

Article

How Design Technology Improves the Sustainability of Intangible Cultural Heritage Products: A Practical Study on Bamboo Basketry Craft

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Abstract: The sustainability problem of many intangible cultural heritage (ICH) products stems from the shrinking of the core practitioner group, which is also the case for bamboo basketry craft. We believe that the problem in bamboo basketry originated in the lack of labor division between design and manufacturing, which prevents professional designers from entering this industry and results in the absence of several key stakeholders related to innovation and R&D. The lack of labor division is due to the technical difficulties associated with expressing the design concepts. The complexity of basket weaving structures makes it difficult to communicate between designer and manufacturer without precise expression tools, thus binding design and manufacturing into an integrated role. Guided by the user innovation theory, our team studied the design technology of bamboo basketry and developed a series of aiding tools, including the modeling of basic over-under structures and free weaving structures, automatic mapping techniques from 2D to 3D and several frequently used weaving skills, such as connecting, wrapping, plaiting and knotting. This technology enables designers to quickly design and express weaving structures with full details in digital models rather than to make samples. The application of the software shows that the technology considerably improved the designer interest and confidence. This technical solution makes designers, rather than programmers, able to do the development work, which also helps to create a sustainable ecological environment of technological research, also avoiding the difficulties associated with attracting business investment for such niche demands in the starting stage. Our practice shows that the sustainability of ICH products and the sustainability of the industry are closely related and that solving the latter supports the former.

Keywords: intangible cultural heritage; sustainability; design technology; bamboo basketry craft



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1. Introduction

Bamboo basketry craft is one of China's intangible cultural heritages (ICHs) and was added to the protected national ICH list issued by the Ministry of Culture of China in 2006 in the category of Traditional Art (number 350VII-51).

Bamboo basketry craft is widely distributed in southern regions of China, such as Zhejiang, Hunan, Sichuan, Guangxi and Fujian. Bamboo grows fast and requires little conservation. In some areas, its excessive spread has threatened the growth of other plants, endowing bamboo with considerable sustainable use value. The manufacturing methods of bamboo basketry products are rather primitive, and in some bamboo resource areas (mostly in rural areas), the leisure time of residents is often used as a supplement for labor [1]. Some companies have set up factories in remote bamboo resources areas as a response the Chinese government's poverty alleviation plan and rural revitalization plan [2] and have achieved win-win situations.

Bamboo is an elegant plant in traditional Chinese culture and is often the subject of poetry and painting. Bamboo basketry products are exquisite in structure and rich

in detail. They are loved by the public, with a strong user base. Backed by a profound cultural background, they have considerable potential to contribute to the sustainability of traditional culture and local economies [3,4]. However, the survival of bamboo basketry in modern society is a complex problem posing challenges for many years. Regions in China that are rich in bamboo resources (such as Anji in Zhejiang Province) have developed bamboo products such as bamboo floor, bamboo charcoal and even bamboo beverages [5,6] by deep processing, achieving positive economic benefits. However, in terms of cultural heritage, the continuous decline of bamboo basketry craft is undesirable.

Our research focuses on the technical requirements of bamboo basketry products in terms of sustainability. According to the premise of maintaining the traditional handcraft manufacturing method (which is difficult to replace with machines [7]), we attempt to enable professional designers to engage in basket design with technical assistance, accounting for complex structural details. In this paper, we present our technical development and application, in an attempt to try to resolve issues in the production processes of traditional basket weaving.

2. Literature Review

2.1. Bamboo Basketry Product Industry of China

Bamboo basketry products are popular in China, Japan and other Southeast Asian countries. According to the *2020 China Bamboo Cultivation and Industry Development Report* released by the Development Research Center of National Forestry and Grassland Administration of China [8,9], by the end of 2020, the area of bamboo resources in China had reached 791.42 million hm. Two main types of bamboo species are used for basketry: Moso bamboo in the central and southeastern areas and *Sinocalamus affinis* in the southwest and southern areas; Moso bamboo accounts for 61% of the total bamboo resources in China [10].

There are 19,754 bamboo production and processing enterprises in China, including 18,338 small and micro enterprises, 1320 medium enterprises and 79 large enterprises. The total number of employees in the bamboo industry is 15.82 million, among which 13.93 million are farmers, accounting for 88.08% of the bamboo workforce. By the end of 2020, the output value of the industry reached RMB 31.99 billion, including RMB 8.22 billion in primary industry, RMB 16.48 billion in secondary industry and RMB 6.81 billion in tertiary industry [9]. According to the *2020 China Bamboo and Rattan Commodity International Trade Report* [11] released by the International Bamboo and Rattan Organization (INBAR), in 2020, China's total export trade of bamboo products totaled USD 2200 million, of which woven bamboo products accounted for about 14%, representing the second largest category following bamboo tableware (42%).

