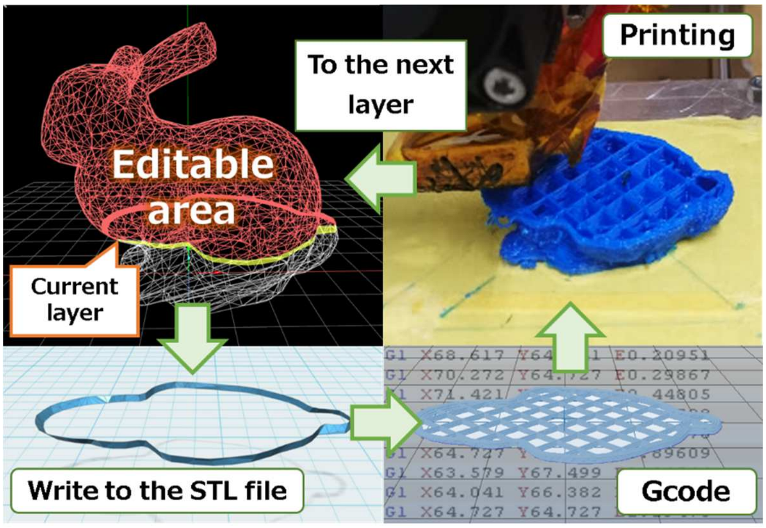

Figure 3. Process pipeline

DISCUSSION

Using our technique, an improved 3D printing process and fabrication environment are realized. Our technique allows users to begin printing with a view toward editing during printing; thus, it is possible to modify a 3D model in the middle of printing or create a 3D model while printing. This printing process is expected to improve printing efficiency. For example, if 3D models have a common lower part (such as the base seat shown in Figure 4a), users start printing first, and then create the upper area of the 3D model during printing.

In general, 3D modeling is an iterative process and users are able to repeatedly modify 3D models using digital software. In our technique, an object that is already printed has an irreversible character, and the non-printed area is created in consideration of previously printed layers. When our system is used to print entire objects, it is possible to engage in

[3] http://reprap.org/wiki/Cura

creative activities that could be characterized as improvised modeling (Figure 4b). Of course, users can use traditional 3D modeling software to print an object and switch the 3D model during printing (Figure4c).

There are a couple of limitations in our system and the process that allows editing during printing. The support structure for stable printing cannot be pre-calculated prior to the printing process. It is well-known that 3D models with overhanging parts cannot be printed without support structures. In our technique, however, these overhanging parts may be created during printing. To address this case, we may need to add support material dynamically during printing, or set up a modeling constraint that prevents the generation of overhanging parts.

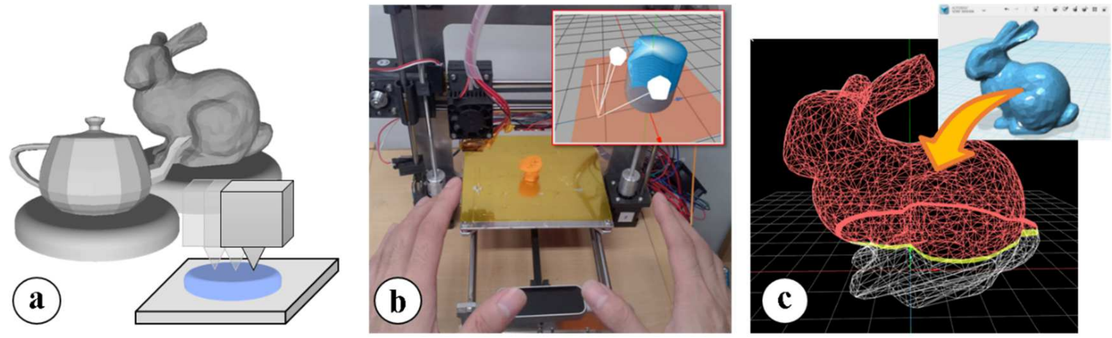

Figure 4. System usage. (a) 3D models with a common lower part. (b) Improvised modeling. (c) Switching the printed object while using traditional 3D modeling software.

CONCLUSION

In this paper, we presented an interactive fabrication system that allow users to edit a 3D model during printing. We described our system's mechanism in detail and discussed the capability of this technique.

We regard 3D printers not as machines that produce completed 3D models but as an interface for creating designs. Therefore, we believe that developing good relationships between people and 3D printers is vitally important. Our technique provides opportunities to integrate design into the fabrication process, and contributes to the discovery of new 3D printing capabilities. In future work, we plan to improve the user interface of our system, and conduct a user study to further evaluate our 3D printing techniques.

REFERENCES

1. Willis, K.D.D., Xu, C., Wu, J.K., Levin, G. and Gross, M.D. Interactive Fabrication: New Interfaces for Digital Fabrication. In *Proc. of TEI'11*, pp. 69-72, 2011.
2. Interactive Fabrication - New Interfaces for Digital Fabrication. http://www.interactivefabrication.com
3. Mueller, S., Lopes, P. and Baudisch, P. Interactive Construction: Interactive Fabrication of Functional Mechanical Devices. In *Proc. of UIST'12*, pp. 599-606, 2012.
4. Mueller, S., Beyer, D., Mohr, T., Gurevich, S., Teibrich, A., Pfisterer, L., Guenther, K., Frohnhofen, J., Chen, H.-T., Baudisch, P., Im, S. and Guimbretière, F. Low-Fidelity Fabrication: Speeding up Design Iteration of 3D Objects. In *Proc. of CHI'15 EA*, pp. 327-330, 2015.

Development of the 3D Food Printing System for Japanese Sweets

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INTRODUCTION

3D printing system is revolutionary technology that is changing the way we fabricate products. The main material used for 3D printing system is plastic in diversity at present. The appearance of the 3D printing system which can fabricate a metal objects is expected in the near future: metal is bigger than plastic in strength. On the other hand, 3D printing system attracts attention in the fields of artificial food or medical instruments. The 3D food-printer is expected to fabricate different examples of food, and the 3D bioprinter makes creature cells and organs. The author developed the 3D food printing system for Japanese sweets in so-called Project Study which is one of the subjects in the machine system course at Tokyo tech high school of science and technology. This paper describes its developmental process and surveys the future of the 3D printing system.

3D Food Printing System

What is 3D printing system?

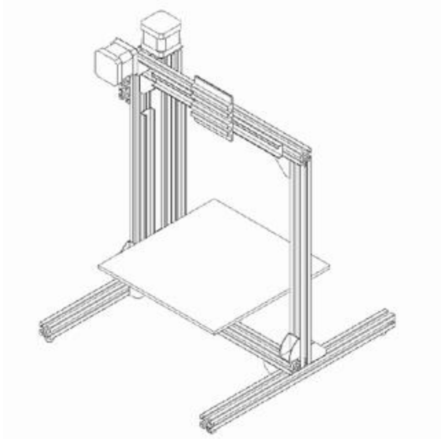
3D printing system is known as additive manufacturing (AM), refers to various processes used to synthesize a three-dimensional object. Fused deposition modeling（FDM）is a typical 3D printing system which works on an additive principle by laying down material in layers. A plastic filament is unwound from a coil and sent to the extruder which heats and melts it. FDM-type 3D printer is known as RepRap which is human-first self-replicating manufacturing machine general-purpose. RepRap is an abbreviation of Replicating Rapid Prototyper, and it is an open-source 3-D printer, under development with the goal of being able to print all the components which are used to fabricate it[1]. These printers can take various forms and sizes. For that reason, RepRap has become the most widely-used 3D printer among the global members of the makers communities.

The use of 3D food printing system

3D food printing system is to laminates raw food and fabricate three-dimensional objects. It offers a great potential to realize of customization at the macronutritional level, allowing users individualize the amounts of calcium, protein, etc, in their meals. It can also help people cut down the amount of chemical additives in their food and reduce overconsumption. Systems & Materials Research Corporation got $125,000 grant from NASA to create a prototype of his universal food synthesizer in 2013. This printer is designed to print a pizza and provides astronauts a nutritious alternative to the canned and freeze-dried prepackaged foods. The different use of the food printing system is realization of personalized soft diets for older people suffering from chewing and swallowing. Instead of putting a regular meal in the blender, a softer version of a favorite food could be printed by using this printer. A lot of food printers have appeared recently; chocolate printers, pancake printers, candy printers, sugar-based confectionery printers. These printers can fabricate three-dimensional shapes which have been difficult by using the former conventional methods. 3D food printing system has not been widely spread and may not fabricate great-tasting food right now. However, they are getting better every year.

Potential of 3D food printing system

Hod Lipson who is an American robotics engineer recognizes food printing as being at a very primitive stage, but with huge potential for a profound impact. If this technology can warm its way to printing in food and biotechnology from printing in plastic and metal, they will become large-scale industry[2]. Seeds & Chips International Conference and Exhibition was held in Italy in March 2015[3], and IoF(= Internet of Food) which was a concept like IoT(=Internet of Things) was introduced which has a similar concept.



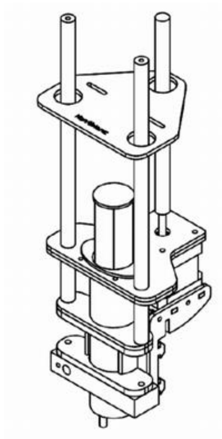


Fig.1 Frame of the RepRap **Fig.2 Extruder of the Food Printer**

This is a new concept that the digital technology such as Internet technology brings innovation in food. In being much more aware of information of the food security, transparency for the process of production, and increased health-consciousness through the Internet, 3D food printer system will be expected to play more significant role in food itself and processing. The objective of this study is to focus on the look, the shape, the aesthetic of the 3D food printer system, and to remodel a self-made RepRap printer into the remodeled 3D food printer system for Japanese sweets.

Development of the 3D Food Printing System

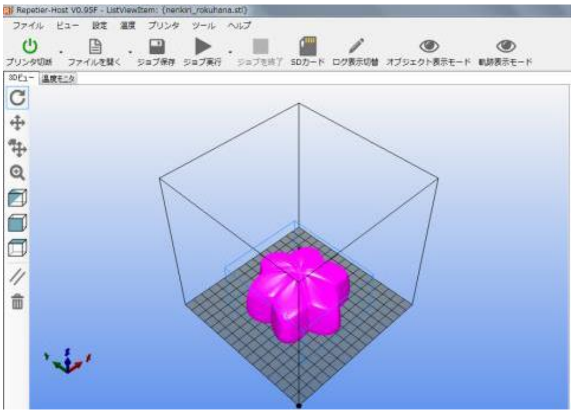
RepRap 3D Printer

RepRap 3D printer is an open design one. All of the designs produced by the project are released under a free software license. Due to the self-replicating ability of the machine, author envisions the possibility to distribute RepRap units reasonably to people and communities, enabling them to fabricate complex products without the expensive industrial infrastructure. We have been interested in self-made 3D printers and fabricated the RepRap 3D printer in 2013 for the first time. By fabricating RepRap 3D printer on our own, we could deepen understanding of hardware and software about 3D printers. And we also felt difficult in accuracy concerned with alignment of the nozzle and the bed, and the setting of the software. The following year four of the students at Tokyo tech high school of science and technology remodeled this RepRap 3D printer into the 3D food printer in the class of Project Study which is the subject students work on research in a group at machine design course.

Design Concept for 3D Food Printing System

The major improvements: having changed the extruder of RepRap 3D printer to syringe, and having corrected the control program associated with this change. The content of hardware and software will be explained in details as follows. Main food materials are whipped cream and white bean paste.

Hardware : the size of the body is 325mm in width, 350mm in depth, 413mm in height, and that of the printing range is 160mm in width, 160mm in depth, 160mm in height. Fig.1 shows a flame of the RepRap. The capacity of the heated bed is 120W, and the pushed head is 40W. The main body consist of four stepper motors, two heaters with temperature sensors, three limit switches, one power unit, and control board which is called RAMPS（RepRap Arduino MEGA Pololu Shield）, etc. Newly designed extruder was fabricated to print food. Fig.2 shows an extruder of food printer. It pushes out food by one stepper motor using the purchased syringe. The turn of the stepper motor is converted into movement to push a syringe through the threaded rod. The main part where large amounts of weight is loaded was made of metal, and the other parts made of plastic materials, by using a 3D printer and a laser cutter.



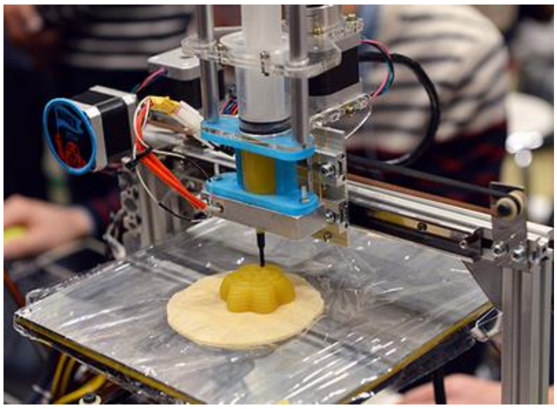


Fig.3 Screen of the Repetier-Host **Fig.4 Food Printer for sweets**

Software : Repetier is software operating 3D printer, which consists of Repetier-Host and Repetier-Firmware. The latter one reads 3D data about the objects which is made by 3D CAD in STL file. This format approximates the surfaces of a solid model with triangles. 3D data can be moved, rotated, and scaled by the software. After a shape is settled, Repetier-Firmware interprets the G code that shows the order of movement of nozzle, and sends a movement signal to a control board RAMPS. It performs temperature management of an extruder and a bed using PID control. A slicer software which makes G-Code is diverse. Even if we use the same STL file, the results of 3D printing are different. In this study, we used Slic3r installed in Repetier. The diameter of nozzle of food printer is larger than that of the regular one which prints a plastic model. Therefore, we had done experiments again and again to change parameters which increase layer height, change a filling rate and speed of the nozzle. Fig.3 shows the screen of the Repetier-Host.

Materials : whipped cream and white beans paste were used for this 3D Food printer. Although whipped cream is softer than white beans paste and able to print by low torque, it is easy to melt after laminating at the normal temperature. In addition, it may be collapsed by own weight. White beans paste was purchased in powder form. After having added water and sugar, and it was heated into paste . White beans paste can be colored by food coloring agent. White beans paste was easy to use because there were few viscous changes by the temperature. Fig.4. shows the picture of 3D printed white beans paste which was colored yellow. Referring to Nerikiri, 3D food printing system for Japanese sweets was developed. Nerikiri (literally, made by kneading) is a Japanese type of unbaked cake that is made by mixing and kneading its ingredients, which are white bean paste, gyuhi (a kind of rice cake made from refined rice flour or glutinous rice flour with sugar and starch syrup) and Chinese yam.

RESULTS AND DISCUSSION

Experimental results

The parameters with good lamination are as follows. Whipped cream: nozzle diameter 5.0mm, layer height 4.5mm, nozzle speed 30mm/s, infill 0% White bean-paste: nozzle diameter 2.0mm, layer height 2.0mm, nozzle speed 2.5mm/s, infill 30%. In either material, the number of the shells which will set the thickness of the exterior wall is two layers. Raft, support, and skirt are unused. Capacity of the syringe is 60 ml. In the case of white bean-paste, the nozzle was heated to 45 degrees Celsius to increase fluidity. We made the stepper motor rotated in the reverse direction for pushing out the syringe in the right direction, and changed the rotational speed of threaded rod to 300mm/s. After having done several trials and errors, we were able to develop 3D food printing system for Japanese sweets. But 3D food printing system still has many challenges to overcome. Printing by using food materials is much more difficult than that of plastic.

Issues and improvements

Three of the issues and their improvements are described below. As the process on putting materials in syringe is hand-operated, it takes time and labor. In order to solve this problem, fully automatic process of putting materials to 3D print is necessary. Because the capacity of the syringe is no less than the maximum volume of 3D printing, it is not possible to print more than the maximum one. In order to solve this problem, device of the supply materials continuously is needed. It is difficult to define the physical properties of food unlike plastic and metal, and especially the grasp of the viscous change by the temperature is important. A database of food materials or the sensors which can measure physical properties in real time is necessary.

Participation in exhibition

We exhibited this 3D food printing system in Maker Faire Tokyo 2014 held in Tokyo Big Sight, which was paid attention to mass media a lot, such as newspaper companies, televisions and Internet News [4].We were very surprised to see the people who are more interested in 3D food printing system as we had expected. We have developed the automatic makers for fried egg, miso soup, and hamburgers so far at the high school where I used to work. It is quite difficult to break an egg before cooking by the automatic machine though a human can do it easily. Whenever we fabricate an automatic cooker, we are always impressed with the excellence of the physical motions. Therefore it is said "hand-made food is more delicious than machine-made food! " It depends on sensibility of personal preferences. Nowadays we have been surrounded by a diversity of foods produced by an automatic food machines. That is how we have been exposed to such processed food even if we still admire hand-made food.

CONCLUSIONS

We developed the 3D food printing system which prints Japanese sweets by using whipped cream and white beans paste. It was better to laminate white beans paste was able to color it red and yellow by using food coloring agent. After having searched for the most suitable parameter by several experiments for adjusting, which laminated the column well and could finally print the shapes, such as cherry blossom, star, heart and frog, etc. Though there is room for the improvement in speed and precision about current one[5], we cannot help imaging the prosperous future concerning food which gives us nutrition in our daily life connects with Internet and a computer. We feel much attracted to the keyword called IoF as well as IoT which has appeared in recent years. When people first heard about microwaves they did not understand the technology, but nowadays almost every family possesses a microwave. 3D food printer is supposed to become common as well as the microwave, isn't it? 3D food printing system may spread as people enjoy food according to the personal tastes and nourishing management, which can be tasted in vision, not as the mass production in the factory. The data should be collected by various sensors connected to the Internet according to the private favor.

REFERENCES

1. RepRap , http://reprap.org/ , [Accessed on line 24 December 2015]
2. H.Lipson, M. Kurman. Fabricated: The New World of 3D Printing, *Wiley,* **2013**.
3. Seeds & Chips , http://seedsandchips.com/ ,
   [Accessed on line 25 December 2015]
4. Make Japan:,http://makezine.jp/blog/2014/11/mft2014_wagashi_3d_kadota.html [Accessed on line 26 December 2015]
5. K.Kadota. Guidebook of 3D printer, *Kodansha Blue Backs,* **2015**

DESIGN OF 3D-PRINTED PROSTHETIC LEG IN A LOW COST

Yutaka. Tokushima1*, Yoko. Kurata, Tsuneo Masuda2

INTRODUCTION

The progress of 3D scanning and 3D printing technology is about to provide us the possibility of a low cost prosthetic leg's production. The recent research on applying digital fabrication to prostheses making instead of traditional hand working can archive advanced performance and affordable price. A prosthetic leg has the great demand in developing countries especially. For example, in the Philippines, average annual income of poor families is PHP 69,000 (approximate USD 1,500) (Philippines Statics Authority 2013), and it means that income per person is PHP 15,000 (approximate USD 320). However, the price of the lowest-cost prosthetic leg is PHP 8,222.41 (approximate USD 175) in our survey. Therefore, 91.8% of amputees never purchase the prostheses at a such price (Bundoc 2010). Besides, currently the main cost of a prosthetic leg's production is hand processing charges that is PHP 4,583.35 (approximate USD 97) and occupies almost 55.7% of whole cost. The digital production flow of a prosthetic leg, included 3D scanning of patient stump, creation of 3D data and 3D printing, can reduce the workload of *Prosthetist and Orthotist* and the cost of above 55.7%.

According to some previous researches on a 3D-printed prosthetic leg's production, it is revealed that there are some prosthetic legs produced with some new parts printed by 3D printer instead of usual ones (Doubrovski 2015) (Nayak 2014) (Herbert 2005). On the other hand, it is shown that making a whole prosthetic leg by 3D printing is unprecedented. Therefore, I designed the new type of prosthetic leg that is specialized for 3D printing. I also fabricated the new prototype by the 3D printer as below and verified whether the test participant could stand stably and walk normally with it.

MATERIALS AND METHODS

Verification of conventional product

There are many patients who need prosthetic legs because of various lower limb amputations. In this paper, we focus on the *Trans-tibial prosthetic legs (below-knee prosthetic legs)* for amputees who keep the knee, because the amount of Below-Knee amputees occupies about half (49.6%) of lower limb amputees in the case of Kobe City, Japan (Chin 2014).

Fig. 1. Desing of exoskeletal prosthetic leg (Left) and design of endoskeletal prosthetic leg (right)

The main part of the *exoskeletal prosthetic leg* (Left of Fig. 1), that is ordinary low cost prosthetic leg made in developing countries like the Philippines and India, has a whole plastic structure. It is affordable cost relatively. However, because it is composed of integrated one plastic structure, it is difficult to replace any parts. In many cases, the patient's stump part transforms because of a body habitus change. Moreover any prosthetic leg becomes decrepit with time. That is why the patient has to re-make the whole new prosthetic leg again and again, and the long-term expense of renewing is getting higher.

Besides, the *endoskeletal prosthetic leg* (Right of Fig. 1), that is ordinary high cost prosthetic leg, is composed of some independent parts. Therefore, maintenance or replacement for transformed stump or decrepit parts of a prosthetic leg is allowed. However, some required parts of *endoskeletal prosthetic leg* are made by high-end metal manufacturing, and not available in target area basically. Hence, procurements depend on import from overseas and the price of these parts is expensive as the result. This is the current situation of the *endoskeletal prosthetic leg* that exists as an hi-end product served for the rich of a small population disproportionately in developing countries.

Basic design of prosthetic legs with 3D printing

The task of the new design of a prosthetic leg is reduction of initial and running costs for long-term using, and realization of the low cost *trans-tibial prosthetic legs*. As mentioned above, basically the material cost of *exoskeletal prosthetic legs* is low. In addition, the advantage of *endoskeletal prosthetic legs,* easy-adjustment, extends its lifecycle. The new design aims at the best cost, adopting above merits of both types of prosthetic leg. This new prosthetic leg is divided into three parts and each part is repairable and replaceable by easy-adjustment (Fig. 2). Using this new design prosthetic leg, the 1st verifying test was conducted.

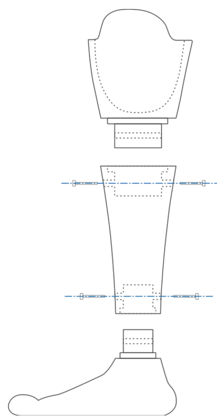


Fig. 2 New design of prosthetic leg.

Selection of materials

Recently, FDM (Fused Deposition Modeling) type 3D printer is known as the cheapest kind of 3D printer. It has a possibility to distribute in rural areas of developing countries as equipment of prostheses making. Moreover, various materials for FDM type 3D printer are popularized. However, the market prices per kilogram of special materials are two times higher than general materials such as ABS and PLA. In addition, current *exoskeletal prosthetic legs* distributed in developing countries are made of thermoplastic resin such as ABS and PLA, and it has plentiful evidences as the structural material. Besides, PLA is easy to process as compared to ABS. Therefore, PLA is selected as the structural material for the new design prosthetic leg in this paper.

Generally, flexible materials, such as rubber, elastomer and CFRP (Carbon Fiber Reinforced Plastic) or thin metal in the shape of flat spring, are utilized to make a part for a foot joint of *Trans-tibial prosthetic legs* in order to make walking more smooth. The new design had the foot joint made of the flexible material, "FABRIAL R" of JSR Corporation (JSR 2015) (Left of Fig. 3) during the verifying test. Moreover, I examined the alternative foot joint made of a general silicon rubber (Center of Fig. 3) made with 3D-printed mold (Right of Fig. 3) for any difficult case to obtain the materials of some specific brands in developing countries.

Assembly

The new design prosthetic leg is consisted of three parts, and two kinds of assembly manufacturing are conducted as below. The first one is screwing. Convex portion and concave portion of the prosthetic leg are fixed from the side with the screws. The second one is gluing. Two parts having flat surfaces are glued.

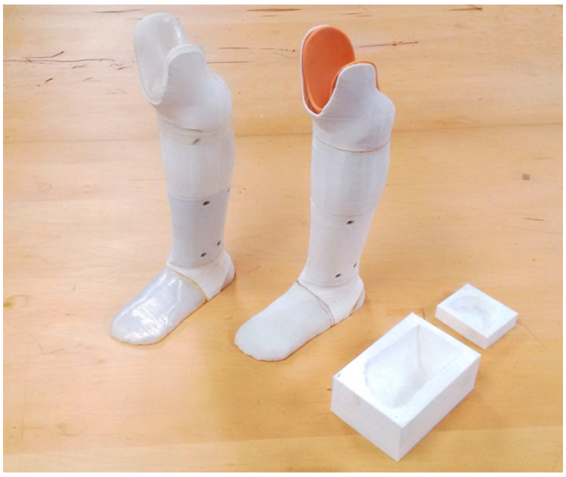


Fig. 3 The foot joint is made with “FABRIAL R” (left), and the foot joint is made with silicon rubber (right). The mold is printed by the FDM printer (Bottom right).

RESULTS AND DISCUSSION

Verifying method

In the verifying test, the test participant wore both kinds of prosthetic leg as shown above (Fig. 3), and test events included standing stably test and normal walking test. The test participant tried to stand and walk for at least 3 minutes. The test participant was a teen-age female amputee.

Verifying basic design of prosthetic leg with 3D printer

In the verifying test, the test participant wearing both kinds of prosthetic leg was able to stand stably and walk without any problem. The result indicates that the our new design has no critical defect in terms of composition, and producing all parts of a prosthetic leg in a full digital production flow is possible. Hence, as mentioned above, the possibility of cost cutting by digitalization is clarified.

Verifying the materials

Both the prosthetic legs had not transformed and damaged during the verifying test, even though it was a short-term test. The result showed the possibility that PLA as one of general plastic materials for FDM printing is qualified as the structural materials. Moreover, according the test participant’s feedback, she had not felt any pain and special difficulty at all during both of the standing test and the walking test, as compared to the prosthetic leg that she usually wore. Besides, the parts made of flexible materials for a foot joint also had worked well in the verifying test. They had kept the basic function to absorb shake force and keep positions for other parts while the test participant

Fig. 4 Verifying test

was walking or standing. The result revealed both materials are useful for producing joints of prosthetic legs.

Verifying the Assembly

The two ways of assembly, screwing and gluing are functional for basic materials as mentioned above. However, PLA and silicon rubber are not suitable materials for the new design required assembly of multiple parts, because both materials limit on using the kind of glue. It is difficult to assemble with a general or high-performance adhesive that can purchase easily anywhere, such as the two-component epoxy adhesive. In the verifying test, the special glue is utilized in order to assemble materials. However, the affordability and availability of this kind of glue in developing countries are severe, especially in rural area. For example, Iloilo City, one of a our verifying test field in the Philippines, required to import from abroad for getting this kind of special glue.

CONCLUSIONS

In this paper, the new design of full 3D printed *trans-tibial prosthetic leg* could pass both of the standing test and the walking test for 3 minutes. This result indicates the possibility that realization of the full digitalized production flow for prosthetic leg making. Therefore, this result also demonstrates the potential of remarkable cost reduction for the prosthetic leg and making equipment for it in the digital production flow.

REFERENCES

1. Bandoc, J, R. 2014. The Challengess of “Walking Free” form Disability, ACTA MEDICA PHILIPPINES, Vol. 44, No,2.
2. Chin, T. 2014. Amputation. In: Ito T, Akai M, ed. 2014. Check point of prosthesis. Tokyo: Japanese Orthopedic Association. pp. 47-89.
3. Doubrovski, E,L, Tsai, E, Y, Dikovsky, D, Geraedts, J, M, P, Herr, H, Oxman, N. 2015. Voxel-based fabrication through material property mapping: A design method for bitmap printing. Computer-Aided Design, Volume 60.
4. Herbert, N, Simpson, D, Spence, W, D, Ion, W. 2005. A preliminary investigation into the development of 3-D printing of prosthetic sockets. Journal of Rehabilitation Research & Development. Volume 42, Number 2. pp. 141–146.
5. JSR Corporation. 2015. JSR's FABRIAL™ R Series of 3D Printing Filaments at the FAB11 -Soft and Flexible Filaments Enhance the Potential of 3D Printing-. [web] Philippines Statics Authority. Available at: <http://www.jsr.co.jp/jsr_e/news/0000613.shtml> [Accessed 30 Dec 2015].
6. Nayak, C, Singh, A, Chaudhary, H. 2014. Customised prosthetic socket fabrication using 3D scanning and printing. AM 2014 Technical Paper.
7. Philippines Statics Authority. 2013. Filipino Families in the Poorest Decile Earn Six Thousand Pesos Monthly, (Results from the 2012 Family Income and Expenditure Survey). [web] Philippines Statics Authority. Available at: <https://psa.gov.ph/content/filipino-families-poorest-decile-earn-six-thousand-pesos-monthly-average-2012-results-2012> [Accessed 30 Dec 2015].

3D Bioprinting for tissue engineering application

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INTRODUCTION

In recent times, the scaffolds used for cell culture have been vastly diversified. Notable deviation from conventional two-dimensional (2D) cell culture models to three-dimensional (3D) tissue constructs has been witnessed. These changes in the microenvironment between two models bring about a difference in cell responses. Rapid prototyping techniques help in such situations wherein the complex 3D structure of the scaffold can be controlled easily [1].

3D bioprinting technology is becoming widely popular as it is capable of 3D printing host of biomaterials, different types of cells and additional growth factors into a multifaceted functional living tissue. The next step to this would be organ printing that is 3D tissue-engineering of living human organs. This involves computer-aided layer-by-layer assembly of biological tissues and organs. Besides organ transplantation, 3D printed organs can be applied for screening assays for drug discovery and testing further biomedical research [2].

3D PRINTED SCAFFOLDS

To start with 3D-printing was applied to a number of biomaterials to fabricate a highly porous, interconnected 3D scaffold for tissue engineering application. 3D-printed polyethylene (PE) scaffolds with 20–50% porosity showed a tensile strength up to 4 MPa, and no toxicity to human osteoblasts [3]. 3D printed β-tricalcium phosphate (β-TCP) scaffolds were used to study the effect of pore size on human fetal osteoblasts. The decrease in designed pore size from 1000 to 750 and 500 mm resulted in an increase in proliferated cell density [4]. Detsch and colleagues showed monocyte differentiation of multinuclear osteoclast-like cells on 3D printed calcium phosphate (CaP) ceramics [5]. Hydroxyapatite scaffolds with high surface areas showed no cytotoxicity and adequate cell adhesion with MC3T3-E1 fibroblast cells [6].

Composite of hydroxyapatite (HA) and poly (vinyl) alcohol have also been 3D printed for bone tissue engineering applications. These scaffolds had an average total porosity of 55% and exhibited non-designed porosity within the bulk structure as observed through computed tomography analysis. These characteristics help in osteoconduction and osteointegration and the imperfect packing of 3D printed parts result in rough topography, altogether beneficial for bone tissue engineering applications [7]. Low temperature 3D printing of composite calcium phosphate and collagen scaffolds hold great promise for fabricating synthetic bone graft substitutes [8].

BIOPRINTING OF CELL LADEN CONSTRUCTS

3D scaffold architecture have the benefit of enhanced cell-matrix interactions, cell densities and cell-cell contact. Additionally, these structures are also capable of having improved nutrient, oxygen and waste diffusion and more effective blood vessel ingrowth. Hence, culturing cells on such 3D scaffolds have these advantages but also suffer from non-uniform cell distribution and/or insufficient seeding deficiency. As a solution, 3D bioprinting techniques can be used to analyse the plausibility of fabricating scaffolds with live cells and tissues [1].

In vitro study of organogenesis of liver tissue using 3D printed poly (L-lactic acid) (PLLA)/poly (lactic-co-glycolic acid) (PLGA) scaffolds has been studied. Seeding a mixture of hepatocytes and endothelial cells on this scaffold gave rise to the preferred tissue structure [9]. High cell viability was seen in 3D printed alginate hydrogel-embedded multipotent stromal cells and chondrocytes. Characteristic extracellular matrix (ECM) formation was seen both in vitro and in vivo [10]. Billiet et al. carried out encapsulation of the hepatocarcinoma cell line (HepG2) in gelatin methacrylamide scaffolds. The constructs had 100% interconnected pore network in the gelatin concentration range of 10-20 w/v%, with high cell viability (>97%) [1].

GROWTH FACTOR RELEASE AND DRUG DELIVERY USING 3D PRINTED SCAFFOLDS

a. 3D printed scaffolds with growth factors

Growth factors are essential for tissue engineering applications to regulate cell proliferation and differentiation. For instance, vascular endothelial growth factor (VEGF) controls endothelial cell proliferation and bone morphogenetic protein-2 (BMP2) induce osteogenic differentiation of mesenchymal stem cells (MSCs). Organ printing methods process (hydrogel) materials under moderately mild conditions, hence, growth factors such as BMP2 or VEGF can be incorporated into the scaffold without loss of their bioactivity. The localized delivery of growth factors have various advantages over systemic delivery such as controlled release pattern, dose reduction, and negligible side effects. Controlled delivery of (multiple) growth factors into printed scaffolds can bring about enhanced cell recruitment, proliferation and differentiation. Phillippi et al. showed the differentiation of muscle derived stem cells to osteogenic lineage under myogenic conditions on printed ECM containing BMP-2 [11].

b. 3D printed scaffolds as drug release matrices

3D printed scaffolds have also been employed for drug delivery applications. Geometry, pore size and connectivity of the scaffold are the factors to be considered to control drug loading and release rates in vivo. Gburek and group studied the adsorption of a combination of antibiotics such as vancomycin, ofloxacin, and tetracycline onto different compositions of 3D printed calcium phosphate scaffolds. Precise control over the release profile was achieved opening the window for a wide range of treatments for different patient groups [12]. 3D printed calcium phosphate scaffolds were also used by Yuan and colleagues for bone excision repair and time-release treatment of tuberculosis. [13]

ECM AS BIO-INK

3D printing excels in producing scaffolds with controlled properties. Since these scaffolds are made of synthetic materials, they have the drawback of limited biological functionality. Cell-laid mineralized ECM was shown to enhance the cellular response. The ECM is known to regulate cellular adhesion, proliferation, migration, and differentiation and also effect cell responses. Therefore, a microenvironment which mimics the natural ECM would lead to enhanced biological cell responses.

Pati et al. used a composite of PLGA, polycaprolactone (PCL), and β-TCP and mineralized ECM laid by human nasal inferior turbinate tissue-derived mesenchymal stromal cells (hTMSCs) to develop 3D printed scaffolds. These ECM laden scaffolds showed enhanced bone formation in *in-vivo* models compared to bare ones [14]. Hence, in this case, ECM is used as a bio-ink, a bio-printable gel in which the cells are suspended for printing. Pati and colleagues also used decellularized adipose tissue (DAT) matrix as bioink for encapsulating human adipose tissue-derived mesenchymal stem cells (hASCs). This made possible 3D bioprinted structures with engineered porosity having high cell viability and induced expression of standard adipogenic genes without any supplemented adipogenic factors [15]. In another study, Pati and group used various types of decellularized ECM bioinks, including adipose, cartilage and heart tissues as bioink and further explored their functionalities [16].

CONCLUSION

3D bioprinting has great potential for applications in the field of regenerative medicine. Organ printing, or computer-aided layer-by-layer assembly of biological tissues and organs, is now possible and rapidly evolving. Issues such as complex tissue design and prevascularization are addressed by the organ printing approach. However, optimal cell density and cell to ECM ratio need to be optimized for obtaining a fully functional organ. For a successful 3D bioprinting, a deeper insight into the microenvironment of the tissues and organs, and their structure is imperative.

REFERENCES

[1] T. Billiet, E. Gevaert, T. De Schryver, M. Cornelissen, and P. Dubruel, “The 3D printing of gelatin methacrylamide cell-laden tissue-engineered constructs with high cell viability,” *Biomaterials*, vol. 35, no. 1, pp. 49–62, Jan. 2014.

[2] V. Mironov, T. Boland, T. Trusk, G. Forgacs, and R. R. Markwald, “Organ printing: computer-aided jet-based 3D tissue engineering,” *Trends Biotechnol.*, vol. 21, no. 4, pp. 157–161, Apr. 2003.

[3] J. Suwanprateeb, F. Thammarakcharoen, V. Wongsuvan, and W. Chokevivat, “Development of porous powder printed high density polyethylene for personalized bone implants,” *J. Porous Mater.*, vol. 19, no. 5, pp. 623–632, Oct. 2012.

[4] S. Tarafder, V. K. Balla, N. M. Davies, A. Bandyopadhyay, and S. Bose, “Microwave-sintered 3D printed tricalcium phosphate scaffolds for bone tissue engineering: 3D Printed TCP Scaffolds for Bone Tissue Engineering,” *J. Tissue Eng. Regen. Med.*, vol. 7, no. 8, pp. 631–641, Aug. 2013.

[5] R. Detsch, S. Schaefer, U. Deisinger, G. Ziegler, H. Seitz, and B. Leukers, "In vitro - Osteoclastic Activity Studies on Surfaces of 3D Printed Calcium Phosphate Scaffolds," *J. Biomater. Appl.*, vol. 26, no. 3, pp. 359–380, Sep. 2011.
[6] B. Leukers, H. Gülkan, S. H. Irsen, S. Milz, C. Tille, H. Seitz, and M. Schieker, "Biocompatibility of ceramic scaffolds for bone replacement made by 3D printing," *Mater. Werkst.*, vol. 36, no. 12, pp. 781–787, Dec. 2005.
[7] S. C. Cox, J. A. Thornby, G. J. Gibbons, M. A. Williams, and K. K. Mallick, "3D printing of porous hydroxyapatite scaffolds intended for use in bone tissue engineering applications," *Mater. Sci. Eng. C*, vol. 47, pp. 237–247, Feb. 2015.
[8] J. A. Inzana, D. Olvera, S. M. Fuller, J. P. Kelly, O. A. Graeve, E. M. Schwarz, S. L. Kates, and H. A. Awad, "3D printing of composite calcium phosphate and collagen scaffolds for bone regeneration," *Biomaterials*, vol. 35, no. 13, pp. 4026–4034, Apr. 2014.
[9] S. Bose, S. Vahabzadeh, and A. Bandyopadhyay, "Bone tissue engineering using 3D printing," *Mater. Today*, vol. 16, no. 12, pp. 496–504, Dec. 2013.
[10] N. E. Fedorovich, W. Schuurman, H. M. Wijnberg, H.-J. Prins, P. R. van Weeren, J. Malda, J. Alblas, and W. J. A. Dhert, "Biofabrication of Osteochondral Tissue Equivalents by Printing Topologically Defined, Cell-Laden Hydrogel Scaffolds," *Tissue Eng. Part C Methods*, vol. 18, no. 1, pp. 33–44, Jan. 2012.
[11] J. A. Phillippi, E. Miller, L. Weiss, J. Huard, A. Waggoner, and P. Campbell, "Microenvironments Engineered by Inkjet Bioprinting Spatially Direct Adult Stem Cells Toward Muscle- and Bone-Like Subpopulations," *Stem Cells*, vol. 26, no. 1, pp. 127–134, Jan. 2008.
[12] U. Gbureck, E. Vorndran, F. A. Müller, and J. E. Barralet, "Low temperature direct 3D printed bioceramics and biocomposites as drug release matrices," *J. Controlled Release*, vol. 122, no. 2, pp. 173–180, Sep. 2007.
[13] J. Yuan, P. Zhen, H. Zhao, K. Chen, X. Li, M. Gao, J. Zhou, and X. Ma, "The preliminary performance study of the 3D printing of a tricalcium phosphate scaffold for the loading of sustained release anti-tuberculosis drugs," *J. Mater. Sci.*, vol. 50, no. 5, pp. 2138–2147, Mar. 2015.
[14] F. Pati, T.-H. Song, G. Rijal, J. Jang, S. W. Kim, and D.-W. Cho, "Ornamenting 3D printed scaffolds with cell-laid extracellular matrix for bone tissue regeneration," *Biomaterials*, vol. 37, pp. 230–241, Jan. 2015.
[15] F. Pati, D.-H. Ha, J. Jang, H. H. Han, J.-W. Rhie, and D.-W. Cho, "Biomimetic 3D tissue printing for soft tissue regeneration," *Biomaterials*, vol. 62, pp. 164–175, Sep. 2015.
[16] F. Pati, J. Jang, D.-H. Ha, S. Won Kim, J.-W. Rhie, J.-H. Shim, D.-H. Kim, and D.-W. Cho, "Printing three-dimensional tissue analogues with decellularized extracellular matrix bioink," *Nat. Commun.*, vol. 5, pp. 3935, Jun. 2014.