Many types of bamboo basketry products are manufactured in China, but innovative designs are rare, as indicated by many research reports in regions with rich bamboo resources [12]. For example, the area of bamboo forest in Zhejiang Province accounts for about 11% of China's total bamboo resources, but the types of bamboo basketry products manufactured in this region are similar to those made half a century ago [13]. Qingshen, a small town in Sichuan Province, is home to a style of bamboo basketry that is famous in China; however, due to a lack innovation, recently developed products involve copying images with finely split bamboo sticks, resulting increased prices and costs. Thus, production is limited, as are the market and user group [14]. The shortage of designers is considered to be the main reason for most problems in the bamboo weaving industry [15], resulting in an industry that is seriously out of touch with the market, failing to cater to or guide user needs.

The production of basketry is primitive and complex [16], involving about 30 processes and more than 10 kinds of homemade tools. The process is not clearly divided [17], and for most products, all manufacturing work is done by one or two people [18]. The average age of bamboo craftsmen is high, especially the craftsmen officially identified as outstanding inheritance keepers. In order to protect ICH, the Chinese government has funded selected inheritors to practice the craft and ensure its prosperity. The main problem associated with

this inheritance method is that designs and skills can only be passed through products, dictation and demonstration, which is an inefficient means of transmission [19,20].

2.2. Study on Basketry

Basketry a craft constituting the manufacture of products from bamboo, rattan, willow, grass and other plant materials based on weaving techniques involving complex structures developed over hundreds of years. Many related discussions have occurred in the field of anthropology through cultural observation.

Meilach [21] summarized and classified the structures of various basketry products, and divided them into four basic categories: weaving, plaiting, twining and coiling. Law [22] studied traditional white oak basketry in the areas of the central Appalachian Mountains and traced the origin of the product shapes and structural features, the style differences between regions, artisans' views on this traditional skill, etc. McGuire [23] investigated Shaker baskets made with materials similar to bamboo. As twilling is the most commonly used basket-weaving skill, LaPlantz [24] systematically studied the structural features manufacturing techniques of twilled baskets. Sentence [25] summarized 16 basic types of basket materials in his encyclopedic book, as well as the weaving techniques associated with each material.

2.3. Study on Bamboo Weaving Skills

Research on bamboo weaving skills has mainly been conducted in China and Japan. Japanese bamboo basketry was derived from China, gradually evolving from functional products to fine art, such as sculpture, representing a unique form of modern art. The Asian Art Museum in San Francisco preserves more than 900 pieces of Japanese bamboo baskets donated by Lloyd Cotsen, which have been the object of numerous studies. Moroyama [26] considered 74 baskets in a review of the development of Japanese bamboo basketry over the 150 years from the Meiji period to modern times. Rinne [27] conducted a thorough study on the working style, living status and teacher–student relationships of the craftsmen in Japan and provided a list of typical skills of Japanese bamboo basketry. Coffland [28] conducted an analysis of the development path of Japanese bamboo basketry, from early Chinese-inspired craft to the eventual development of modern Japanese woven sculpture. It is believed that the disillusion of China's cultural idol status in Japan about 1000 years ago indirectly led to the separation of Japanese bamboo art styles from Chinese practice. Earle [29] focused on modern bamboo basketry in Japan after the new millennium, reporting the trend of Japanese bamboo basketry approaching sculpture art, even borrowed the name of bamboo sculpture.

Laufer [30] introduced Chinese bamboo basketry and compared its practice with the traditional plant-weaving skills practiced by North American Indians, as well as in the Philippines, Hawaii and New Zealand. Zhang [31] reported on bamboo classification and material properties, categorizing bamboo basketry styles in different parts of China. He also compiled a list of commonly used Chinese bamboo weaving skills and 40 typical structures. Xu Huadang [32] conducted a detailed study on fine bamboo weaving crafts in Zhejiang, which to some extent, represent the value orientation of modern Chinese bamboo basketry. Zhang [33] conducted a comparative study on bamboo basketry styles in modern China and Japan, highlighting their differences. Liu [34] studied the form and technological innovation of modern Chinese baskets and discussed the possibility of applying traditional patterns in weaving structure innovation.

2.4. Development of Digital Design Techniques

At present, digital techniques are mainly applied in bamboo basketry for the purpose of demonstration, such as the Qingshen bamboo basketry digital platform [35,36] and the Mingdao bamboo basketry digital texture library [37], etc. Most digital platforms and databases focus on ICH protection and knowledge dissemination rather than promotion of innovative design [38].