A Review of Hydrogels in Droplet-based Bio-Fabrication Techniques

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ABSTRACT

The Rapid Prototyping (RP) technologies with hydrogels as biomaterials have gained tremendous popularity in Tissue Engineering applications for scaffold development, especially for the soft scaffold developments. Droplet-based RP technologies which use hydrogels as printing materials have seen growing acceptance in past decade, as they facilitate the encapsulation of living cells and improvement of cell seeding efficiency. In this review different droplet-based RP techniques have been briefly reviewed along with various natural hydrogels used for the fabricating the scaffolds.

INTRODUCTION

Tissue Engineering (TE) which aims to repair, replace or improve the functionality of ill or damaged organs using cell seeding *in vitro* or *in vivo* environment is finding as a very promising technology for the realization of the same with the help of rapid prototyping techniques [1]. While the traditional RP techniques use the thermoplastic polymers, metals and ceramics are not suitable for the living cells and bio-active proteins due to high fabricating temperatures [2]. The hydrogels containing high water content can be processed under cell friendly conditions and looks more fascinating biomaterials for incorporating the living cells and bioactive component as they can furnish an instructive, aqueous environment, simulating natural extracellular matrix [3], [4]. Most of the hydrogels like alginate, fibrin, gelatin, chitosan, collagen and hyaluronic acid have been used for the TE applications are derived from the natural polymers. These naturally derived hydrogels provide the highest cell viability and proliferation rates because of the presence of the abundant chemical signals [5]. But because of their different printability, construction of the scaffolds with these materials become the challenging. In contrast to natural hydrogels, the synthetically prepared hydrogels like poly (ethylene glycol) and poloxamer are having the better printability [6]. However, they are providing the inert environment to the living cells and hence resulting into the low viability and proliferation rates [3]. In order to deal with these difficulties bio-active compounds like peptide sequences and growth factors are added into synthetic hydrogels to use them in bio-fabrication [7].

Although considerable progress has been made in the bio-fabrication with both natural as well as synthetic hydrogels, they still have significant difficulties in fulfilling the biological and physical requirements, like complex architecture, mechanical integrity and variational degradation rates with respect to time, in order to facilitate cell migration, exit to degradation byproducts, differentiation among original cells and embedded cells and proliferation [8], [9] .

RP TECHNIQUES FOR DROPLET-BASED BIO-PRINTING.

There are many RP techniques in the area of TE which use hydrogels as a printing material and can be broadly classified as (i) Laser-induced forward transfer, (ii) Inkjet printing & (iii) Robotic dispensing. **Fig. 1.** Shows the broad classification of hydrogel based RP techniques [4], [9]. In the laser-based system, focused laser pulses induced on donor slide causes local evaporation of absorbing layer resulting in high gas pressure which propels bioink from another side. These systems provide better resolutions with high gelation rate but fabrication speeds are low [10]. The inkjet printing, in which the bioinks dispense through micro dispensing tips and small droplets are positioned precisely can be further subdivided into the three types based on the actuation methods [9] viz., (i) Electromechanical in which biomaterials are actuated with a piezoelectric material (ii) Electrothermal in which bioinks are thermally actuated. (iii) Electrostatic spraying in which bioinks actuated with voltage difference [11]. The Robotic dispensing approach to is also subdivided into the following three subcategories: (i) Pneumatic (ii) Piston & (iii) screw actuated. Generally in the robotic dispensing system, to maintain the construct shape, more hydrogel is yielded instead of positioning single droplet [4]. Each of these methods is having advantages & disadvantages.

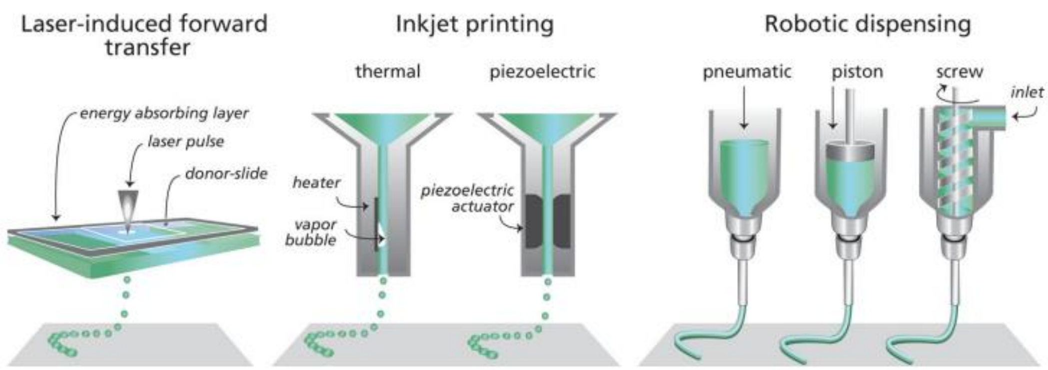

Fig. 1. Classification & working methodology of the hydrogel based RP techniques [4]

Hydrogel	Fabrication technique	Gelation method	Remark	References
Alginate	Laser-induced	ionic	High viability, Medium to high printability	[10], [12]
	Electromechanical Electrothermal Electrostatic Piston-driven Pneumatic-driven	ionic	Good printability, High viability	[13] [14] [11] [15]
Gelatin	Electromechanical Electrostatic Piston-drive Pneumatic-driven	ionic chemical thermal+chemical pH+themal	Low printability with less viscosities, poor cell differentiation	[16] [11] [16] [2]
Collagen type1	Electrothermal Pneumatic-driven	ionic+enzymatic thermal	Migrating cells	[4], [17]
Agar	Piston-drive Pneumatic-driven	thermal thermal	Good printability	[4]
Agarose	Piston-drive Pneumatic-driven	thermal thermal	Good viability	[3], [18]
Alginate+fibrin	Pneumatic-driven	ionic+enzymatic	Poor printability	[4]
Alginate+gelatin	Piston-drive	ionic+thermal	High printability, good viability	[19]
Alginate+gelatin +chitosan	Piston-driven	ionic+chemical + enzymatic	Proliferating cells	[18]

Table 1.Hydrogels used in droplet based tissue construction techniques.

HYDROGELS FOR DROPLET-BASED FABRICATION

The selection of the hydrogel for any specific fabrication method mainly relies on the physicochemical properties of the hydrogels under the conditions imposed by that method. The major properties which decide the printability of the bioink for the specific process are rheological properties such as viscosity, pseudo-plasticity, yield stress as well as the crosslinking mechanisms like ionic, chemical, thermal, enzymatic, photo-polymerization crosslinking [4]. These properties also affect the cell viabilities & proliferations. As concentration (viscosity) of hydrogel increases, the solution becomes less aqueous and reduces viability [2], [4]. **Table 1** shows the different hydrogels used for different droplet-based construction techniques. With mixing different bioinks, droplet-based as well as continuous hydrogel printings were carried out and has been reviewed.

CONCLUSION:

Currently available hydrogels with droplet-based fabrication techniques allow to design & build better architecture for bio-fabrication application. But a lot of biological and physiochemical demands of the tissues needs to be overcome by the researchers. With the new mixing of hydrogels, the new bioinks are providing better printability and in satisfying the complex requirements. But still there is a lot of scope for the optimization of both techniques as well as the properties of hydrogel and future research on the same will help in the evolution of TE.

REFERENCES

[1] T. Boland, T. Xu, B. Damon, and X. Cui, "Application of inkjet printing to tissue engineering.," *Biotechnol. J.*, vol. 1, no. 9, pp. 910–7, 2006.

[2] F. P. W. Melchels, M. A. N. Domingos, T. J. Klein, J. Malda, P. J. Bartolo, and D. W. Hutmacher, "Additive manufacturing of tissues and organs," *Prog. Polym. Sci.*, vol. 37, no. 8, pp. 1079–1104, 2012.

[3] N. E. Fedorovich, J. Alblas, J. R. de Wijn, W. E. Hennink, A. J. Verbout, and W. J. A. Dhert, "Hydrogels as extracellular matrices for skeletal tissue engineering: state-of-the-art and novel application in organ printing.," *Tissue Eng.*, vol. 13, no. 8, pp. 1905–25, Aug. 2007.

[4] J. Malda, J. Visser, F. P. Melchels, T. Jüngst, W. E. Hennink, W. J. A. Dhert, J. Groll, and D. W. Hutmacher, "25th Anniversary Article: Engineering Hydrogels for Biofabrication," *Adv. Mater.*, vol. 25, no. 36, pp. 5011–5028, 2013.

[5] D. Seliktar, "Designing cell-compatible hydrogels for biomedical applications.," *Science*, vol. 336, no. 6085, pp. 1124–8, Jun. 2012.

[6] R. Censi, W. Schuurman, J. Malda, G. di Dato, P. E. Burgisser, W. J. A. Dhert, C. F. van Nostrum, P. di Martino, T. Vermonden, and W. E. Hennink, "A Printable Photopolymerizable Thermosensitive p(HPMAm-lactate)-PEG Hydrogel for Tissue Engineering," *Adv. Funct. Mater.*, vol. 21, no. 10, pp. 1833–1842, May 2011.

[7] C. a. DeForest and K. S. Anseth, "Advances in Bioactive Hydrogels to Probe and Direct Cell Fate," *Annu. Rev. Chem. Biomol. Eng.*, vol. 3, pp. 421–444, 2012.

[8] F. O'Brien, "Biomaterials & scaffolds for tissue engineering," *Mater. Today*, vol. 14, no. 3, pp. 88–95, 2011.

[9] T. Billiet, M. Vandenhaute, J. Schelfhout, S. Van Vlierberghe, and P. Dubruel, "A review of trends and limitations in hydrogel-rapid prototyping for tissue engineering," *Biomaterials*, vol. 33, no. 26, pp. 6020–6041, 2012.

[10] B. Guillotin, A. Souquet, S. Catros, M. Duocastella, B. Pippenger, S. Bellance, R. Bareille, M. Rémy, L. Bordenave, J. Amédée j, and F. Guillemot, "Laser assisted bioprinting of engineered tissue with high cell density and microscale organization," *Biomaterials*, vol. 31, no. 28, pp. 7250–7256, 2010.

[11] W. Zhang and X. He, "Encapsulation of Living Cells in Small (∼100 μm) Alginate Microcapsules by Electrostatic Spraying: A Parametric Study," *J. Biomech. Eng.*, vol. 131, no. 7, p. 074515, 2009.

[12] S. Catros, F. Guillemot, A. Nandakumar, S. Ziane, L. Moroni, P. Habibovic, C. van Blitterswijk, B. Rousseau, O. Chassande, J. Amédée, and J.-C. Fricain, "Layer-by-layer tissue microfabrication supports cell proliferation in vitro and in vivo.," *Tissue Eng. Part C. Methods*, vol. 18, no. 1, pp. 62–70, 2012.

[13] T. Boland, X. Tao, B. J. Damon, B. Manley, P. Kesari, S. Jalota, and S. Bhaduri, "Drop-on-demand printing of cells and materials for designer tissue constructs," *Mater. Sci. Eng. C*, vol. 27, no. 3, pp. 372–376, 2007.

[14] K. Arai, S. Iwanaga, H. Toda, C. Genci, Y. Nishiyama, and M. Nakamura, "Three-dimensional inkjet biofabrication based on designed images," *Biofabrication*, vol. 3, no. 3, p. 034113, 2011.

[15] X. Shi, W. Wang, and A. Wang, "pH-responsive sodium alginate-based superporous hydrogel generated by an anionic surfactant micelle templating," *Carbohydr. Polym.*, vol. 94, no. 1, pp. 449–455, 2013.

[16] R. Gauvin, Y.-C. Chen, J. W. Lee, P. Soman, P. Zorlutuna, J. W. Nichol, H. Bae, S. Chen, and A. Khademhosseini, “Microfabrication of complex porous tissue engineering scaffolds using 3D projection stereolithography.,” *Biomaterials*, vol. 33, no. 15, pp. 3824–34, May 2012.
[17] K. Jakab, C. Norotte, B. Damon, F. Marga, A. Neagu, C. L. Besch-Williford, A. Kachurin, K. H. Church, H. Park, V. Mironov, R. Markwald, G. Vunjak-Novakovic, and G. Forgacs, “Tissue Engineering by Self-Assembly of Cells Printed into Topologically Defined Structures,” *Tissue Eng. Part A*, vol. 14, no. 3, pp. 413–421, 2008.
[18] M. Neufurth, X. Wang, H. C. Schröder, Q. Feng, B. Diehl-Seifert, T. Ziebart, R. Steffen, S. Wang, and W. E. G. Müller, “Engineering a morphogenetically active hydrogel for bioprinting of bioartificial tissue derived from human osteoblast-like SaOS-2 cells.,” *Biomaterials*, vol. 35, no. 31, pp. 8810–9, 2014.
[19] B. Duan, L. A. Hockaday, K. H. Kang, and J. T. Butcher, “3D bioprinting of heterogeneous aortic valve conduits with alginate/gelatin hydrogels.,” *J. Biomed. Mater. Res. A*, vol. 101, no. 5, pp. 1255–64, May 2013.

The Copyright Approach for Protecting Works of Applied Arts in the Digital Fabrication Era

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ABSTRUCT
Many of the products created by digital fabrication belong to `*applied arts*`. Whether these works of applied arts will be protected under copyright law will be dependent on the laws of each country. Therefore using an open license will not always work as in the case of typical, copyrighted works. In this paper, the author will introduce three major approaches to copyright laws in protecting applied arts, or approaches which will grant to the `authors` exclusive rights over the use of their works. Examples from different countries using these different approaches accompany these descriptions. This comparative perspective will be a foundation of policies and license designs in the digital fabrication era.

INTRODUCTION
With the emergence of the digital fabrication era, actors/artists of all types can now participate in the process of making things. In addition, an `open movement of tangible objects` is developing. Many of the products created by digital fabrication belong to `*applied arts*`, a term used in copyright law meaning that these arts have a usefulness, (in other words, functional parts), in addition to their aesthetic value, (in other words, aesthetic parts). Also, in digital fabrication, these art objects have physical bodies in addition to Digital Fabrication Source Codes. Whether these works of applied arts will be protected under copyright law will be dependent on the laws of each country. Therefore using an open license will not always work as in the case of typical, copyrighted works. In this paper, the author will introduce three major approaches to copyright laws in protecting applied arts, or approaches which will grant to the `authors` exclusive rights over the use of their works. Examples from different countries using these different approaches accompany these descriptions. This comparative perspective will be a foundation of policies and license designs in the digital fabrication era.

BACKGROUND
With the emergence of the digital fabrication era, diverse groups of actors/artists are increasingly making things. As a result, an open movement of creativity which had existed within the confines of the world of `computer software and digital contents` is now spreading into the world of hardware and design. With tangible objects becoming a part of this open movement, participants can grant interested parties an open license for their work and share it on the Internet. Many of these works are applied arts and, currently, are granted an open license based on copyright law such as `The Creative Commons License.`

However, the protection of applied arts is applied differently in each country. Some countries do not allow the copyright for works of applied arts, while others do. Similarly, in some countries, an open license becomes ineffective if creators want to share their works with an open license. In this paper, I would you to think about whether or not it will become difficult for this open movement to spread into the world of hardware and design. Personally, I do think that it will become difficult because the diverse actors cannot participate in the process of making things because of a lack of protection for their works.

DISCUSSION

Three Major Approaches for Protecting Works of Applied Arts

The author has concluded that there are three major approaches for the legal protection of such applied arts having researched such protection in the major industrialised countries. They are based on different theories of fine arts, applied arts, the role of copyright, and its relation to other relevant laws.

The Patent Approach

There are three characteristics of the Patent Approach:

(1) substantive examination and registration are used for the granting of design protection;

(2) there is no grace period and the applied arts works must meet the strict criterion of `novelty`;

(3) this protection has very monopolistic rights. In other words, there is such a thing as `*unwitting* infringement`, because awareness of the existing rights of a particular design is not a requirement for infringement.

Compared to the Copyright Approach mentioned below, the most important characteristic of the Patent Approach is monopolistic rights. In addition, there are non-cumulative protection between Copyright and Design Right in the Patent Approach.

The Copyright Approach

In comparison with the Patent Approach, the Copyright Approach has the following characteristics:

(1) design rights begin upon creation or when the design is made public;

(2) novelty is not required, but originality is;

(3) design protection has a relative strength. In other words, unwitting infringement does not exist under this approach because awareness of the existing rights of a particular design is a requirement for infringement. In addition, there are some limitations of copyright like `Personal Use`, `Fair Use`, `Quotation`.

This approach is said that it has its origin in the French `Théorie de l'Unité de l'Art`, (Theory of the Unity of Art). It should be noted that compared with the monopolistic protection of the Patent Approach, the Copyright Approach has only limited protection. In addition, there are cumulative protection between Copyright and Design Right in the Copyright Approach.

The Design Approach

The Design Approach combines both the Patent and Copyright Approaches. In the European Commission Green Papers of 1991, the Design Approach was proposed. The Green Papers narrowed design protection into two areas:

(1) the protection of the unregistered design from imitation of the same design or of a similar design would be only for a short term commencing from the first public announcement of the design in question; (ie, as is the case with similar protection under The Japanese `Unfair Competition Prevention Act`);

(2) protection is achieved when the design is registered at the Europe Design Office and then made public.

The protection is for 25 years and novelty and originality are included features of this protection. In addition, there are some cumulative protection between Copyright and Design Right in the Design Approach.

By means of this approach, if a design needs to be protected for a longer term it can have the protection renewed within a certain time frame from the initial filing. In other words, the major characteristics of this Design Protection Approach are:

(1) the scope of protection from a relatively strong one with lax criteria, to a monopolistic one with strict criteria and;

(2) the possibility to change the type of protection.

International Comparisons of Applied Arts Protection

Below is a brief review of such protection in several countries from the perspective of the three protection approaches.

The USA

The United States is a country which has adopted the Patent Approach. It seems that the protection structure of the United States covering applied arts avoids the cumulative protection of copyright and design patents and rather, tends to rely on the idea that the artistic and functional parts of an object are a `separable /severability issue`. Even for works of applied arts, the U.S. copyright law grants protection only for the aesthetic parts and not for the functional parts. It is difficult for law experts to determine which part is functional and which is aesthetic, and so at the moment, it is not realistic to ask for a decision on behalf of the actors/artists involved in digital fabrication.

France

France is a country which has taken the Copyright Approach. French copyright law`s reliance on the`The Théorie de l'Unité de l'Art`, (hereafter to be referred to as the `Theory of the Unity of Art`), implies that there are no criteria by which to differentiate between the fine arts and applied arts in relation to copyright law and thus cumulative protection is allowed.

During the 19th century, French Law scholars made efforts to come up with standards to separate copyright in arts and industrial design. They considered several methods, and they concluded that the most appropriate standard was the so-called `Artistic Value of Design`. However, in these cases it would be for the judge to decide whether or not a design was considered an art. This standard was criticised because there was, and still is, no objective tool by which to judge `artistic value` and the judgment thus becomes subjective and lacks accuracy and legal stability. Taking into consideration all of these factors, Pouillet, a law specialist, came up with `The Theory of the Unity of Art`. Modern academics such as Gaubiac criticised Pouillet`s theoretical stance, believing that if under the proposed theory of the unity of art, both copyright and design rights were allowed, then there would be too much protection. However, Gaubiac concludes that since there are no other satisfactory criteria by which to narrow the definition of art copyright, the Theory of the Unity of Art stands. Under the theory, a tangible object and the design data for that object can be protected under copyright and design rights.

Germany

In Germany, the protection of applied arts by copyright law is clearly stated in the current `Copyright Law 2-1-4`. However, the protection has not been limitless and in order to be protected under applied arts copyright law, a high degree of creativity has been required, based on `Stufentheorie` (`Stage Theory`). In Germany, copyright law and the old `Design Patent Law` have been integral parts of each other. However, with the amendment of the Design Patent Law in 2004, the situation has changed.

The new Design Patent Law clearly severs the close tie with the Copyright Law. In order to be protected under the new Design Patent Law, a newly added criterion of `discernment` has to be met. At the same time, the Copyright Law has seen some changes. In modern European copyright law, it is said that a special creativity criterion should not be required for protection. As a result, there is a current discussion going on amongst German legal specialists that the criterion requirement for `a high level of creativity to applied arts` should be abandoned. Consequently, in this case, regarding works of applied arts, the demand for the cumulative protection of copyright and design rights such as in France, seems to be gaining traction.

Japan

Like Germany, Japan has traditionally adopted the Stage Theory. However in 2015, the Intellectual Property High Court made a decision which overturned the legal reliance on this criterion. In making this decision, the IPHC stated that the criterion of a high level of creativity was not solely applicable to the applied arts and rather that the existence of the uniqueness of the artist or designer should be considered. Whether or not this idea will become mainstream thinking for Japan's IPHC is yet to be seen.

The A.I.P.P.I (Association Internationale pour la Protection de la Propriété Intellectuelle)

During the October 2012 International Congress of AIPPI, the interplay between design and copyright protection for industrial products was discussed and the following agreement emerged:

(1) copyright protection should be available for industrial products;
(2) copyright protection should be available for industrial products without the requirement for registration of the copyright;
(3) having original artistic character should be a sufficient qualification for copyright protection for industrial products;
(4) copyright and design right protection of industrial products may be excluded in so far as the shape or appearance of the product is dictated exclusively by functional considerations;
(5) cumulative protection should be made available for industrial products via both copyright and design rights;
(6) the term of copyright protection for industrial products should be independent of the term of design right protection for such products;
(7) the scope of copyright protection for an industrial product should not differ from the scope of protection normally conferred by copyright law.

It can be deduced from the above that the position of agreement is that of the Copyright Approach. However, there still needs to be a discussion about what constitutes `Original Artistic Character.`

The EU

An example of the Design Approach is the EU`s `Industrial Design Protection Scheme`. This double-track framework is comprised of a registered `*Community Design Right*`, a term meaning a unitary industrial design right which covers the European Union and an unregistered `*Community Design Right*`. This double-track structure was adopted to accommodate the needs of various companies.

The Consideration for Applied Arts Protection in the Digital Fabrication Era

Regarding the recent issues raised about the protection of applied arts, there is a tendency to admit a need for a cumulative protection of copyright and design rights. This tendency must be considered when forming policies and designing licenses. At the same time, in order to promote collaboration amongst the diverse actors/artists in making things, an approach to obtaining rights easily and protecting rights widely, should be taken.

As mentioned repeatedly, there is a tendency in the digital fabrication era for a diverse group of actors/artists to participate in the process of making things. The current `Applied Arts Protection Scheme` has been enacted mainly with a mass production model in mind. In other words, diverse individuals and small companies have not been considered. Therefore, more attention needs to be given to the protection of these diverse actors/artists. To assume that copyright exists for works of applied arts shared globally over the Internet should be a common understanding amongst those involved in the digital fabrication community. Furthermore, based on this understanding, the cumulative protection of copyright and design rights of the Copyright Approach should be taken. If there is indeed a common understanding that copyright protection exists for works of applied arts, then this can be the basis for releasing a design, (at least within the community), with an open license such as the Creative Commons License.

Considering the De-Merits of the Copyright Approach
To apply copyright protection to applied arts will invite many predictable criticisms; it will result in the increasing of rights of applied arts, the monopolisation of functions and the disruption of the Market. However, we must not forget that compared with the very monopolistic rights of the Patent Approach, the rights under the Copyright Approach are only relatively effective. However, such a concern can be lessened by the inclusion of the concept of `Fair Use` or `Rights of Repair` as in the U.S. There is no justification in thinking that only one of the two rights can be applied for protection. We should think that rights belong not to the same layer but to different layers. The nature of these rights are different. Copyright is for culture and design rights are for industry / the market.

Given the fact that even after long periods of discussion by law experts and scholars no clear decision has been made about which form of protection should be applied; either copyright or design rights. It can only be assumed that much more time will be taken in reaching this decision. A further discussion should be continued in the academic field. In the meantime, for the protection of applied arts to be effective in the real world, as with the Theory of the Unity of Art, it would be practical to have the same minimum protection, whether this is for fine arts or applied arts. Based on the statement that applied arts should be utilised fully in the Market, it is the author's belief that Monopolistic Patent Rights should be used. These are similar to the Design Approach but have the advantage of not differentiating between fine arts and applied arts. The author thinks of this as a true idea of the Copyright Approach.

CONCLUSION

Many of the products created using digital fabrication belong to applied arts. Whether or not there is copyright protection for such applied arts creations differs country by country. In this paper, the three major approaches to protection, accompanied by examples of their use from different countries, have been introduced. The author's view is that we should use the Copyright Approach to forming policies and licenses in the digital fabrication era.

Regarding policy recommendations for designing an open license for digital fabrication, further research is required. Specifically, the following is needed:

(1) further research on the protection structure of other countries not included in this paper, for example England and China;

(2) an international comparison between the various product liability acts.

The Future of `An Open Movement of Creativity`

In 1968, the book `Whole Earth Catalogue` was published by Stewart Brand. He said that, “Information wants to be free.” In other words, information on the internet is to be free because the internet’s creator, Tim Berners-Lee, wanted it to be an expression of worldwide, democratic inter-relationships. I agree totally with this concept and want to simply modify this expressed idea. I want to say that, “Creativity wants to be free and to be connected.”

Before digital fabrication, an open movement of creativity had existed only in a digital world of display. We must go beyond this creative, digital display to create a digital manufacturing process, protected fully by an appropriate legal framework. Digital fabrication is the technology which gives information a physical body. Consequently an open movement of digital creativity is spreading now into our physical world. Making objects is not only a functional activity but it is aesthetic also. Works of applied arts can express our personalities. Consequently, more attention needs to be given to the protection of this creative expression of our personalities. I believe that we should use the Copyright Approach to create appropriate policies and licenses. Such ensuing cumulative protection of both Copyright and Design Rights means that, as these diverse `actors/artists`, we are able to focus our attention soley on the `Creative Process`, safe in the knowledge that our rights have been protected comprehensively.

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REFERENCES

1. Riichi, U. Research on Design Act, *Hatsumei Kyokai* (in Japanese), **1994.**
2. Tatsuhiro, U. Copyright Protection of Applied Arts, *Patent Vol67 No.4* (in Japanese) , p96-116, **2014**.
3. Waseda University’s Global COE Programe. Legal Protection of Applied Arts, *Law Creation and Company Vol5 No.3*(in Japanese), p37-76, **2009.**
4. AIPPI. Resolution Question Q231, The interplay between design and copyright protection for industrial products, October 2012, **2012a**. Online at: http://aippi.org/library/
5. Weinberg, M. 3 steps for licensing your 3D printed stuff, Public Knowledge, **2015.** Online at: https://www.publicknowledge.org/assets/uploads/documents/3_Steps_for_Licensing_Your_3D_Printed_Stuff.pdf
6. Jerome, R. Design Protection in Domestic and Foreign Copyright Law, *Duke Law Jornal vol.1983 n.6,* p1143-1264, **1983.** Online at: scholarship.law.duke.edu/cgi/viewcontent.cgi?article=2862&context=dlj

Proposing a compulsory insurance system in the fab society

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Abstract: This paper concerns a proposal of compulsory insurance system in the fab society. Non-corporate entities with small capital will engage in manufacturing of products. It means the people harmed by defective products will face difficulty obtaining legal remedy under the current product liability law. One conceivable solution is to have a mandatory insurance to cover such remedy. Major questions such as moral hazard of the insured, lessons from obsolescence of the similar system in copyright space, and timing of introduction are discussed.

1. INDRODUCTION

This article addresses product liability issues for fab society and suggests a compulsory insurance system. In fab society, objects being distributed are not things but information. Information are distributed and then printed out by people who wants to use them or consigned to print them out. There are possibilities someone to be injured caused by defect in the information. In other words, there are problems that damages could be caused by information creating harm in the real space. In this case, suits concern with *strict* product liability could occur. But there are some problematic characteristics in fab society in this context. They are

a, Objects being distributed are data; in the product liability law, data does not constitute a product.

b, Producers in fab society are not necessarily companies.

2.IDENTIFICATION OF PROBLEMS

2-1. Limit of the product liability law

In Japan, objects of product liability law are limited to "movable property" and this means tangible things that are not real estate. Information such as software is regarded as object of product liability law if they are installed or embed in tangible things according to the commonly accepted theory. Therefore, it is hard to think that production of information that be distributed in fab society has called to product liability. Then victims will investigate negligence liability of civil law Article 709 for data designers and printout companies. Victims have to prove the negligence of the designer and the printout company, not the defect of the design. According to the commonly accepted theory, negligence is understood as failure of a reasonable person in duty of due care to foresee and prevent damages(Uchida、2012). It is difficult to prove existence of such failure at the stage of product design or production; given a broad asymmetricity of information between big companies as assailants and individuals as victims, it is going to be hard to realize victim relief. The idea of strict product liability is a doctrine first developed in the United States with the assumption of such broad asymmetric information of mass-production society [i], and then the idea spread to other developed countries (e.g. European Countries and Japan).

2-2. Insubstantiality of the product liability of the information

Assuming that product liability of information is accepted, and then can makers pay for the damages? There are possibilities that victims can never receive relief due to the makers' lack of funds. Fab society is a society that all people can fabricate things if they want, and thus it is easily imaginable that people without deep pockets engaging in production activities. For example, Engstrom(2013) pointed out that 3D printers democratized productions and "3-D printing severs the long-established identity between manufacturers and sellers, on the one hand, and enterprises, on the other". As described in 2-1, strict product liability doctrine is created with the assumption of broad asymmetric information between company (i.e. assailant) and individuals (i.e. victim). Thus are some problems to apply product liability to information in this situation.

3. SUGGESTION

As described above, the entity responsible for causing damage through a defect in a product is not a company and not always with a deep pocket, and then there could be a large hurdle for ensuring relief for the victims. One solution for this type of situation may be an insurance system serving victim relief function. However, how to design such insurance system is not immediately clear. For example, product liability insurance is bought by producers and car liability insurance is bought by drivers. In this way, liability insurance is bought by the ones who create risks to indemnify damages. Makers should buy such insurance because they are the ones who create risks in fab society. But it seems not realistic that makers, data producers, buy insurance every time they create data in fab society where individual makers produce data actively. Companies that print out 3D data could be another entity creating risks. But there are 2 problems.

a, Is the conduct of "printing out" production in product liability law?

b, Are these company producers in product liability law?

If the answer is no, so, the companies should not be liable and they have no incentives to buy insurance.

So, there are needs to social system to collect a premium forcibly for victim reliefs. I suggest system that every one who buys fab equipment buys insurance at the same time. In Japan, there are similar system for recording equipment, so called "compensation for private sound and visual recording". This is a system when you buy recording equipment, rates are added, and the fee is distributed to creators through management organizations and right holder organizations. The basis of this system is to compensate creators for lost profits by digital equipment that can copy data easily.

4. DISCUSSION

There are some problems to solve to realize this system.

4-1. Moral hazard

Moral hazard is one of the most famous problems concerning insurance - buyer of insurance tends to take more risks (Schavell, 1979). Kuwana (Kuwana, 2010) derived theoretically improvement measures. According to Kuwana, when the amount of damage is below a certain level, it is possible to avoid the drop in the level of due care of the insured company. This is done by setting the appropriate reduced compensation ratio in insurance conditions. On the other hand, when the amount is higher than a certain level, it is also possible to avoid the decrease in due care level of the insured company by inhibiting insurance coverage less than asset of the company.

4-2. Facts of "compensation for private sound and visual recording"

The section 3. described "compensation for private sound and visual recording" as a system similar to my suggestion. But today, this system is regarded as unnecessary one because development of Digital Rights Management technologies, and there are no need to protect creators from copying by recording equipment. Indeed, some manufacturers of recording equipment refused to add charges to their equipment prices, and then the relevant collection society sued these manufacturers [ii]. Manufactures have incentives to refuse to add fees when they sell their equipment because of market competition. So perhaps some manufactures refuse the system suggested in this article.

4-3. Number of accidents

Car liability insurance system is one of the most typical compulsory insurance systems. However, this type of insurance is developed in 1930’s, but not has been forced until 1970’s when car shipments exceeded 10 million. In 2014, 3D printer shipments stay to 9,927 in Japan. The system suggested here could be accepted in the distant future.

5. CONCLUSION

Compulsory insurance system suggested in this article can realize victim reliefs in fab society. But there are some hurdles for gaining acceptance widely. There is another way to relief victims. It is first party insurance witch victims buy. But according to Cohen and Dehejia(2004), effect of moral hazard with first party insurance is greater than it with liability insurance. Furthermore, liability rules and damage brings incentives to due care and brings efficient and “best rights “society (Cooter, 1989). Liability insurance system could be necessary to fab society in future.

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REFERENCES

1. Cohen, Alma and Dehejia, Rajeev, The Effect of Automobile Insurance and Accident Liability Laws on Traffic Fatalities, Journal of Law and Economics, 2004, 47, 357-393.
2. Engstrom, Nora Freeman 3-D Printing and Product Liability: Identifying the Obstacles University of Pennsylvania Law Review Online, 2013, 162, 35.

3. Robert Cooter, The Best Right Laws: Value Foundations of the Economic Analysis of Law, Notre Dame Law Review, 1989, 817.
4. Shavell, Steven, On Moral Hazard and Insurance, Quarterly Journal of Economics, 1979, 93, 541-562.
5. 内田貴『民法Ⅱ　債権各論(第3版)』東京大学出版会、2012. (Takashi Uchida, Civil lawⅡ Credit detailed exposition 3rd. ed., University of Tokyo Press, 2012)
6. 桑名謹三「責任保険の強制付保化政策におけるモラルハザードの改善策」、『危険と管理』2010年、第41巻、93頁～103頁(Kinzo Kuwana, Remedy of the moral hazard in the compulsory insurance policy of liability Insurance, Risk and Management,2010, 41,93-103.)

[i] Greenman v. Yuba Power Products, Inc., 59 Cal. 2d 57, 377 P. 2d 897（1963）is the very first leading case.
[ii] SARVH・東芝訴訟、東京地判平成22年12月27日(SARVH v. Toshiba, Tokyo District Court,2010,12.27 ）

Responsibility Assignment and Digital Fabrication: Toward a socially grounded legal system

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Abstract
This paper discusses the Japanese product liabilities law in the context of the emerging landscape of digital manufacturing. Digital manufacturing technologies will enable non-traditional players to engaged in manufacturing activities – a source of innovation. However, the current law imposes rather heavy responsibilities to a wide range of entities. It is argued that the law's assumptions about the manufacturers and consumers will become unfit. Considering the innovation potential and risks newly emerging manufacturers imposing strict liability by the law may not be the optimal solution. What is best for the society is not clear, because of the non-legal, social factors shaping the emerging manufacturers' choices.

INTRODUCTION: Responsibilities in relation to Manufacturing

The current change in technological environment makes it important that we revisit the assignment of responsibility surrounding manufacturing at least for the innovation and economic growth, such as who should be held accountable for a damage caused by unintended use of a manufactured object. The scope of people engaged in making tangible things is broadening, while their legal responsibilities are often as heavy as industrial manufacturers. The former presents a large innovation potential, while the latter seems to have a sizable chilling effect on the very people who could bring about the innovation. This paper discusses the basic layout of the problem, and requirements for the solutions, and reports on the preliminary findings from an ongoing empirical research, taking the Japanese society and law as a case. The major requirement, the author argues, is the understanding of the social dimension of how the law takes effect. Designing a legal system for this matter requires a more nuanced approach, because of the broad range of people newly engaged in manufacturing activities. They are less informed in terms of the law, and less motivated by monetary gains and rational calculation of risks typical of industrial manufacturers. The influence of social dimension is greater, and the understanding of the dimension more important for the design.

BACKGROUND AND PROBLEM

Changing Landscape of Manufacturing

The major change we are witnessing as developments and diffusion of digital fabrication technologies is broadening of the scope of people involved in the design, production, and distribution of tangible things. For the lack of better term these activities, especially design and production, are called manufacturing in this paper. The scale of those activities are not necessarily large. This change in many respects is probably similar to the way sharing one's programming code or opinion became common through the diffusion of personal computer, Internet access and portable, connected devices. Those who are getting engaged in manufacturing are not limited to experts nor those who are paid. They are increasingly inclusive of people who are amateurs and volunteers. Greater number and scope of people can engage in larger scope of manufacturing activities without being concerned about associated cost and time requirements, because they are smaller now. Some of the new people are interested in taking advantage of lowered barrier to the entry into the manufacturing business by forming hardware start-ups, and some were even financed through crowd-funding platforms such as kickstarter (Ebersweiler and Joffe, 2014). Yet others look like artists and performers than business people - they may create thing that are not useful but fun, amazing, or impressive - you can find those creations easily at events like *Maker Faire*. Somewhere in between amateurs and professional manufacturers lays yet another type of entities – businesses whose core expertise is outside of manufacturing. Medical applications of 3D printers receive a fair amount of research and practice, for example (Murphy & Atala, 2014, Rengier et al., 2010). Theatres, schools, architects, farmers, and many others may find it beneficial to engage in some manufacturing now that the barrier to the entry is lowering – this could be likened to the fact that taking and creating photographs are increasingly done by everybody, not photographers and photo studios. Creating printed documents are increasingly done by everybody, not by publishers and printers, for the same reason.

Amateurs and volunteers alone would not make a big difference in industry or economy, one might think. Yet similar to the world of programming, there are many who practice sharing - sharing of not just end products but also of design data so that others can recreate the product or their modifications freely and easily. Thingiverse is the largest of sharing platform, providing more than one million data sets. Similar to the world of programming, some of the sharing results in a series of reuse and derivative works or concerted effort to collaboratively create a sophisticated piece of work. In the world of the Internet, similarly collaborative works such as Wikipedia, Linux, Apache, are shaping the market competition and consumer behavior. In years time, we might see similar change in the world of manufacturing.

Responsibilities in Manufacturing

The legal landscape in Japan for broadening the horizon of manufacturing, which is the focus of this paper, is not encouraging. The product liability law in Japan, enacted in the 1994, established that the damages arising from the defect associated with a tangible product, are presumed to be the responsibilities of the manufacturer, as in the U.S., EU member countries, and other countries (Akabori, 2009). The scope of manufacturer and others held accountable in this context is rather broad - if people are repeatedly engaged in the provision of goods, individuals, non-profits, and regular business entities all fall in the scope. Those who import goods from abroad are also included. It means that amateur makers, as they often are called, who are not intended to make profit but are providing their creations at Maker Faires may turn out to be responsible. It is also interesting that the manufacturer's lack of design knowledge does not immunize them. Those businesses that provide 3D-printed goods upon customers' request are manufacturers for the purpose of the law, and while they do not know anything about the 3D data that the customer provided, they are the one who could be held responsible for the defect in a printed object in the context of product liability law, not their customers who selected the data. It is also notable that digital fabrication gains support partly from those who are concerned about energy and environmental impacts of conventional manufacturing and mass consumption. For those people, digital fabrication technology's capabilities to let people repair, replace components of, or recycle products are quite significant. During the years leading to the legislation, there were some discussions on the responsibilities of entities providing product-related services, such as renting, leasing, and repairing (Economic Planning Agency, 1991, pp55-58), partly inspired by EU's inclusion of those entities to those who could be held liable. The current Japanese law excludes those type of entities (Economic Planning Agency, 1994, p.88, Japan Federation of Bar Associations, 2015, p.53), yet how to treat second hand and refurbished products are still not clear.