The most important technical requirement for bamboo basket design is the automatic generation a large number of complex structures, whereas most CAD software does not provide such functions. Liu [39] developed an automated 3D modeling technology for orthogonal weaving structures for bamboo or rattan products, proposing a technique for mapping a black and white image into 3D weaving structures [40]. Zhang [41] proposed fast and interactive methods for intelligent 3D modeling of free weaving structures. Liu [42] developed rapid techniques to model non-circular strip cross section forms using bamboo materials. Wu [43] developed parametric modeling technology for 3D printing of bamboo baskets. Cao [44] developed a digital design system for bamboo baskets and realized the rapid modeling of basic basket types.

Grasshopper for Rhinoceros is one of the most commonly used development tools for weaving structure design, with which Jiang [45] and You [46] developed parametric modeling technology for basic weaving structures. Similar studies are occasionally published but with few new patterns developed. Some studies have investigated the design of baskets with intelligent technologies. Liu [47] generated innovative weaving patterns based on generative adversarial networks (GANs), and Wang [48] designed weaving patterns based on deep learning technology. Most of the designed objects are planar weaving patterns, whereas 3D smart modeling of weaving structures has rarely been reported.

2.5. User Innovation in Design Technology

Because bamboo basketry design technology has a relatively smaller user group and the profit is not sufficient to attract considerable investment, here, we adopt a user innovation strategy of open innovation for R&D.

Open innovation is a fifth-generation innovation mode of technological innovation [49]. The concept was proposed in 2003 by Chesbrough [50], who suggested that creative ideas can be obtained from both within and outside of a company. There are four modes of open innovation, namely user innovation, supplier innovation, inter-enterprise cooperative innovation and university–industry cooperative innovation [51]. The concept of user innovation proposed by Von Hippel refers to the innovation activities implemented by users, including new ideas, techniques, equipment, materials or processes [52].

Assistive tools are important factors for user innovation because many users have their own ideas, but not all users can express their ideas well. Von Hippel referred to the concept of a *user innovation toolbox* and outlined four characteristics [53–55]: (1) ability to get people to go through a series of cycles and then learn by doing; (2) friendly interface with low learning cost; (3) a variety of modules and components to enable users to focus on innovation work; and (4) information about the capabilities and limitations of the manufacturing system to ensure the feasibility of the user's solutions.

After years of research and practice, user innovation theory has been verified in many fields. Venesz conducted a systematic study on the characteristics of *leading users*, the main body of user innovation [56]. Fursov demonstrated the value of user innovation in a non-market environment and implementation methods through five product design cases [57]. Escobar studied the user innovation phenomenon in small- and medium-sized enterprises and investigated the correlation between innovation and entrepreneurship [58]. Keinz discussed the operational issues associated with user innovation through several cases [59].

The form of user innovation investigated in this paper is that of bamboo basket designers developing their own assistive design tools in the software with which they work. Most design software provides two kinds of secondary development interfaces: one is for professional programmers, using the VC++ platform as the main development tool, and the other is for users, using low-efficiency but easy learning tools, such as VBA [60] and scripts [61], or non-programming tools, such as Grasshopper for Rhinoceros [62] and ArduiBlock for Arduino [63] (a hardware design platform).

2.6. Summary

CAD technology is commonly used in ICH product design, most of which do not significantly differ from ordinary products. For example, the design tools for traditional art are basically the same as those for graphic design. However, bamboo basketry is an exception due to its rich 3D structural details, which are connected as a whole. The functions of common CAD software functions cannot solve this problem. Thus, the design method of bamboo baskets has not changed meaningfully over the years, whereas other ICH products, such as embroidery [64], paper cutting [65] and traditional patterns [66], have benefited from the achievements of modern technology.

Most literature studies of bamboo basketry design tools have focused on automatic modeling of basically cross woven structures, rarely exploring basketry patterns, such as Stout's Celtic interwoven pattern generated with 2D design tools [67]. The weaving skills necessary to make bamboo baskets very rich, involving dozens of high-quality exquisite structures [32], which seldom appear in the technical literature. Tools for innovation (not just for demonstration) remain in the initial stage of development.

Given the CAD platforms and their development tools (such as Grasshopper, VBA, etc.) used in the literature, most developers are designers rather than professional programmers. This is an important sign of user innovation. Research papers have been published on the bamboo basketry industry, but analysis of the long-term impact of design technology is lacking, possibly as a result of the immaturity of the associated technology.

3. Technical Requirements

3.1. Product Types

Bamboo basketry products can be roughly divided into four categories [31]. The first category is functional daily necessities, such as containers or furniture, which are manufactured according to the traditional manual mode of production. The markets and user groups of these products are mainly in rural areas, as they can easily be replaced by industrially manufactured competing products made of plastic or metal. The second category is handmade high-value-added bamboo art by ICH master inheritors. With high a price and low production, the user group is small, and the market is similar to that of art collections. The third category is traditional bamboo handcrafts that are both functional and artistic, with an affordable price. The fourth category includes bamboo curtains, mats, and other plane-woven products, the manufacturing process of which has been industrialized to some degree, with labor division and machine application.

As an ICH, bamboo basketry mainly refers to artworks (category 2) and functional crafts (category 3). With the support of China's national ICH preserving policies, artworks have stable practitioners and inheritance paths, and there are no concerns with respect to their sustainability. Functional crafts are widely appreciated, but consumers are sensitive to their price, which is affected by their high complexity and the low productivity. Furthermore, product quality relies on the skills of the workers. Therefore, sustainability concerns with respect to bamboo basketry are focused on functional crafts, with two main problems. The first is the shrinking worker group. The craft requires workers to complete a period of training before they are able to make products of standard quality. Workers are required for full-time participation, which is not attractive to young people. Current practitioners are mostly people with a traditional family background, and it is difficult to attract enough workers and qualified outsourcers to improve productivity. The second problem is the minimal added value of the products. As an ICH, bamboo basketry has been subject to few adaptive innovations to meet the needs of modern society, either functional or aesthetic.

These two problems of functional crafts are both deficiencies and opportunities. Solving these problems will incorporate innovation resources from outside of the industry. In return, research on design and design technology can also be promoted to form a cycle that leads to sustainability.

3.2. The Absence of Professional Designers

The disadvantages of bamboo basketry in the modern world are often attributed to the competitive disadvantages compared with industrial products [68], although this is not the key issue. In modern society, product markets and user values tend to be diversified and can accommodate a variety of unique preferences. The main problem lies in the product itself. According to Laufer's book, *Chinese Baskets* [30], published in 1925, bamboo basketry products have hardly changed in the current Chinese market from those made a century ago. The products appear to be in a static state and unaffected by changes in the world.

However, bamboo basketry has been subject to innovation, although mainly in artworks. *Chinese Bamboo Craft* by Zhang Qisheng [31], academician of the Chinese Academy of Engineering, and *Chinese Bamboo Weaving Art* by Xu Huadong [32], a national ICH inheritor of bamboo basketry, provide a detailed overview of bamboo weaving art in China. In the past 50 years, there have been many innovations in large and high-price bamboo artworks, the common innovation style of which can be summed up in one word: *complexity*. The degree of fineness, the number of pattern types, the difficulty of the process and even the size of works have become competitive indicators that are pursued the masters.

However, these innovations are unlikely to create enough sustainable opportunities for the industry due to three reasons. First, the production of such works is very low, and most of them require experienced masters. It is quite usual for a master to produce a single work every few years. Secondly, the circulation scope is quite narrow, and gifts and collectibles are the most probable destination. Thirdly, the difficulty of the craft and the excessive time cost makes it unattractive as a full-time career.

The value of innovation in Chinese bamboo basketry is largely anchored by labor input [69], such as splitting the width of the strip down to less than one millimeter, employing an increasing number of patterns, using complex weaving techniques and making products of larger size. In this type of innovation, professional designers do not have much of a role to play. Therefore, the crux of the problem is the lack of low-cost, highly creative, high-value-added products for the mass user market. The solution is to introduce enough professional designers rather than to train more skilled craftsmen. The latter is usually difficult. Due to the lack of labor division between design and manufacturing in many traditional ICH products, handicraft occupies an absolute dominant position. Design and creativity often mean change, which is not what the craftsmen were trained to pursue. In many ICH industries, there is no such independent stakeholder as a designer, whose role has long been fulfilled by manufacturing technicians. The hand-weaving process is the core of the whole industrial chain, which depresses the position and influence of creative design work.

Without professional designers, it is difficult for modern design ideas to serve this ICH product, although such ideas have been accepted for many years in the product world. Furthermore, there is a corresponding lack of studies on markets, users, demand study a series of industrial units to adapt products to the modern environment.

The underlying reason the lack of professional designers is technical obstacles.

3.3. Technical Requirements for Introducing a New Stakeholder

For ICH products comprising visual patterns, such as batik or embroidery, painters can be invited to draw the pattern, and they do not need to know the manufacturing details. However, the drawing of bamboo baskets is difficult [69] due to the complex and diversified weaving structure details. The exact painting of woven products is not easy, even for professional painters, so the design scheme has to be completed and stored in the mind of the craftsmen.

In the past, craftsmen usually communicated with customers by showing samples, which was enough for customers to make their choice. The problem now is that producers have to actively communicate with potential clients to ascertain their preferences and needs and innovate to satisfy them. The medium for communication may not necessarily be samples, and digital images or models for design are more suitable for this information era.

The development of digital design technology is rich, yet the problems of weaving structure design and expression remain unsolved. The operations required for 2D drawing or 3D modeling are considerable, and the accuracy usually cannot meet the requirements. These difficulties often frustrate designers and extinguish their interest in participating in bamboo basket design unless they are willing to spend time to be trained to become a skilled technician, enabling them to express their creative ideas by their own hands.