Behind this assignment of responsibilities in Japanese law is a series of assumptions about typical manufacturers. For a defective product that cause damages, the law assumes that manufacturers are the ones who have introduced the products, gained consumer trusts, and earned profits (Asami, 2012). It is also explained by some that asymmetries of capital and information lay on the basis of the law. Manufacturers are assumed as having more capital, best positioned to purchase the insurance covering the whole of the consumers and provide compensation. They are also assumed to possess more knowledge about the products than consumers. It is clear that in the face of above-mentioned changes in manufacturing, these assumptions do not hold well to the people newly engaging in the manufacturing.

However, it is also clear that the increase in the amateurs, volunteers, and start-ups in manufacturing are going to introduce risks to the society. Left unmanaged, they may cause more damages to the people and their properties. The policy goals should consider if the expected benefit is large enough and damages are small enough.

TOWARD POSSIBLE SOLUTIONS

Social Dimension of the Law

When we explore responses to the emerging problem regarding the assignment of responsibilities, it is important to consider social dimension for at least two reasons. First, for those manufacturers who do not have legal department or legal counsel, the law and legal change may or may not produce intended effects. Lack of knowledge or misunderstanding of the law may result in unintended consequences including chilling effects. In areas such as personal information protection law and copyright law, such unexpected effects are rather common. What exacerbates the problem in effective communication is typical participants of legal reform discussions: large corporations, industry associations, and experts, but not so much of consumers and smaller and non-business players. Case in point, a government-convened panel recently issued a guidance material for stakeholders explaining the legal aspects of the digital fabrication, along with the final report (Commission on the General Planning of Fab Society, 2015a, 2015b). There were some non-industrial manufacturers complaining to a member of the panel indicating that the current legal risk was unacceptable, and they had to stop their manufacturing activities now that they learned about it from the guidance material. Given this situation, simply adjusting the legal assignment of responsibilities differently is only part of the adjustment needed to respond to the new reality. Secondly, these emerging manufacturing activities are less driven by monetary motivations compared to conventional industrial manufacturers. It means that their risk-taking might be different from that of a simple economically rational player. Some are mission-driven non-profits, others are individuals in pursuit of their passion, artistic, social reform, ideological, or otherwise. For those, change in legal responsibilities may or may not have the kind of effects that such change has over more rational, calculating for profit large organizations.

Additionally, one may point out that even the traditional manufacturers in Japan have been shaped by social factors, rather than legal ones in their pursuit of the product safety and risk management. Even before the enactment of the product liability law, there existed a rather extensive social institution of testing and labeling safe products, and insuring the labeled products. In case of harms caused by a defect in product, consumers received fast and cheap adjudication and compensation based on strict liability standard when defect caused the harm (Ramseyer, 1996). Writing before the enactment of the law, Kobayashi (1993, p.61) observed that U.S. placed heavier responsibility to manufacturers, safety level of the products are not higher than Japan, which relied on the standard of negligence at the time.

Interview Research

In order to further understand this issue of assignment of responsibilities, the author has conducted a series of interviews. Their focus was not on the perception of the current law such as product liability law. The topic of the interview was set more generally as responsibilities related to manufacturing, including ethical obligations interviewees might have.

The interview sessions were semi-structured - i.e. the interview for the most part was broad and generic in nature, with four general questions, letting the respondents speak at length about such things as their perceived responsibilities related to the things they design, create, or provide, expected consequences of materialization of perceived risks, and so forth. Toward the end of a session, up to six more specific questions were asked about the interviewee's understanding of legal aspects of the responsibilities, and any measures taken in response to mitigate perceived risks. This design was selected so that the interviewees first think about the subject matter recalling relevant information, providing rich back ground for later analysis, and then answer more specific questions to increase ease of comparison across interviewees.

The interview also included informed consent component, explaining the purpose, benefits, risks, treatment of the information provided, right to freely withdraw from the research at any time, contact address of the research ethics committee for filing complaints, and so on. At the end of a session, signed consent form was obtained from the interviewee to confirm his willingness to cooperate with the research. Typical session lasted for an hour. The interview sessions were recorded with the permission of the interviewees, but with the provision that, upon their request, any part of the interview could be excluded from the recording. One interviewee requested the interview not to be shared with anybody else (including other members of the research project), nor to be transcribed. The interview data have been treated accordingly. Anonymity was granted to all interviewees, given that the interview dealt with fairly sensitive issues including their understanding of legal risks related to their business or public activities, their understanding of law, including their lack of confidence and inaccuracies, and potentially socially undesirable facts and remarks about their manufacturing activities that might come out during the interview. In addition, the interview started with a segment to establish rapport, in order to alleviate their self-inhibition about making socially undesirable remarks.

Preliminary Findings

The interview research is still at a preliminary phase at the time of writing of this paper, having completed only three interview sessions with three different interviewees. However, there are already some interesting indications from those sessions, along with less formal conversations and discussions the author has been engaging in many occasions. First, the interviewees were conscious of the legal risks associated with providing things they manufactured. They had ideas about ways to mitigate the legal risks associated with it. It is fair to say that the chilling effect has already been in effect, and at least some of their activities might have been advanced faster had they been freed from the perceived risks associated with it. Second, there are signs of inaccuracies in some of the interviewees' understandings of law and legal risks. Third, because their activities are more personal than impersonal, they are not necessarily choosing their risk-related actions based on calculations of what is the best option. Some of their projects were driven by their life-long interest, or defined by passion, as opposed to the perceived business opportunities. As a part of their non-monetary motivations to engage in manufacturing, their frame of reference when speaking about responsibilities and risks were not necessarily that of social norm (what the society expects of them as good citizen, corporate or individual) nor rational *homo economicus*. They discussed these issues with their personal sense of justice or sensitivities, and some of their preferences of risk-taking were explained in connection to those than business decisions on costs and benefits. To be clear, the working of the social dimension does not always suppress risk-taking. One possible persistent tendency could be that the sense of justice or mission pushes them to take extra risks than economically optimal for the individual. If this is the case, it may be better for the society to have a legal system in which such prosocial motivation is taken into account to reduce their liability in one way or another. Overall, while interview research is still at a preliminary phase, the above arguments on the social dimension seem to be corroborated with these results.

CONCLUSIONS

This paper pointed out that the broader adoption of digital fabrication technologies will make the current legal assignment of responsibilities related to manufacturing unfit to the social reality and potentially harmful for innovation and economic growth. This is primarily because the fabrication technologies are increasingly adopted by amateurs, volunteers, small start-ups, and others who are not typical industrial manufacturers. While international comparative legal analysis remains a task for future research, the existing literature suggests that product liability laws are mostly similar to each other, where they are introduced. The similar problem, then, can be found in other countries. However, legal reform would benefit from better understanding of the social factors at work. Legal system is not necessarily well understood by them, and economic calculation does not determine their behavior as much, because they are not organized and motivated like large corporations and their employees. Findings from ongoing interview research also indicated the same. It should be noted that the understanding of the social dimension is required when we think of the legal effects on consumers. Simply relieving the non-industrial manufacturers by law would not make consumers automatically more cautious. More attractive in light of this may be 1) stronger role of risk communication among stakeholders, and 2) semi-mandatory insurance distributing the costs widely among those involved in the risks and beneficiaries of not just the sales, but also the innovation, to cover damages.

Notes:

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REFERENCES

1. Akabori, K. Product Liability Act and Corporate Risk Management. *Kobe Gakuin Hogaku: The Law and Politics Review*, v.38 n.3&4, pp.1-81. **2009**. Online at: http://www.law.kobegakuin.ac.jp/~jura/law/files/38-3_4-01.pdf
2. Asami, Y. Subject of Responsibility in Product Liability Act, *Lives of the Nationals* (in Japanese) December 2012, pp.33-36 **2012**. Online at: http://www.kokusen.go.jp/wko/pdf/wko-201212_13.pdf
3. Commission on the General Planning of Fab Society, *Guideline on Legal and Social Institutions toward Fab Society* (in Japanese) **2015a.** Online at: http://www.soumu.go.jp/main_content/000361196.pdf
4. Commission on the General Planning of Fab Society, *Strategy for Realizing Fab Society: Digital Society 3.0* (in Japanese) **2015b.** Online at: http://www.soumu.go.jp/main_content/000361195.pdf
5. Committee on Addressing Consumer Affairs, Japan Federation of Bar Associations *Product Liabilities Act: from a practical point of view, 2nd Edition*

(in Japanese) **2015.** Yuhikaku.

6. Ebersweiler, C. and Joffe, B. Why Makers Fail At Retail. *TechCrunch*, February 3, **2014**. Online at: http://techcrunch.com/2014/02/03/why-makers-fail-at-retail/
7. Kobayashi, H. *Product Liability Law: Legislation and Response* (in Japanese) **1993.** ChuoKeizi Sha.
8. Murphy, S. V. and Atala, A. 3D Bioprinting of Tissues and Organs, Nature Biotechnology **2014.** v.32, pp.773–785.
9. Ramseyer, J. M. Products Liability Through Private Ordering: Notes on a Japanese Experiment. *University of Pennsylvania Law Review* **1996** v.144, n.5, pp.1823-1840.
10. Rengier, F., Mehndiratta, A., von Tengg-Kobligk, H., Zechmann, C. M., Unterhinninghofen, R., Kauczor, H.-U. and Giesel, F. L. 3D printing based on imaging data: review of medical applications. *International Journal of Computer Assisted Radiology and Surgery*. **2010.** v.5, n.4, pp.335-341.
11. The First Section of Consumer Affairs, Bureau of Civic Life, Economic Planning Agency (Ed) *Discussion Points of Product Liabilities Law* (in Japanese) **1991.** ShojiHomu KenkyuKai.
12. The First Section of Consumer Affairs, Bureau of Civic Life, Economic Planning Agency (Ed) *Commentary on Product Liabilities Law* (in Japanese) **1994.** ShojiHomu KenkyuKai.

Business Model Typology for FabLabs: Examining the sustainability question with Asian Labs

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Abstract
Based on interviews and literature survey of seven FabLabs in India, Indonesia, and Japan, it is observed that FabLabs are capable of financially cover its own operational costs, based on a number of different revenue sources, such as providing access, education and training, or commissioned projects. However, their operational costs are subsidized in a number of ways. Somewhat conspicuously missing given general expectation is the income from supporting successful commercialization of users' innovation.

INTRODUCTION

There are more than 500 FabLabs around the globe. Thanks in no small part to the attention from media, government, and others regarding its potential, the number has been growing year by year. However, even for those who operates FabLabs, how to financially sustain a lab is not readily apparent. Our study reports, based on the interviews, a typology of FabLab's business models to improve the state of our knowledge.

There are global network of labs and workshops identifying themselves as FabLabs, abiding by a common charter (*The Fab Charter*, undated), sharing enthusiasm, know-hows of how to make things, values and future visions. Among their core values is the openness to the public, something shared widely within the broader *maker movement.* More specifically, the charter requires any FabLab to make itself available to the general public; it also requires documenting and sharing of know-hows with others via online. Revenue generation, on the other hand, is not required. It is assumed that some users of the labs are business-oriented, but they are not expected to shoulder any specific cost of running a FabLab. They are expected to contribute to the FabLabs' finance. When we observe how FabLabs are operated, some are supported by grants, and necessarily sustainable. In fact, financial sustainability is a frequent topic among FabLabs directors and staffs.

METHOD

This paper is based on a series of interviews conducted to explore the broader question of how to successfully run a FabLab, and how different lab managers and other stakeholders define a success for FabLabs. Interviewees were selected based on a number of considerations. They are not *representative* sample of the FabLabs. FabLabs are apparently rather diverse, and randomly sampling the labs without considering the diversity may or may not result in unbiased sample for the purpose of investigating business models for a lab. Considerations were geography, duration of operation, urbanity, level of development and type of organization operating the lab. The first two were used to decide the scope of our research, whereas the remaining three were used to ensure distribution and diversity. First, in terms of geography, they are located in South East to East Asia, to complement an earlier study on the same subject (Troxler, 2010). In order to learn how labs establish revenues, labs with less than one year of operation were excluded. Both urban and rural labs, and those located in developing and developed countries were included. We also ensured that the labs operated by a private firm were included. The Table 1 summarizes the locational variations of the FabLabs included in the study.

Table 1: FabLabs included in ths study

	Country	GDP per cap.*	Location	Local Pop.**	Entity
Vigyan Ashram	India	1596	Pabal	4	Edu
F.L. Bohol	Philippines	2871	Bohol	97	Edu
F.L. Kamakura	Japan	36194	Kamakura	177	NPO
F.L. Tsukuba	Japan	36194	Tsukuba	221	Priv
F.L. Oita	Japan	36194	Oita	479	Gov
F.L. Sendai	Japan	36194	Sendai	1054	Priv
HONFabLab	Indonesia	3492	Jakarta	9608	NPO

*The GDP per capita is in 1,000 US dollars (current) for 2011-2015. Source: World Bank (undated) *GDP per capita (in current US$)*: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD
**Population is in 1,000. Source: *Pabal Population - Pune, Maharashtra*
http://www.census2011.co.in/data/village/555583-pabal-maharashtra.html;
Philippine Statistics Authority, Republic of the Philippines (undated)
Total Population by Province, City, Municipality and Barangay:
as of May 1, 2010
https://psa.gov.ph/sites/default/files/attachments/hsd/pressrelease/Central%20Visayas.pdf; Japanese Ministry of Internal Affairs and Communications (2013) *(Grand Total) Basic Resident Registration-based Population, Household, and Population Dynamics. (By Municipalities). http://www.soumu.go.jp/menu_news/s-news/01gyosei02_02000055.html*

Interviews were typically conducted using Skype for at least an hour. The interviewees were lab's managers or someone close to the lab's revenues and expenses. The questions relevant for the findings were phrased neutrally regarding the desirability of revenue generation, or specific revenue source. At the beginning of the interview, it was explained that protection of the interviewee's and lab's anonymity would be available if desirable. This is so that the interviewees can discuss sensitive financial issues with less hesitation.

RESULTS AND DISCUSSION

Revenue Sources

The interviewees cited mainly four types of revenues: usage fee, membership fee, workshops and training programs held at the FabLab, and commissioned projects. Usage fees and membership fees could be bundled as revenues from providing “access.” It could be a significant source of income as exemplified by HONFabLab. HONFabLab has partnerships with local universities or similar entities so that the students can visit the lab for use. Multiple labs, including HONFabLab indicated that the universities often found outside labs valuable because they were more accessible and less bureaucratic. In general, many FabLabs selected for this study had ties with universities, including project partners (Kamakura, Bohol) and one of the major groups to serve (Vigyan Ashram, Bohol, HONFabLab and Tsukuba). Some of the relationship leads to direct revenue, others provide the significance for the lab's existence. Holding workshops or providing more serious training programs, usually at the lab, but possibly elsewhere, is a source of revenue that takes more staff-resource. Even more resource-intensive is the provision of services, such as designing and prototyping of some product upon request. While they were mentioned by multiple labs, it should be noted that none cited as the main source of revenue. In some cases, it served staff members or hosting organizations rather than the labs (Sendai, Bohol). In other cases, the revenue was significant only in the past, but not at the time of the interview, due to the change in the business model (HONFabLab). Whether and to what extent a lab charges for the membership, usage, training participation is a matter of lab's policy. FabLab Oita let anyone use the lab free because it aims at serving the broad range of citizens interested in prototyping. Vigyan Ashram's workshops are all free of charge and open to the general public. Table 2 below summarizes the findings.

Table 2: FabLabs sources of revenue and other benefits to owners

	main revenue	owner rev	entity	est. in
Vigyan Ashram	N/A.	tuition, etc.	Edu	2002.
F.L. Bohol	N/A	N/A	Edu	2014.5
F.L. Kamakura	training	N/A	NPO	2011.5
F.L. Tsukuba	N/A.	projects	Priv	2011.5
F.L. Oita	N/A.	N/A	Gov	2014.1
F.L. Sendai	mixed	projects	Priv	2013.4
HONFabLab	membership	N/A	NPO	2011.7

In-Kind Support

The variations on the revenue sources hardly capture FabLab's business model for their continued existence, because of the difference in the broader ownership structure. Some FabLabs are independent and self-sustaining: the Lab's expenses are covered by its revenue, and its staff paid by the revenue. However, other FabLabs are a part of a larger entity or project, and the financial loss at the part of FabLab in itself may not matter in the larger picture (sukuba, Ooita, and Vigyan Ashram, most notably).

Some FabLabs manage to keep the expenses at a low level by receiving in-kind support. When located within a university, the lab space may be available for free. Volunteer staff may be available from local citizens or student population (Tsukuba, Bohol). The volunteer may gain monetary or non-monetary returns. In a monetary case, working at a FabLab may bring a staff member some projects from visitors and users (Sendai). In a non-monetary case, a staff member finds it gratifying for reasons such as contributing to the community, learning about equipment, or helping others who share their interests (HONFabLab). They may gain privileged access to the lab equipment and working space, as multiple indicated by multiple labs. In case of FabLab Tsukuba, the lab master was able to find clients to his company by operating the lab. The interviews suggested that not many FabLabs are sustainable without taking these measures to reduce their expenses, but most, if not all, are able to cover the cost. It is probably not an overstatement that balancing revenues and expenses is possible for FabLabs if one is sufficiently creative.

This pattern presents a different picture from the prior study on this subject (Troxler, 2010), in which the FabLabs were found to rely on government support. Broadly speaking, educational institutions, such as Bohol Island State University hosting FabLab Bohol or Vigyan Ashram are partly supported by government subsidies. FabLab Oita is owned by the local prefectural goverment of Oita. Even FabLab Sendai is not free of government money as a part of income. However, government support remains only a part of the overall revenues of even those labs. The overall picture is not that of reliance to the government funding. FabLab Sendai and HONFabLab seem to show less and less reliance on government support over the years.

Missing Element

What is missing from the list of revenue sources is perhaps as noteworthy as what are on the list. Namely, FabLabs do not seem to receive revenue directly from the innovations they help generate. FabLab users include some business users and entrepreneurs. This is not a surprise given that FabLab is often conceived as having a potential to boost local economy by helping product development. Vigyan Ashram's FabLab have been producing numerous products and prototypes, some commercialized, but without generating revenue to the lab. FabLab Bohol has also provided a number of useful products (Watanabe and Tokushima, 2015), some for existing local businesses and others for new businesses, again not generating any direct revenue to the lab. Not receiving money from any fruits of innovation that labs help to generate seems to be a partly a matter of policy, and partly a matter of lack of proper means to do so. On one hand, the effect of not charging the business users any special fee for their improved profit does encourage the commercially-oriented activities to a degree. At the same time, it is not easy to account for the exact contributions a lab use makes towards increased sales or profits. Businesses are usually not forthcoming about their books, and even if all the financial data were provided, it would still be fairly difficult to determine the amount of contribution a lab use had made toward such increase. However, making a lab's contribution to increased profit generated by the lab's business user may potentially incentivize lab managers and staffs to provide extra support. For some labs, generating economic effects is an important mission.

FabLab's Growth Model and Allocation Issues

It seems possible to draw a simple growth model for FabLabs from those major sources of revenues. Namely, the simple revenue source is based on memberships and usage fees. Workshops and training programs takes more skills, concept developments, and preparations. Done right, it may generate more revenues per person and intensify the use of lab's equipment. Providing services for commissioned projects takes more expertise and time, but potentially bring larger revenue from smaller number of clients.

This three-stage model of FabLab's growth comes with a challenge for each upgrading of business model from one stage to the next. The challenge is about allocation of space and time. The revenues for the lab from users and members may decrease if significant amount of time and lab space starts to be allocated for workshops. The same thing happens when the equipment are used to serve clients who commissioned some projects. The change in the revenue source accompany reorganization of lab operation schedule for this reason. FabLabs Sendai, Tsukuba, and HONFabLab in fact indicated time and space management issues in this regard.