We investigated and interviewed designers and craftsmen, deriving the following technical requirements [70]:

- (1) Generation of 3D forms of bamboo baskets with precise weaving structure details;
- (2) Automatic transformation of design drafts into patterns with over-under structures;
- (3) For non-orthogonal free weaving structures, automatic conversion of interweaving free curves in a sketch into 3D over-under structures; and
- (4) An accurate estimation of the material preparation.

We also propose two basic principles:

- (1) The original handicraft features should be maintained to the greatest extent possible within the scope of users' direct experience; and
- (2) In the design process, R&D, management and other units invisible to users, the industry's organization and behavior should be enhanced to a standardized level of modern production.

According to these principles, technology can help the bamboo basketry industry adapt to modern society and prevent the loss of the authenticity of ICHs, which is a concern of many inheritors and scholars.

4. Technical Development

4.1. Sustainability-Oriented Technical Objectives

Many different technical solutions are available to realize software functions, depending on the developer's commercial benefits, the sustainability of the bamboo basketry industry, ICH preservation and even the personal interests. Our goal is to introduce new stakeholders into the industry by creating convenience through technical tools [71]. These new stakeholders fall into three categories:

- (1) Professional designers with regular design education;
- (2) Designers who shifting from traditional bamboo basketry craftsmen; and
- (3) R&D for bamboo basketry design technology.

The three types of stakeholders include both designer and developer roles (designers come from two different sources). These two roles are stable in regular modern industries but not in many ICH industries, especially the role of technology developers [72]. Therefore, the essence of the technical goal is to bridge the missing links.

ICH industries could solve many problems if they professional designers could be deployed, who can make flexible changes in response to the social environment. However, many ICHs are in remote and undeveloped areas in which it is difficult for designers to stay and remain engaged in the design of a single type of product for long time. Design technology enables designers to work anywhere and convey their ideas and designs to producers through well-expressed technical files.

The introduction of designers can be realized through design technology, which provides efficient and accurate technical means to express design ideas. If bamboo craftsmen can easily understand a designer's idea, the independent product design role can be smoothly implemented in the industry.

The shift from the role of craftsman to that of designer can be achieved through positive user interaction through the technology's working style. Craftsmen are generally not skilled in using design software, so the technology needs to be user-friendly. Von Hippel's definition of the user innovation toolbox [53] illustrates the basic principles. In the case of bamboo basketry, well-designed software can enable more people to participate and take on the role of designer.

The introduction of design technology developers is based on the fact that bamboo basketry products comprise structurally complex design elements, each of which require specific design tools. This is a considerable undertaking and requires a sizable investment, requiring a considerable number of developers with non-commercial background to maintain the sustainability of the work.

The above three goals provide guidelines and constraints for our development work.

4.2. Technical Functions Realized

4.2.1. Platform and Development Tool

We chose secondary development to implement the project, i.e., based on an existing CAD platform through a software plug-in.

The programming platform provides a rich library of functions that can perform basic mathematical and graphic calculations, such as finding the tangent of a curve, dividing a curve, finding the normal vector of a surface, calculating the intersection of curves or surfaces, moving along the surface normal vector, etc. The function library considerably simplifies the programming work.

The survey results show that more designers than programmers are interested in developing software for bamboo basket design, as designers are more familiar with the product and understand the value of such technical tools. The motivations of designers and programmers differ; programmers are commercially driven and are less likely to use the software they develop, whereas designers are career-driven and are comfortable with being the sole user of the software they create. The goal of a designer is not to develop a software for commercial sale but to use it themselves to increase the competitiveness of their designs.

Stimulating the R&D potential of the designer group is a basic strategy of user innovation, which can initiate R&D activities at a low cost.

Von Hippel's research on user innovation showed that users involved in innovation and development activities generally do not work with the goal of economic gains [52]. They are more interested in the value their achievement can bring to themselves, such as status and respect from their peers, as well as potential business opportunities. Many secondary development tools of CAD software are designed for users rather than professional developers and are therefore easy to use. The biggest challenge is that users need to learn to use secondary development tools. Our practice proves that such tools possess the characteristics of a user innovation toolbox as defined by von Hippel, enabling users to realize impressive design ideas, most of which are difficult for professional programmers to conceive of.

The following chart shows the technical route of the work described in this paper and the expected social effects in the bamboo basketry industry (Figure 1).

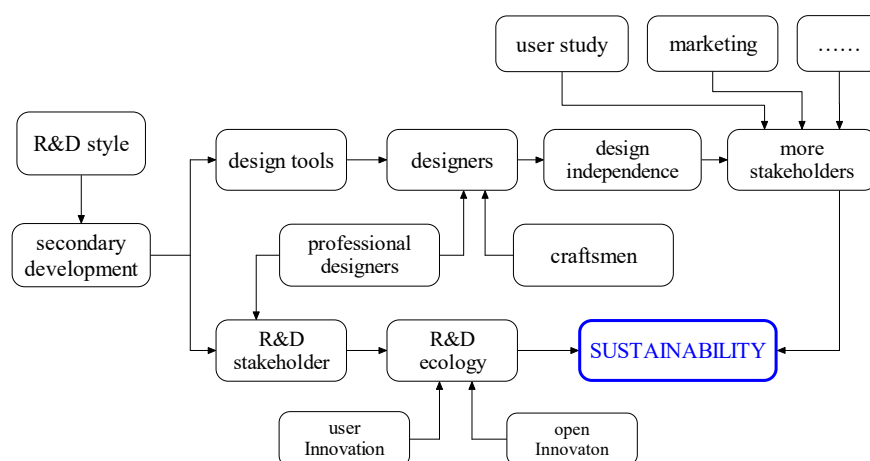


Figure 1. Technical route and expected effects.

We adopted three software platforms, namely Rhinoceros, CorelDraw and Excel. All three are commonly used by designers and include secondary development tools. Their working modes are shown in Figure 2.

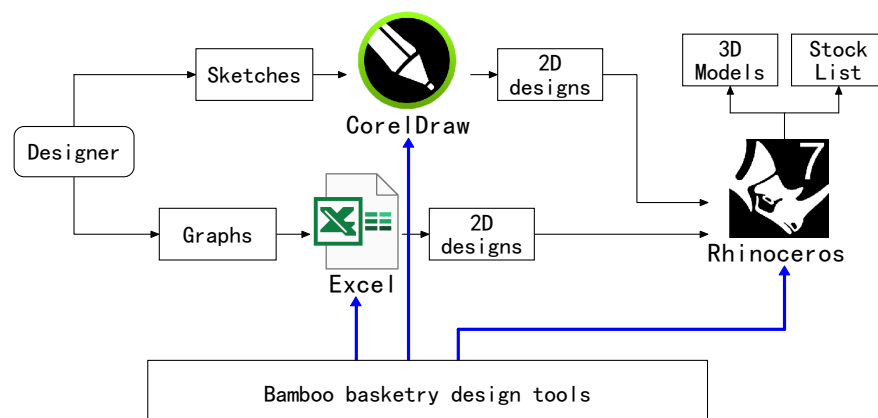


Figure 2. The collaborative working mode of three software platforms.

CorelDraw helps designer to draw 2D sketches, Excel defines accurate cross-weaving structures and Rhinoceros accepts the output from CorelDraw and Excel and builds 3D models, together with the material list. The sketch a designer draws certain format requirements, which are relatively easy to master.

The following is a brief introduction to realization of the four basic functions, which are demonstrated in the Supplementary Materials *Bamboo and Rattan Product Modeling Tools*.

4.2.2. Basic Cross Weaving

Cross weaving is the most basic and common basketry structure for which visual display is the primary task of bamboo basket design.

In this work, we adopted the modeling method of *basic surface shape and strip mapping deformation*; the surface shape details are established first without weaving structure, and then the bamboo strips are mapped to the surface. In this way, the modeling task is divided into two parts: the designer completes the surface design and defines the strip structure; then, the program builds the 3D structure with the strips, as shown below:

In Figure 3, the surface was manually built in Rhinoceros. The strip structure was defined with a matrix to express the over-under relationship at each cross point. The weaving structure on the right was built via the mapping method according to the surface model and the matrix. If the strip section is not circular (most of sections of bamboo strips are not circular), extra operations are required to correct the spatial directions of the strips (by the program).

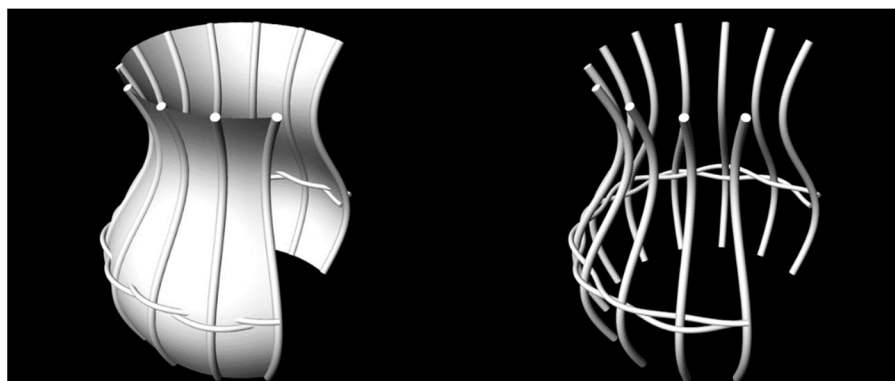


Figure 3. Model of basic orthogonal weaving structure.