Table 3. Types of Revenues and their Characteristics

Type of Revenue	# of payers	payment size	expertise needed
Access	large	Small	low
Workshops/Training Prog.	medium	medium	medium
Projects/Service Bureau	small	Large	high

Interference Issues

When multiple FabLabs are densely established in a given area, it is possible that the diversity of business models cause interference that is challenging to the labs' financial stability. When some service or access is freely available from one lab and not free from another neighboring lab, users may pick combinations of lab's services that save their cost of lab use. In Barcelona, Spain, many FabLabs do already exist. In Kannai area, there are three labs with different orientations within a walking distance to each other. While there is no reported issue of inter-lab competition in these areas, and it is not necessarily bad from user's perspectives that labs compete with each other, the competition issue may potentially interferes with the business model selection. Size of local population accessible to the lab, capacities of the labs, and other issues affect the degree of competition.

CONCLUSIONS

This paper reported major sources of FabLab's revenues based on interviews with diverse labs from East and South East Asia. The three major sources of revenues are access, training, and projects. The labs could be self-sustainable than reliant on government support, especially when they are able to find in-kind support to keep the expenses low.

Notes:
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REFERENCES

1. Troxler, P. Commons-based Peer-Production of Physical Goods: Is there Room for a Hybrid Innovation Ecology?, *The 3rd FreeCulture Research Conference*, Berlin, October 8-9, **2010**.
2. Watanabe, T. & Tokushima, Y. A FabLab for development in rural Philippines: Reflecting on the recipe for success for a community technology center. *International Telecommunications Society Regional Conference*, Los Angeles, October 25-28, **2015.**
3. *The Fab Charter*, **undated**. Online at: http://fab.cba.mit.edu/about/charter/

ofxEpilog:
An openFrameworks addon for controlling an Epilog laser cutter

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ABSTRACT

We describe ofxEpilog which enable people to control a laser cutter of Epilog in real time. ofxEpilog is an addon of openFrameworks, an open source C++ toolkit for creative coding. With the addon, people could directly send their image object to a laser cutter through Ethernet. By alternating the generation and transmission of the command of cutting, the addon could sequentially control a laser cutter in real time. In this paper, we introduce our initial trial of a dynamic focus (z-axis) control and discuss our upcoming challenges.

INTRODUCTION

Laser cutter is one of a core tools in personal fabrication [FAB]. In accordance with the rapid growth of the community, several systems explore the use of laser cutter in their unique ways beyond the standard applications (i.e. Adobe Illustrator, Corel Draw, Inkscape) and the proprietary drivers [6]. VisiCut allows positioning of the material through a live camera [10]. LaserOrigami produces 3D objects with a laser cutter by bending the materials [7]. SketchChair allows people to design and build their own digitally fabricated furniture by using a simple 2D sketch-based interface and design validation tools [13]. Laser cooking proposes a novel cooking technology by using a laser cutter as a dry-heating device [4]. In this paper, we go step further the exploration with the flexibility of creative coding in which people try to produce something by programming at the intersection of art, media and technology. Specifically, we introduce ofxEpilog, an addon of openFrameworks [8], which enable people to control a laser cutter of Epilog [3] in real time.

BACKGROUND

The beginning of the addon is cups-epilog.c, a cups driver for Epilog laser engraver by AS220 [1]. With the driver, people could control the laser cutter through a network with a diverse range of systems such as Mac, Linux, instead of a proprietary driver just for windows. Trammell Hudson updated the driver into a command line tool [14] that translates the PDF files into commands for the laser cutter. The both software (and the proprietary driver, of course) generate commands based on Hewlett-Packard Graphics Language (HP-GL) [5] to control the laser cutter. Standing on the shoulders of the precursors, we have developed our software from scratch as an addon (i.e. external library) of openFrameworks, an open source C++ toolkit for creative coding. Because of the capability of openFrameworks for computational graphical programming, people could algorithmically generate a diverse range of vector graphics and send the data directly into the laser cutter.

SYSTEM

ofxEpilog

ofxEpilog works as an addon of openFrameworks that directly control a laser cutter of

Epilog (e.g. Zing, Mini, Fusion). With the addon, the coder could directly send their image object such as ofPolyline (i.e. multiple points vector data) or ofImage (i.e. pixel data) within openFrameworks through Ethernet. The parameter of power, speed, and frequency of a laser cutter could be controlled in the cutting process instead of the pre-configured setting of the proprietary driver. In addition of those parameters, we also added several extensions such as the thickness of material for z-axis, settings for cutting parameters based on HP-GL. By alternating the generation and transmission of the command of cutting, the addon could sequentially control a laser cutter in real time. The code is open-source [9].

Example - live control

Once established the connection, the processing path can be sequentially transmitted to the laser cutter and processing is performed according to the data. By utilizing this, the laser cutter is able to support various input data sources with changing cutting parameters. For example engraving along with body motion, such as mouse movement in real time.

Example - A dynamic focus (z-axis) control

When we have a contour (i.e. difference in height) in a material for cutting, we could dynamically change the focus (z-axis) of a laser cutter with ofxEpilog instead of dividing the data into different layers with the height with the proprietary driver. As an initial experiment for controlling z-axis, we used Rhinoceros and Grasshopper, which is combination of CAD software and Graphical Algorithm Editor. To obtain the cutting path along the surface, we used projection function in Rhinoceros and then check projected polylines in Grasshopper to avoid collisions between head of laser cutter and the model. The cutting path is saved as Drawing Exchange Format (DXF) contained three-dimensional coordinates (Fig.1). According to a given 3D object with a free-form surface, the addon engraves 3D curves to the 3D object while keeping the focus (z-axis) by changing table height (Fig.2).

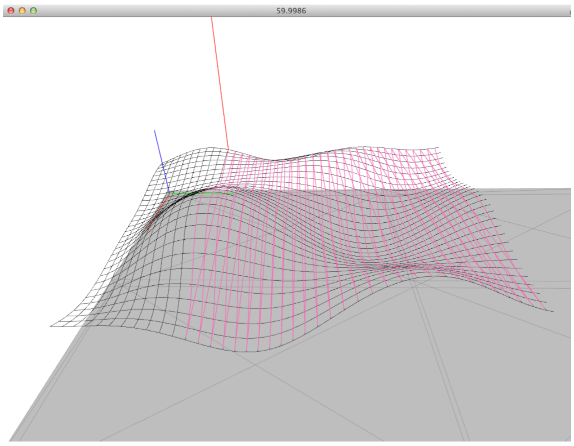

Fig.1 A 3D object with free-form surface as cutting path generated from Rhinoceros.

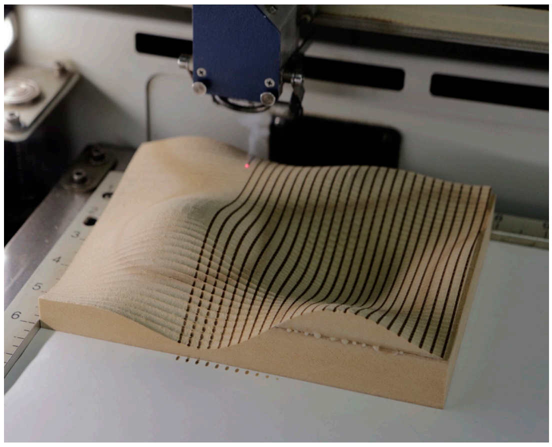

Fig.2 Engraving 3D curves to a 3D object with free-form surface while keeping the focus point by changing table height.

In a typical fabrication process, because the constant focal length, it’s not able to process engrave or cut 3D object at the optimum focal length. On the other hand our proposed method is able to process the object such as a free-form surface without getting fire (Fig.3). In combination with a high-resolution 3D scanner, we could engrave 3D curves on a wide range of objects with a scanned 3D data instead of a pre-structured 3D model of CAD software.

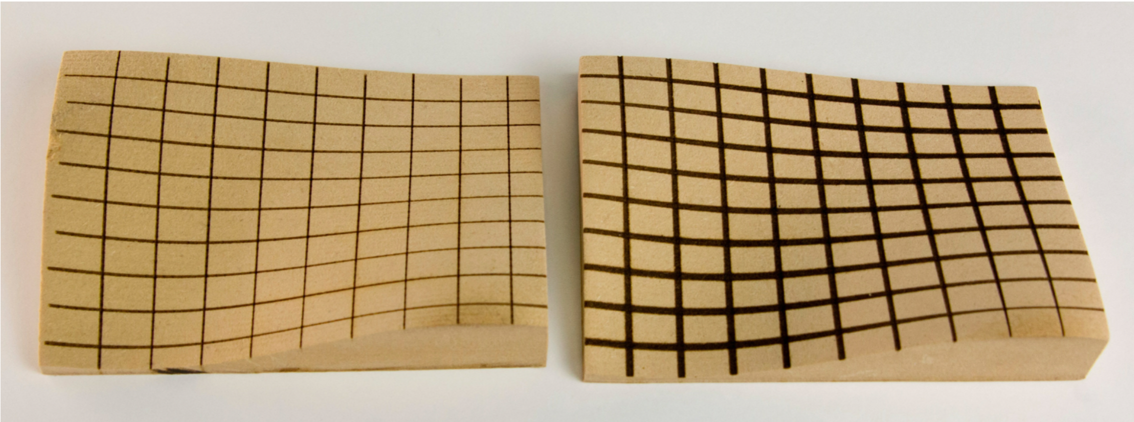

Fig.3 Example of comparison, with dynamic focus control and without. The both parameters of vector process are 40% power, 40% speed, 100% frequency. (Left) The result of our method, the width of each line is fixed. The process time is 5:34 minutes. (Right) Normal process cannot be applied properly because of the focus point is fixed. The process time is 1:00 minutes.

DISCUSSION

In this paper, we have explained our initial development of ofxEpilog. Our upcoming technical to-do is a simultaneous control of z-axis and xy-axis which we could not achieve with the current implementation because of the dependency on HP-GL. As our applications of the addon in addition to the dynamic focus control, we're also considering to build converters for existing graphical programing/markup language such as Logo [11] or GML (Graffiti Markup Language) [12]. With our approach, we envisage further unique applications of laser cutter, as if the advent of Windows Drivers for Kinect [2] in which a grassroots community shifts the strategy of a corporation from propriety to open source.

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REFERENCES

1. AS220 Labs, cups-epilog.c, http://mtm.cba.mit.edu/cups/cups-epilog/src/cups-epilog.c, 2008.
2. Chung Lee, Jonny,Windows Drivers for Kinect, Finally!, Procrastineering-The Personal Blog of Johnny Chung Lee, http://procrastineering.blogspot.jp/2011/02/windows-drivers-for-kinect.html, 2011.
3. Epilog, https://www.epiloglaser.com/
4. Fukuchi, K., Jo, K., Tomiyama, A., & Takao, S. "Laser cooking: a novel culinary technique for dry heating using a laser cutter and vision technology." Proceedings of the ACM multimedia 2012 workshop on Multimedia for cooking and eating activities. ACM, 2012.
5. Hewlett-Packard, The HP-GL/2 and HP RTL Reference Guide: A Handbook for Program Developers (3rd Edition), Addison-Wesley Professional, 1997.
6. Mueller, Stefanie, and Patrick Baudisch. "Laser cutters: a new class of 2D output devices." interactions 22.5 (2015): 72-74.
7. Mueller, Stefanie, Bastian Kruck, and Patrick Baudisch. "LaserOrigami:

laser-cutting 3D objects." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2013.
8. openFrameworks, http://www.openframeworks.cc/
9. ofxEpilog, https://github.com/YCAMInterlab/ofxEpilog
10. Oster, Thomas. Visicut: An application genre for lasercutting in personal fabrication. Diss. RWTH Aachen University, 2011.
11. Papert, Seymour. Mindstorms: Children, computers, and powerful ideas. Basic Books, Inc., 1980.
12. Quaranta, Domenico, and Geraldine Juárez. The FAT Manual. Lulu. com, 2013.
13. Saul, Greg, et al. "SketchChair: an all-in-one chair design system for end users." Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction. ACM, 2011.
14. Trammell Hudson, Epilog driver, https://trmm.net/Epilog_driver, 2011.

High Efficiency Connection Method on Electric Signal Lines between Modular Circuit Boards

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INTRODUCTION

The "Bit-shift connection" is a novel connection method for electric signal lines between modular circuit boards. This method is especially useful for FPGA and CPLD prototyping modular boards. General modular circuit boards such as an Arduino and its shield boards use a BUS connection. However it has critical problem that many boards are not able to use together. The reason why it is not able to use together is pin conflict. Ideally all connection between MPU, FPGA, CPLD and I/O interface should be independently. However it is not realistic, because it is required vast area for electric connection lines and huge number of pins of connectors. So there are some research that build more high speed line on PCB[*1], or connect without wires[*2]. The "Bit-shift connection" solves these problems on normal PCB by using a simple method of independent connection on limited board area and number of pins. So it is easy to implement.

MODULAR BOARD

"Modular" and "Modularization" means to be disassembled to some basic modules that can be re-assemble. Fig.1(b) shows an example of "modular circuit boards" that are modularized from a single board of Fig.1(a). Modular boards set works same function of the single board. So each modular board has same connectors and its pin assignment standard. Modular system's advantage is to achieve rapid prototyping of electric circuits. For example, you can built a custom circuit board that has three USB interfaces, one stepping motor driver, and one WiFi interface with main MPU. Arduino and its shield boards are famous example of "modular boards".

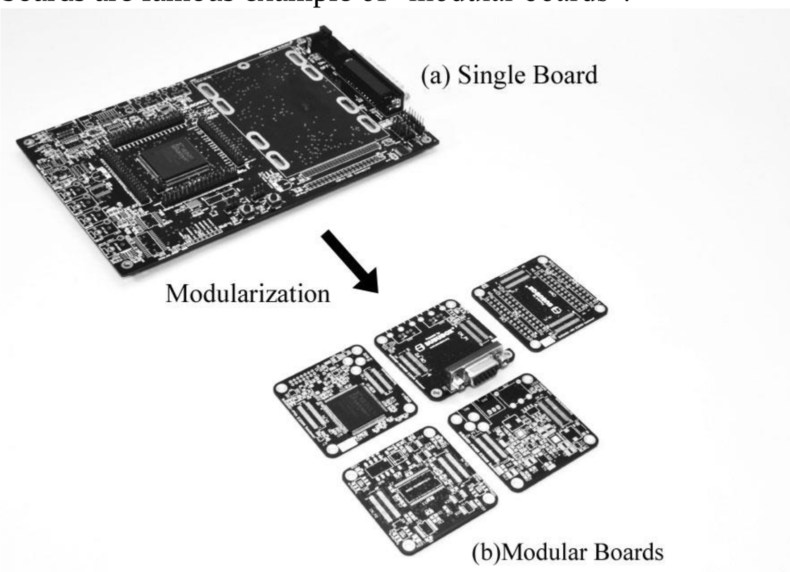

Fig. 1. Single board and modular board

CONVENTIONAL ASSIGNMENT METHOD

Conventional connecting methods between MPU and I/O interfaces are two types. The first method is to connect with each I/O interface independently. The other one is BUS connection. Independent connection method is the best on electric specification and performance. However it requires wide space for connection lines and many pins of connectors. The BUS connection shares some connection lines and pins. So it's connection line space can be reduced. However BUS line cannot use each I/Os at same time.

Bus line connection

The BUS line shares some bits lines. So it called “n bits bus” such as 8 bit bus, 16 bit bus. The BUS connection is the least number of connection lines. Fig.2 shows an example of 3 bits bus lines with four modular boards. The left side board “Module A” is a MPU board. The other boards “Module B” to “Module D” are I/O interface board such as a switch input, a LED output, and an UART interface. Each board has same connectors of CN1 and CN2. CN1 is able to connect to CN2. Each numbers inside of the frame shows pin numbers.

The critical problem of BUS connection is each function is not able to work at same time on shared lines. On Fig.2, function B and C or function B and D is able to communicate with MPU at same time. However function C and D is not able to do. So function C and D works with time-sharing technique. This problem occurred often on Arduino using two or more shields.

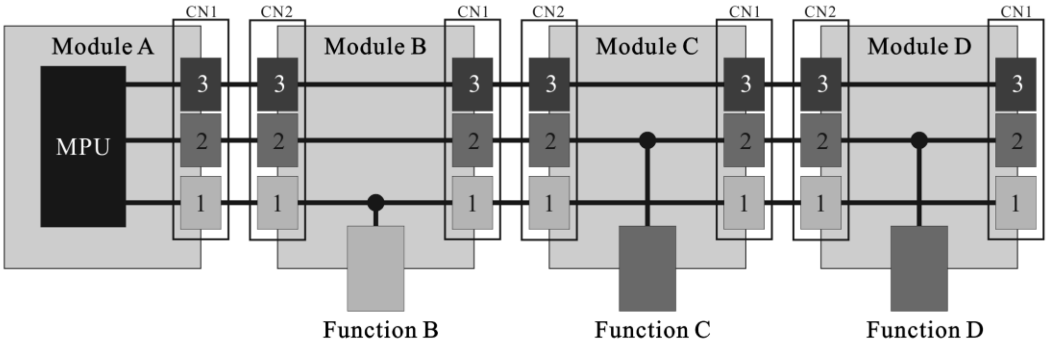

Fig. 2. Bus line connection (ex. Arduino)

Independent connection

Fig.3 shows an example of the independent connection with “star topology”. If you can use wide area for line space and much number of pins, it is the best connection between MPU and the other I/O interfaces. In Fig.3, MPU board is centered on the other I/O interface boards. So each connection line distance between MPU and function parts are minimum length. Of course, each functions are able to communicate with MPU at same time. However independent connection requires most wide area. Then star topology’s structure tends to spread on flat. So the star topology is not useful for embedded systems.

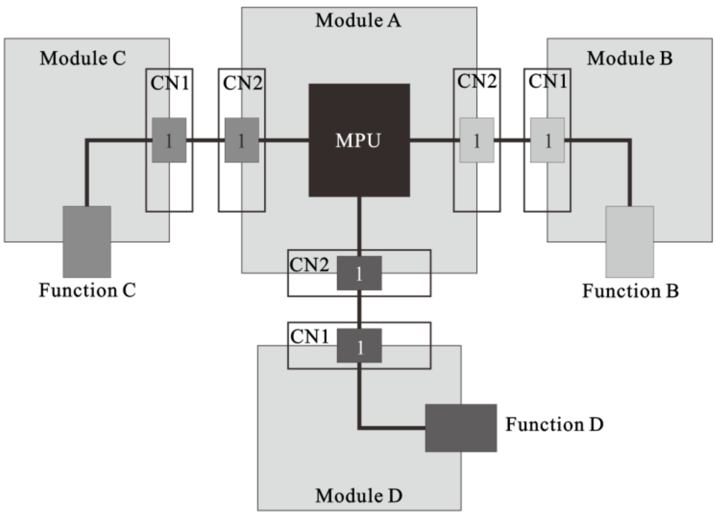

Fig. 3. Independent connection (Star topology)

On many circuits that are not so fast about under 100 MHz, you can use independent connection with “line topology” (Fig.4). On Fig.4, function B is assigned to pin 1 of CN2 and the other lines are sent to next module. Function C is assigned to pin 2 of CN2 on module C and it is connected through the line assigned to pin 2 on module B. Function D is assigned pin 3 and connected through module B and C. On this connection method, all modular boards are designed with the “sending lines” and decided pin assignment from modules which is used together in advance. So some combination of modules are not able to connect, if it remains many lines and pins. Then same modules are not able to connect together too.