This modeling approach considers the designer's creative concept and the computational accuracy and efficiency of the program, whereas the user's task is to build the surface model and define the matrix, both of which are simple tasks.

4.2.3. User-Friendly 2D Drafting Tools

High learning cost is one of the factors that prevent designers from introducing new products. Our interview revealed that among the main reasons designers are willing to learn new skills is the need for frequent use. Unfortunately, the design of bamboo baskets does not fall into this category, nor is it a high-return business.

Therefore, we adopted the concept of *heat transfer printing*, which allows the user to sketch with 2D tools, and the program converts the sketch into a 3D weaving structure.

Two types of 2D design tools were developed, both of which are orthogonal cross-weaving design tools.

The first tool enables design work by processing black and white images. The program interprets black and white pixels as the lifting and pressing of bamboo strips in the longitudinal and latitudinal directions. As shown below, the black and white image is mapped to the product surface (Figure 4).

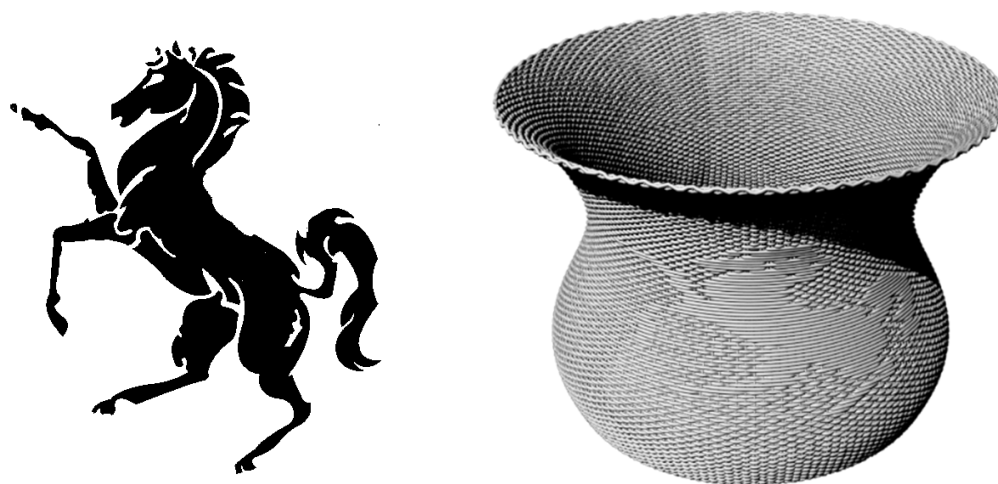


Figure 4. Black and white pattern mapped as a weaving structure.

The other tool uses Excel, which can incorporate more design variables than a bitmap. The program is designed to interpret Excel information as follows:

- (1) The color of a cell (black or white) represents the lifting and pressing relationship of the bamboo strips in the two cross directions;
- (2) The width of the row or column represents the width of the bamboo strips in two respective directions; and
- (3) The color of the cell in the last row or column represents the color of the bamboo strips in the row or column.

Designers can create Excel files manually or using plug-ins (provided by the developer). The software reads an Excel sheet in the 3D software Rhinoceros and models the strips based on the previous built surface and the Excel file, as shown below (Figure 5).

The designer makes an Excel sheet (presented above the 3D model in Figure 5), from which data is read and mapped onto the surface to form a 3D model with full details of weaving structures.



Figure 5. Excel sheets mapped as woven structures.

4.2.4. Free Weaving and Interactive Design

Most existing bamboo basket design tools are applicable to orthogonal cross weaving. However, many creative designs may contain free weaving structures that cannot be expressed in Excel or 2D graphs. Therefore, we designed an interactive modeling method (Figure 6) that functions as follows:

- (1) A planar vector sketch is created of the strips in CorelDraw or Rhinoceros without considering the over–under relationships;
- (2) A program running in Rhinoceros identifies the cross points of the curves and processes them into alternate over–under structures. After 3D models are built, an identifier is placed at each cross point;
- (3) The user interactively selects (or deselects) the identifiers, and the program flips the over–under relationship of the cross points linked to the selected identifiers, generating a new 3D model. This loop continues until the modification is complete.