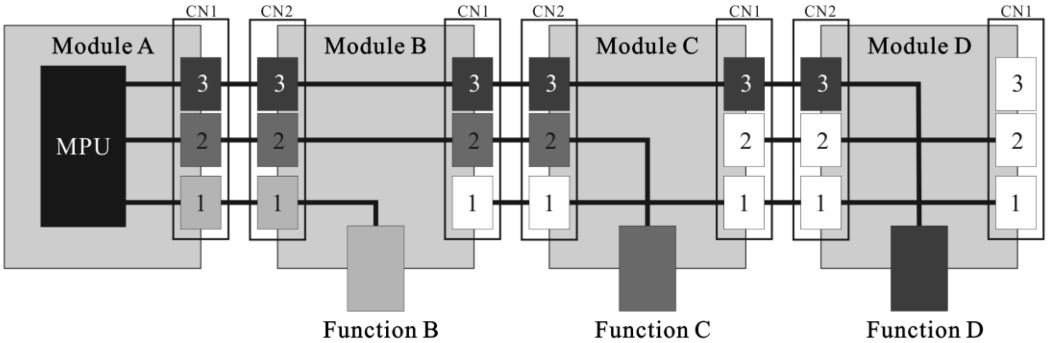

Fig. 4. Independent connection (Line topology)

PROPOSED METHOD

The “Bit-shift connection” is a solution of these problems. It is one kind of independent connection. The “sending lines” on Fig.4 re-assigned with bit-shift connection. On Fig.5, pin 1 is assigned function B on module B. It is same as Fig.4. However pin 2 and 3 on CN2 is assigned pin 1 and 2 on CN1 of module B. So function C is connected to MPU with “pin 1” on CN2 of module C. Function D is assigned “pin 1” on CN2 of own module. On this method, all connection lines are able to use and it is not required to be designed pin assignment of the relation between each module in advance. You can use same modules together and possible to use any order of modules. However the pin assignment of MPU side must be able to replace freely. So it is especially useful for FPGA and CPLD.

Fig.6 shows an example of modular boards using the “Bit-shift connection”. It is able to stack as long as the number of MPU’s I/O pins allows. All I/O interface modular boards are possible to change the order too.

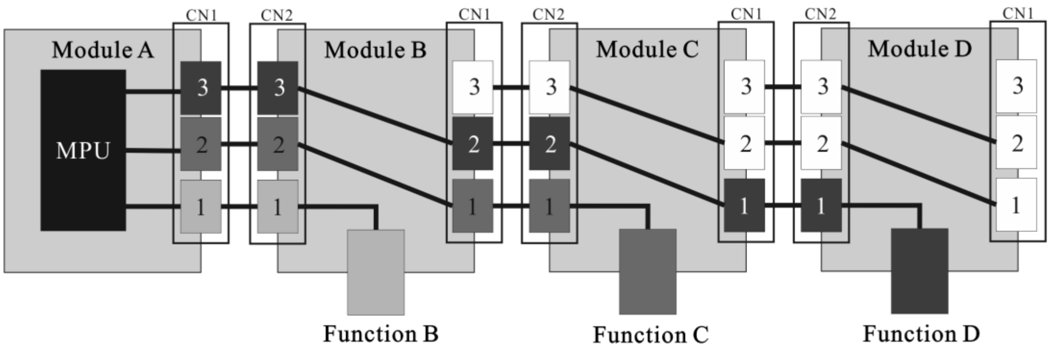

Fig. 5. Bit-shift connection

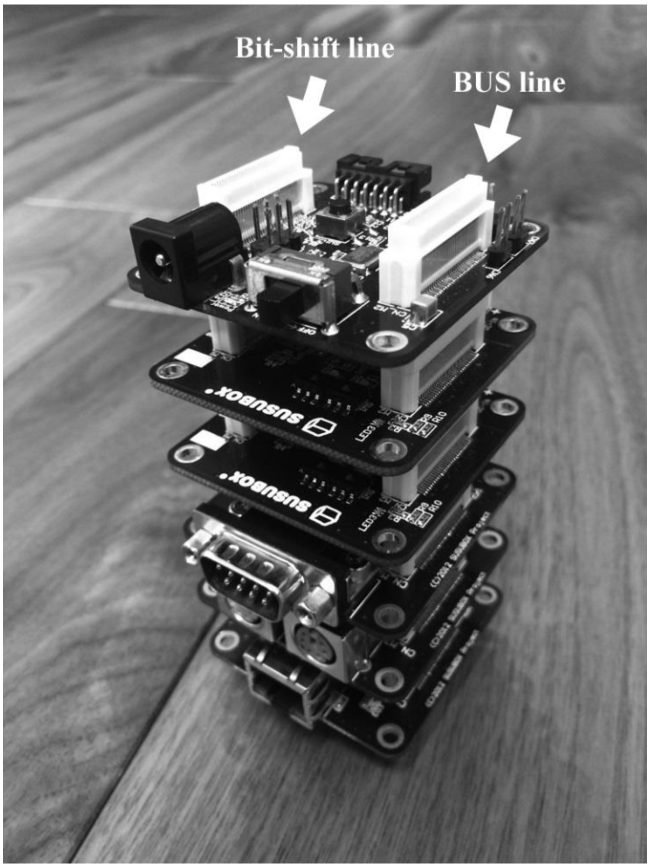

Fig. 6. Modular boards using the Bit-shift connection

On the real application, it requires BUS or daisy chain type connections such as I2C, SPI, JTAG, clock line, and reset line too. So one of the recommended implementation is to use both types with dual lines as shown in Fig.6.

CONCLUSIONS

The “Bit-shift connection” is a novel method of independent connection between modular boards. On this method, all I/O pins of MPU, FPGA, or CPLD are able to use without leaving. These modules that are designed using this method are possible to use same module together and possible to change the order. However on this method, the pin assignment of MPU side must be able to replace freely and it is a little difficult to manage pin assignment.

REFERENCES

1. Hidefumi Inoue, Moritoshi Yasunaga, Kenji kanazawa, and Noriyuki Aibe, “Signal Integrity Evaluation of Segmental Transmission Line under Real-world Application”, Proceedings of 2013 IEEE Electrical Design of Advanced Packaging & Systems Symposium (EDAPS 2013), pp. 108-111, Nara, Japan, Dec. 2013.

2. Skjin Kim, "High-Efficiency PCB- and Package-Level Wireless Power Transfer Interconnection Scheme Using Magnetic Field Resonance Coupling", IEEE Trans. Packaging and Manuf, Vol. 5, No.7, pp(863-878), 2015.

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Biomimetics bricks, *BioBricks*; a Platform of Knowledge Integration for Biomimetics by Digital Fabrication

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INTRODUCTION

The concept of Biomimetics is learning from living systems; researches of Biomimetics have long history, Leonard da Vinci had already mentioned about this concept and he proposed various biomimetics designs such as a Hung glider, Helicopter and so on. The word of "Biomimetics" was named by biologist, Otto Schmitt in late 1950s [3].

Many characteristics are able to identify biomimetic mechanisms such as capabilities to autonomously adapt to complex natural environments, natural environments are unplanned and unpredictable, so that changes and perform multifunctional tasks. In such natural environment, such tasks must operate whole a day without rearrangements or repairing for over coming risks. Benefits from such capabilities can include performing security monitoring and surveillance, search and rescue, operating under chemicals, biological and nuclear hazards, taking immediate corrective and warning actions as well as many others that are only limited by our imagination. Some of the biologically inspired capabilities that are/can be implemented into effective mechanisms include [5].

Biomimetics has been leaded by the U.S., recently European Union, especially Germany has been catching up to the U.S. and United Kingdom begin to concentrate scientific resources to this area. Japan is "one lap behind [1] to the U.S. and EU", while China is about to take over Japan. This situation was shown in the patent application technical trend surveys 2014 by Japan Patent Office [2]; 49.5 percent of nationalities of applicants for the Japanese patent on Biomimetics were the U.S. (26.9%) and E.U. (23 %) , while Japan was 21.1 percent and China was 17.6 percent (Korea, 8.1%) .

A CHALLENGE

Japan has been promoted Biomimetics; many researchers have been engaged in this area; prof. Shimomura who is the leader of Biomimetics researches of Japan pointed out that the level of research is high but researches have been done independently and there are no mechanisms of integrating these researches interdisciplinary. Hence, interdisciplinary platform to integrate Biomimetics researches are required.

FOR BEYOND THE CHALLENGE

In order to integrate results of Biomimetics researches, we propose a platform by using the digital fabrication that is Biomimetics bricks, *BioBricks*. BioBricks are bricks likewise LEGO bricks; their surfaces and / or structures are bio-mimetically designed.

There have investigated a lot of biomimetic materials for surface or structure, BioBrikcs enable us to implement these biomimetic surface or structure as bricks by using digital fabrication; each BioBrick has biomimetic characteristic, hence by combining these brick, we are able to create novel biomimetic materials.

Natural Computing by using BioBricks

BioBrick symbolizes biomimetic materials as a shape of brick and we can give name to each bricks; for example, a biomimetic material such as |||[][][]|||[][][]+++[][][] can be regarded as a composition of following three types of bricks A, B and C;

brick A; [][][],

brick B: |||
brick C; +++;
so we can symbolize the material as BABACA; we can also describe 2 dimensional structure ;

|||[][][]|||[][][]+++[][][]
[][][]|||[][][]|||[][][]+++
||||||[][][]|||[][][]+++[][][],

as

BABACA
ABABAC
BBABACA,

and we can describe 3 dimensional structure by accumulating the 2 dimensional structure.

Hence we are able to investigate biomimetic materials by extracting grammar of combining the symbols by using theory of Formal Language, Machine Learning including Deep Learning and so on. And when we can extract the grammar, we can design novel biomimetic materials that possesses required characteristics by using it.

BIOBRICKS OF A WING OF DRAGONFLY

BioBricks of a wing of Dragonfly are obtained from analyzing the wing; the wing of Dragonfly has been investigated not only in biology but also in Biomimetics; since a Dragonfly can fly without flapping a lot, it can fly quickly and can stop in the air by hovering, so the structure of the wings has been interested. And it turns out that the structure of the wing has zigzag surface in three dimensionally, so the zigzag structure causes spiral flows on the surface of a wing and generate power of lift; hence the wing of Dragonfly is high lift generating blade (Fig.1).

During gliding, dragonfly wings can be interpreted as acting as ultra-light aerofoils which, for static reasons, have a well-defined cross-sectional corrugation. This corrugation forms profile valleys in which rotating vortices develop. The cross-sectional configuration varies greatly along the longitudinal axis of the wing. This produces different local aerodynamic characteristics [4].

Process of making BioBricks of Dragonfly

BioBricks of Dragonfly are made through following processes;
1. Modeling a skeleton of Dragonfly wing (Fig.1),
2. Adding 3 dimensional information on the skeleton model (Fig.2, top)
3. Dividing modeled wing into parts according to biomimetic characteristics (Fig.2, top A-G),
4. Modeling each parts (Fig.2, middle),
5. Adding joints to each brick.

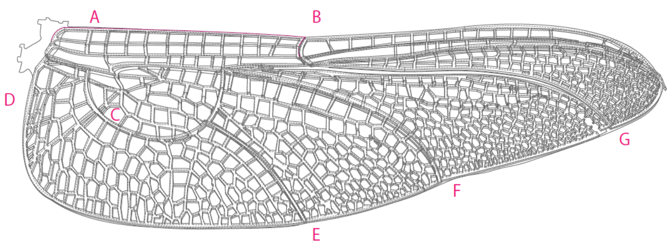

Fig.1 Modeled Dragonfly wing

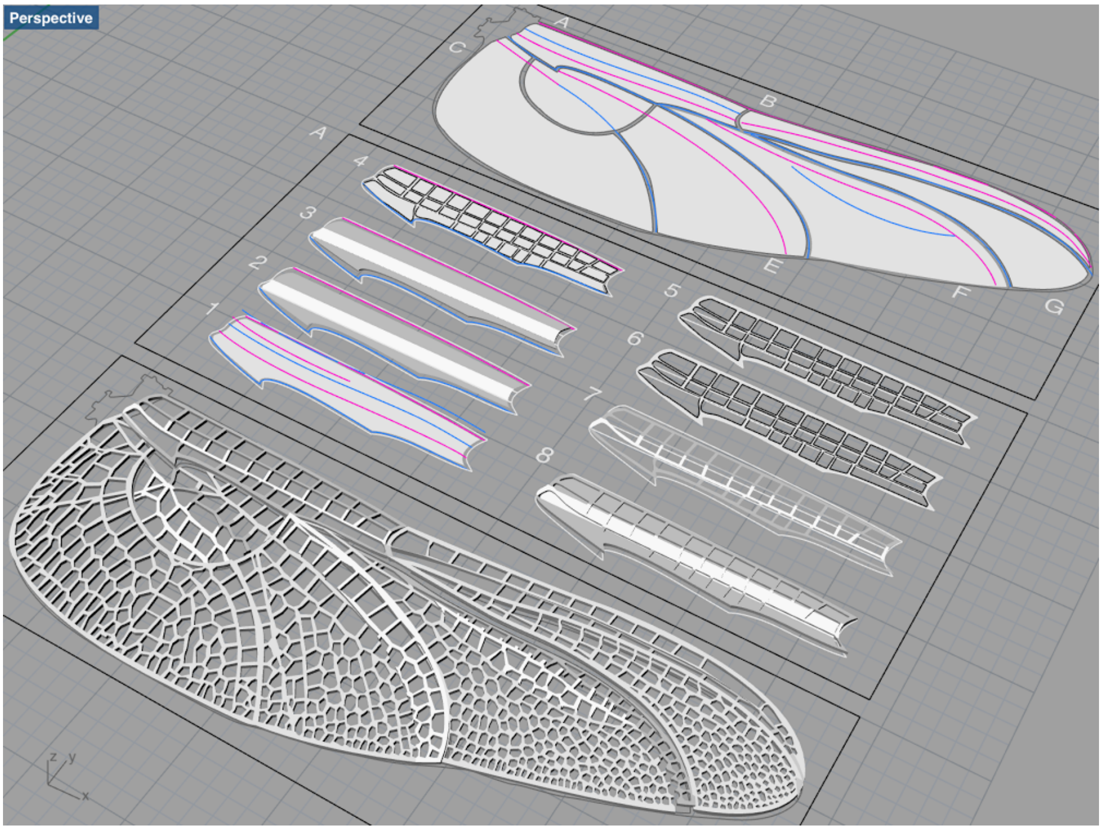

Fig 2. Perspective view of BioBrick A of Dragonfly wing

We created 8 types of BioBricks of Dragonfly wing, brick A to G; so we can re-compose a Dragonfly wing by connecting the bricks horizontally (Fig.3).

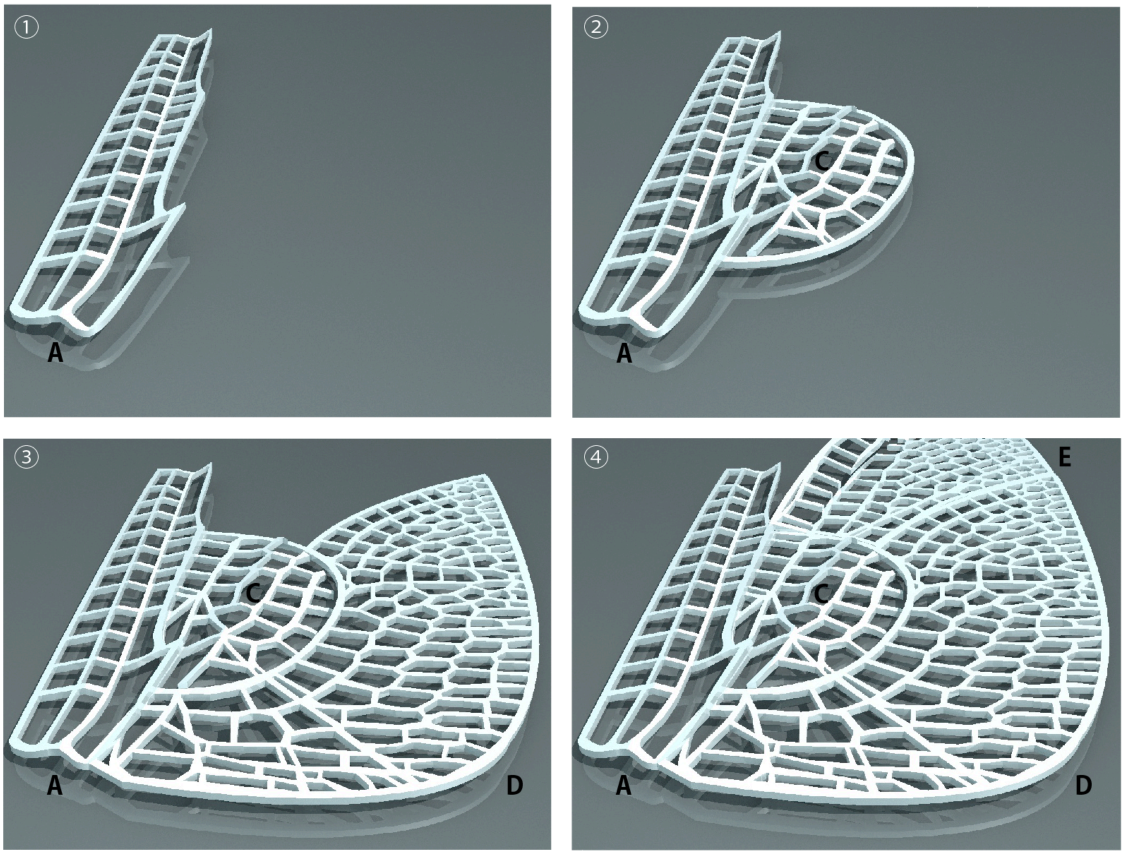

Fig.3: Re-composing a Dragonfly wing by combining bricks A to D; (top left) brick A, (top right) combining A and C, (below left) A,C and D, (below right) A, C, D and E

RESULT AND DISCUSSION

By using these bricks, we can denote the Dragonfly wing as

$$\frac{A}{C\ D\ E\ F} - \frac{B}{G},$$

where symbol "-" means bricks are neighboring and horizontally (2 dimensionally connected) and

$$\frac{X}{Y_1\ Y_2\ \ldots\ Y_n}$$

means brick X and bricks Y_1, Y_2, ... Y_n are neighboring and vertically connected; this composition of bricks are biologically optimized and it gives aerodynamics characteristics for the wing.

CONCLUSION

We propose a Biomimetics Bricks, BioBricks in order to integrate biomimetics research results by using digital fabrication; we create BioBrick of Dragonfly wing. In this example, we only show the case when the bricks are 2 dimensionally connected and re-compose a Dragonfly wing but the usage of the bricks are not limited to re-compose a wing but also we can create a novel structure by using the bricks. We plan to translate various Biomimetic structure into BibBricks and compose novel biomimetic materials.

Acknowledgement
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REFERENCES

1. M. Shimomura, Learning from Bio-diversity, Trends in Biomimetic Materials in the Next Generation, Learning from Bio-diversity symposium, 2010
2. The patent application technical trend surveys 2014, Japan Patent Office, 2014
3. Schmitt O. H., "Some Interesting and Useful Biomimetic Transforms," Proceeding, Third International Biophysics Congress, Boston, Mass., Aug. 29-Sept. 3,1969, p.297.
4. ANTONIA B. KESEL, AERODYNAMIC CHARACTERISTICS OF DRAGONFLY WING SECTIONS COMPARED WITH TECHNICAL AEROFOILS, The Journal of Experimental Biology 203, 3125–3135 (2000)

Additive manufacturing in the cycling industry: mainstream or gimmick?

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INTRODUCTION

Additive manufacturing (AM) for various industries has been trailed, prototyped and used in limited production runs (Gibson, 2015). But considering additive manufacturing with metallic materials has been around for over 15 years the penetration into an industry such as cycling that values customisation and progressive design techniques has been quite limited. This case study looks at the potential of and why additive manufacturing has not progressed from concept development and prototyping into production and mainstream. Selective Laser Melting (SLM) additive manufacturing systems mainly use Stainless Steel 316 (SS316) and Titanium 6Al.4V (Ti64) as a baseline material; both these materials are extremely common in the custom and high volume bike industries. For the purposes of this article we will focus on smaller custom bike manufacturers who are typically more agile and open to high levels of customisation in their products. The study finds that whilst a high number of companies will experiment and prototype with additive manufacturing there is little evidence that the design and development process translates to ongoing production for sale to the consumer, this could be due to knowledge of design and fabrication techniques.

REVIEW OF PROCESSES, COMPANIES AND PRODUCTION

Process

One of the most common forms of metallic AM is Selective Laser Melting (SLM) there are a number of machines that use this process from a number of manufacturers. For this study a baseline machine will be the SLM125, which was ordered and commissioned in late 2013 at Deakin University, Geelong, Australia. This study will not delve into the relative benefits of various machines.

Companies and Production

Figure 1 is a small snapshot of what is currently happening in industry today. Figure 1A shows collaboration between Renishaw and Empire Cylces based out of the UK (Renishaw, 2014). It was a prototype, designed and constructed to showcase the larger Renishaw metal printers. Whilst a road-going bike that passes all legislative requirements it is not a commercial product. Figure 1B is from Richard Sachs (Richard Sachs, 2012) a bespoke bicycles manufacturer from the United States. His main use of additive manufacturing is the concept development using Fused Deposition Modelling (FDM) before going into a casting process for his components. In this example it is part of the design and development not for functional use. Figure 1C is a commercially available yet limited item. The design was specifically for Bradley Wiggins (Pinarello, 2015) UCI world hour record which was attained in June 2015. The handle bars where designed by Pinarello and Jaguar Motors as part of the attempt, but due to UCI rules for record attempts all components must be commercially available. The bars are constructed in Ti64 using the SLM process. Figure 1D represents a lug design bike by Australian start-up Bastion Cycles (Bastion Cycles, 2015), this will be a commercially available product in mid-2016, using an AR-CAM process to produce the parts the lugs are joined via carbon fibre tubes to created a custom hybrid frame.

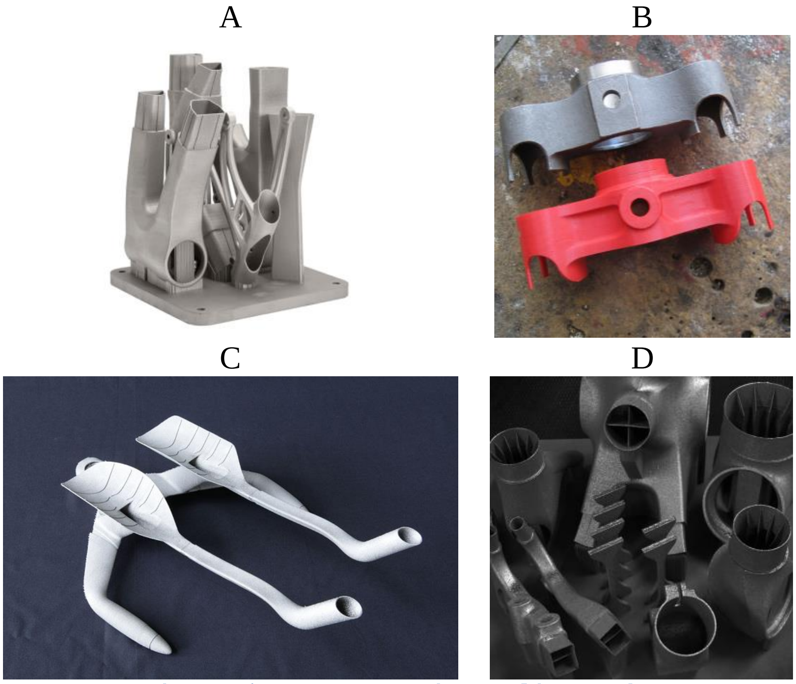

Figure 1 - AM Parts in Cycling Industry

There are very few examples of AM parts in end use as a commercial concern, realistically at the moment it is really just for showcases, design development, the elite and soon to be if successful for high-end bespoke frames in the near future. Considering the size of the cycling industry especially in the custom hand built bicycle industry there are very few good examples.

Case study with respect to design, fabrication and cost

As an example of production quality parts we use the example of a rear dropout set (Figure 2) from paragon machine works (PMW, 2015). As a CNC produced sample it costs $102.60 AUD and has a total mass of 71.1 grams, however needs a minimum billet of 80 x 80 x 30 mm (~850 grams) with a 90% machining wastage cost. With a SLM125 machine using Ti64 powder at $1500/kg it equates to a raw material cost of $107 AUD. So with no design, development, set-up, cleaning and personnel costs already the SLM process is more expensive than the CNC process.

Figure 2 - PMW Ti Dropout, DR0001

If we take another case example from paragon machine works part MS0060, which is a yoke attachment for mountain bike rear wheels (Figure 3). It is machined in two halves and must we welded together and has a cost of $477.50 AUD. The total component weight is 136 grams (68 grams for each half), which is machined from a 2.25 kg billet of materials; this represents a total wastage of 94% of the base billet material. If we take the already designed component into the SLM process the materials cost including supporting materials will be $223.75 AUD.

Figure 3 - PMW Ti Yoke, MS0060

With a re-design of the yoke component for this case study into a more SLM-friendly process (Figure 4) two important concepts have been achieved; firstly a reduction of material needed and secondly a reduction of support material. The redesigned component is now 120 grams as opposed to 136 grams and support material has been reduced by ~ 25%, this brings the cost down to $193.50 AUD. The re-design considered the elimination of most over-hanging edges to minimise support material as well as removal of all CNC fixtures. This part has be designed to be printed in the vertical orientation, thus allowing for five components to be printed at once on a SLM125 machine thus optimising the plate layout.

Figure 4 - AM optimised re-designed yoke

DISCUSSION

It is possible to design and produce cost effective components for commercial use in additive manufacturing. As shown with the above case studies a degree of complexity is needed to meet the minimum threshold. Once that threshold is met there is a clear financial advantage as shown with the yoke concept. As a simple substitution between CNC and SLM there was a 54% difference in cost, if then use the re-designed component we get a 60% improvement. This is a substantial difference; any offset in materials, labour, capital and profits can be accounted for within those margins. There is clear demand as companies such as PMW are producing these products.

CONCLUSIONS

There is and will continue to be on-going debate about additive versus conventional manufacturing processes. In this study a case study was presented on two commonly available components for the hand built cycling industry. A company such as PMW supply numerous companies around the world all using CNC machined parts. Whilst CNC is cost effective for many of their components as the complexity of a design increases additive manufacturing has a clear advantage as shown by this study. The initial literature showed that there are quite a few companies that have experimented with additive manufacturing mainly for concepts or prototypes there seems to be only a couple of companies building bicycles as full solution to manufacturing. These companies such as Bastian Cycles located in Australia are yet to have a commercial product however will be launching in mid 2016 to the public.

In summary, additive manufacturing in the cycling industry is more than a gimmick, the business case around the process, its applications and the end use to the consumer is developing. But at the same time it is not mainstream. Manufacturers clearly need to think about manufacturing methodologies and what process works best with respect to the design. For example Bastion Cycles are making components similar to the PMW dropouts using AM that would in fact better be served by CNC and vice versa.

REFERENCES

1. I. Gibson, D.W.Rosen, and B. Stucker. 2015. *Additive Manufacturing Technologies: 3D printing, Rapid Prototyping, and Direct Digital Manufacturing. 2nd Edition*. Springer-Verlag, New York
2. Renishaw. 2014. *First metal 3D printed bicycle frame manufactured by Renishaw for Empire Cycles*. Retrieved from http://www.renishaw.com/en/first-metal-3d-printed-bicycle-frame-manufactured-by-renishaw-for-empire-cycles--24154
3. Richard Sachs. 2012. *Richie-issimo 2.0 Fork Crown*, Retrieved from http://www.richardsachs.com/site/2012/09/24/richie-issimo-2-0-fork-crown/
4. Pinarello. 2015. *Pinarello Bolide HR White Paper 1.0*. Retrieved from http://www.pinarello.com/en/resources/files/WHITEPAPER_BOLIDE_ENG4.pdf
5. Bastion Cycles. 2015. Bastion Cycles – 3D printing X Filament Winding. Retrieved from http://bastion-cycles.com/process.html
6. PMW. 2015. Paragon Machine Works. Retrieved from http://www.paragonmachineworks.com

A New Search Engine for 3D Print Models and 3D Data Conversion Platform

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INTRODUCTION

Recently, the number of 3D Printed Models on the Internet is rapidly increasing. Especially, not only famous portal sites like Thingiverse[1] but also many private/company sites which offer free 3D Printed Models appeared. However, from user's point of view, it's becoming harder and harder to find the exact 3D model which he/she looks for, because 3D models are scattered on the Internet, and there is no specific entrance to start navigation. In order to overcome that inconvenience, we started to develop a new search engine for 3D Printed models. Also, we implemented sophisticated 3D Data conversion platform to deal with various types of 3D formats (Mesh[STL], Voxel[VOXEL] and Annotation[AMF]). In this paper, we introduce our concept, system and future visions.

BACKGROUNDS

The number of 3D Printed Models on the Internet is rapidly increasing. Table.1 shows famous portal sites for 3D printed models. Not only repository sites like "thingivese" and "google 3D warehouse", but also public sectors (museum, research center like NIH and NASA) and universities actively offer free/Open 3D Data mainly for educational purposes.

WebPortals	http://www.shapeways.com/
	http://www.cloudfab.com/
	http://i.materialise.com/
	http://www.ponoko.com/
	http://www.sculpteo.com/
	http://www.figureprints.com/
Industrial	http://3dproparts.com/
	http://www.materialiseonsite.com/
	http://www.redeyearc.com/
	http://www.redeyeondemand.com/
	http://www.quickparts.com/
	http://www.solidconcepts.com/
Blogs	http://fabbaloo.com/
3D DataBase	http://www.thingiverse.com/
	http://sketchup.google.com/3dwarehouse/
	http://www.the3Dstudio.com/
Public Sector/ University	http://3dprint.nih.gov/
	http://nasa3d.arc.nasa.gov/models/printable
	http://3d.si.edu/
	https://sketchfab.com/britishmuseum
	http://www.museum.kyushu-u.ac.jp/3d/index-ja.html
	http://fab3d.cc/zukan

Table.1 Website for 3D Print Models (Partially Referred from http://fabbaloo.com/3d-resources#services)

However, from user's point of view, it's becoming harder and harder to find the exact 3D model which he/she looks for, because 3D models are scattered on the Internet, and there is no specific entrance to start navigation.
To overcome this problem, several search engines for 3D models appeared. There are three of famous search engines. The first one is STLFinder (http://www.stlfinder.com/), the second one is Yeggi (http://www.yeggi.com/), and the third one is Yobi3D (https://www.yobi3d.com/).
We also decided to develop a new search engine for 3D Printed models. Though basic concepts and functions are the same to the other engines described above, we add the new feature of 3D Data conversion, in order to deal with various types of 3D formats (Mesh[STL], Voxel[VOXEL] and Annotation[AMF]). We discuss importance of this function in the next section.

3D DATA FORMAT

In the world of 3D Printing, STL (Stereolithography, Standard Triangulated Language, or Standard Tessellation Language), which was originally proposed by 3D systems, has been used as the 'de facto' standard for over 20 years. 3D Search Engines are based on STL (some of those process OBJ file for color textures). The original specification is still available: http://www.fabbers.com/tech/STL_Format
STL is very simple, since a file consists of a list of only facet data. STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. Needless to explain, however, recent progress of 3D Printing machines is going far beyond coverage of STL.
The group called "STL2.0" (https://groups.google.com/forum/#!aboutgroup/stl2) had started in this context. This is an informal ASTM-driven group for discussion of a new file-format for 3D Printing, which was supposed to replace the de-facto STL standard (Of course, also to keep connecting to STL).
AMF (Additive Manufacturing Format) is a fruitful outcome from this discussion group. AMF is a new XML-based standard with native support for curved surface, color, multiple materials, internal meso-structure, constellations, and metadata. It overcame major limitation of STL.
Overview is available at:
https://en.wikipedia.org/wiki/Additive_Manufacturing_File_Format
Official Specification of AMF 1.2 is available at:
http://www . astm.org / Standards / ISOASTM52915.htm

For the next version of AMF, some of researchers start to discuss possibilities of adopting Voxel File Format. AMF is powerful but not enough to represent precise internal structures. Voxel is useful for describing solid infill of 3D object, multi material dithering, path planning for CAM and also effective for FEM simulations in CAE software. There are some of Voxel File formats shown in Table.2. We proposed a new voxel file format ".fav" with Fuji Xerox Company in Japan [1].

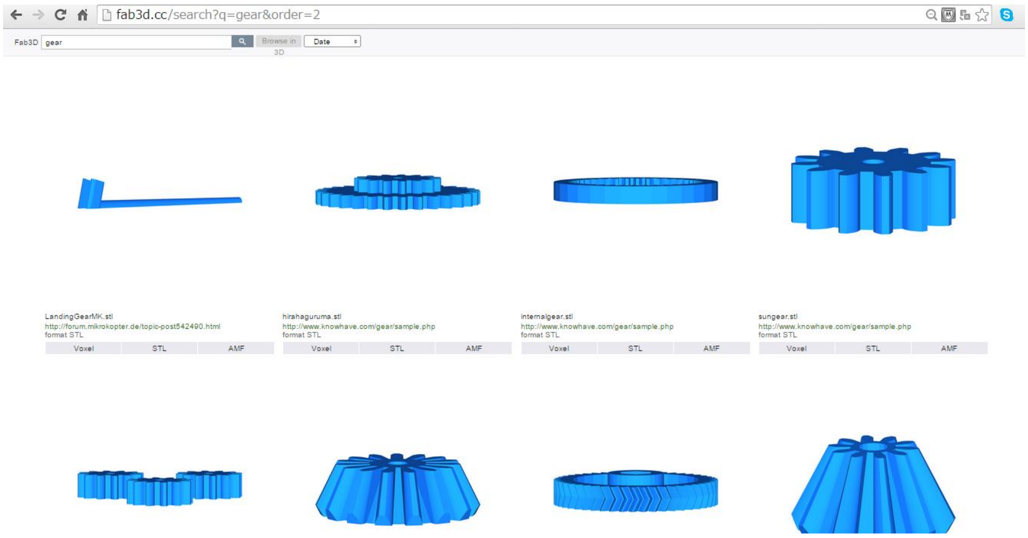
.binvox	Princeton University, Minecraft)	http://www.cs.princeton.edu/~min/binvox/
.SVX	Shapeways adopted	AbFab3D (http://abfab3d.com/
.VXC	Cornel University developed by Dr. Hiller and Dr. Hod Lipson	VoxCad (http://www.voxcad.com/)
.Vol	Harvard School of Architecture	Monolith (http://www.monolith.zone/)
.Tiff, .Gif, .PNG(s)	(many)	DICOM, fabmodules (http://fabmodules)

.Fav	Keio University SFC and Fuji Xerox	VoxFab (under development)

Table.2. Famous Voxel Formats

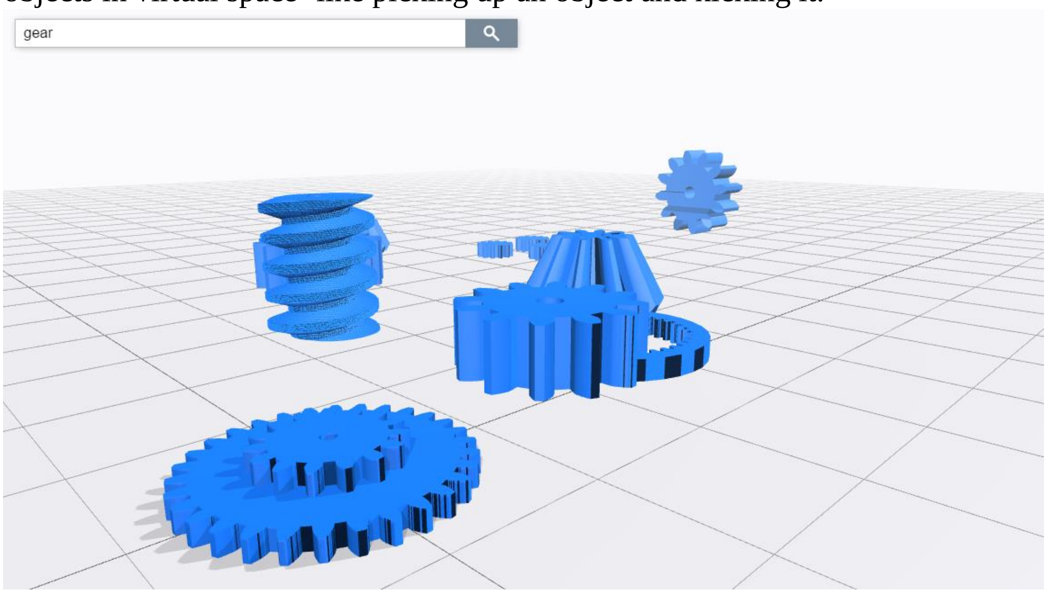
SERVER IMPLEMENTATION

First, we implemented the basic search engine which consists of (1) STL crawler (using Microsoft Bing API), (2) SQL DB/Server for indexing, (3) Web 3D Viewer (using three.js Javascript). So far we stored more than 300,000 STL files, and we estimate we will get more than 1,000,000 STL files at the end. Our search engine is already available at : http://fab3d.cc/



(Fig.1) Fab3d.cc (http://fab3d.cc)

User can input a query as a key word (such as “bunny” “iPhone” “tower” “virus”..), and the system shows searched results. We also offer an attractive mode called “Browse in 3D”, which offers users to see found objects in one 3D Space. User can interact with 3D objects in virtual space- like picking up an object and kicking it.



(Fig.2) Browse in 3D (http://fab3d.cc)

Moreover, user can get converted 3D models with our data conversion functions discussed in the previous section. In AMF view, users can attach annotations/tags to a part of an object, and paint colors on surfaces of an object, by making use of new features of AMF. In Voxel view, users can add/remove new voxel cubes and modify the shape with the simplest interaction like Minecraft or Lego.

Taking accounts of legal issues, we crawl Creative Commons License with STL model when our crawler finds the model. Only in the case that system confirm a specific Creative Commons License attached to the model, the system shows [save] button to urge users to download the model, with Creative Commons License.

IMAGE PROCESSING

We generate 2D image from 3D model for using it as a thumbnail image of search results. Before generating the image, 3D model are normalized with respect to the scale and the pose in order to get more conspicuous image. Specifically, the 3D model is scaled so that its largest edge of the axis-aligned bounding box becomes same to that of all other 3D models. Furthermore, 3D model is rotated in units of 90 degrees about Z-axis in order to make a largest side face faces the front and also rotated about X-axis depending on a balance between height and depth of the bounding box for better viewing.

In current system, we use the images only as a thumbnail image of search results, however, in future work, we are going to use it for various studies of 2D image-based similar shape retrieving and machine learning with 3D model.

AUTOMATIC SEGMENTATION

We also implemented auto segmentation, which helps users to recognize several parts of one model. The following algorithm is used to decompose a mesh into sub meshes. We adopt the Shape Diameter Function (SDF) for segmentation. This algorithm is composed of three steps. First, it computes the SDF values that measure local shape volume of a mesh (the detail is described later). Second, it divides facets of a given mesh into several clusters stochastically based on the SDF values; soft-clustering. The final step is fine partitioning to smooth boundaries between parts; hard-clustering.

In the first step the SDF value is computed as follows. For each facet, we use a cone: the centroid of the facet as apex and inward-normal of the facet as axis. We send several rays inside this cone from the apex to the other side of the mesh. For each such ray, we check the length between the apex and the first intersection point on the mesh. The SDF value is defined as the average of the lengths. We compute the SDF values for each facet one by one.

In the second step, soft-clustering is achieved by fitting the histogram of the SDF values with normal distributions using Gaussian Mixture Model (GMM).

In the hard-clustering, we applies k-way graph-cut algorithm to the result of the soft-clustering, and finally we get the segmented mesh from the output of the graph-cut.

CONCLUSION

Our prototype service is already available on the Web. We are planning to do an evaluation test of our service in cooperation with 3D printer users. Our future plan also includes “Geometry-based search”, which would show ‘geometrically’ similar models to a model as a query (user input). Our final goal is to offer the hybrid search which combines key-word search and geometry-based search.

REFERENCES

1. H.Tanaka, New File Format for 3D Printing, its extensions and applications, NIP 31 Digital Printing and Digital Fabrication, Invited talk., 2015
2. Lior Shapira, Ariel Shamir, Daniel Cohen-Or, Consistent Mesh Partitioning and Skeletonisation using the Shape Diameter Function, The Visual Computer 24(4) 249-259, 2008.

Official Website:

http://iith.ac.in/~icdf16/