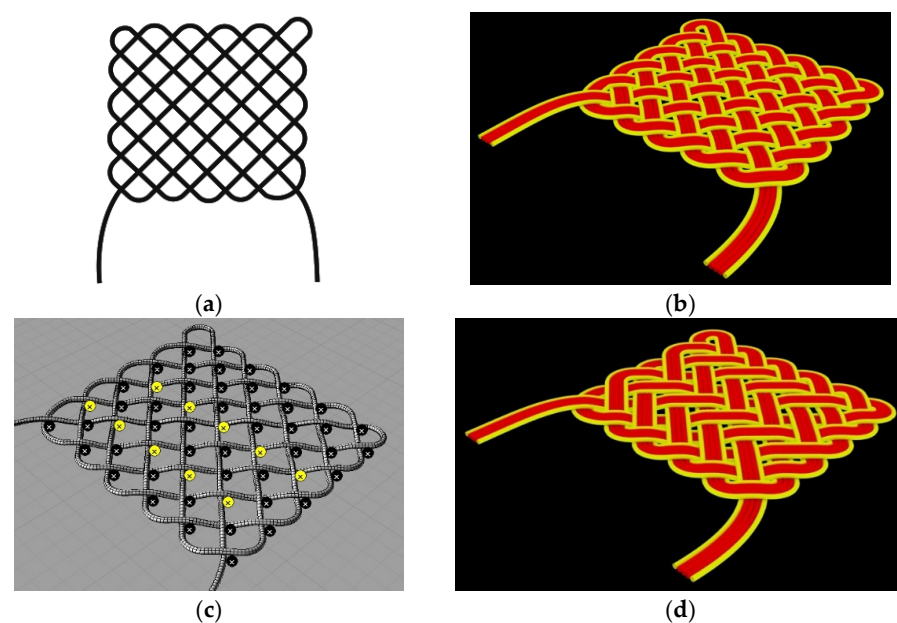


Figure 6. Free-woven structures created through interactive operation. (a) Original 2D sketch; (b) automatically built 3D model; (c) identifiers at the cross points (yellow points are selected to be flipped); (d) regenerated model according to the identifier selections.

This interactive method creates a design process of continuous engagement for the user, who can improve their design step by step with real-time visualization instead of specifying all the details at the beginning of the process. It is a challenge to instruct the program to modify a specific part in a complex weaving structure model. The proposed technique solves this problem by presenting identifiers as visible avatars for every cross point.

4.2.5. Connecting, Wrapping, Plaiting and Knotting

In addition to orthogonal cross weaving and free weaving, there are many auxiliary structures for edges and accessories. We developed design tools for four frequently used auxiliary structures: connecting, wrapping, plaiting and knotting.

Connecting structures are used to join multiple weaving structures together as a whole because breaking a complex product into separated parts can simplify design and modeling work. Building a digital model involves logic distinct from that required to build a real product. The connecting tool automatically joins independently built curve groups at their nearest ends to form a complete curve path for subsequent sweeping modeling of bamboo strips (Figure 7).

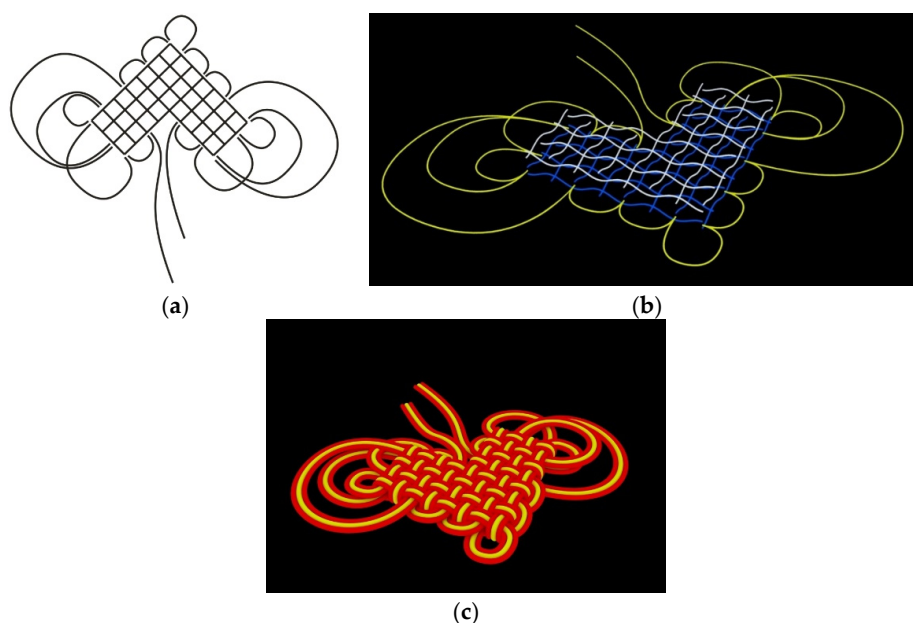


Figure 7. Connecting of parts. (a) Original 2D sketch; (b) generated 3D curves (the center part has double layers to be connected); (c) complete model.

Wrapping structures wrap and bind solid bodies, such as the edges of a container. Physical and mechanical factors are considered ensure that the winding structures are in a tensioned state (Figure 8).

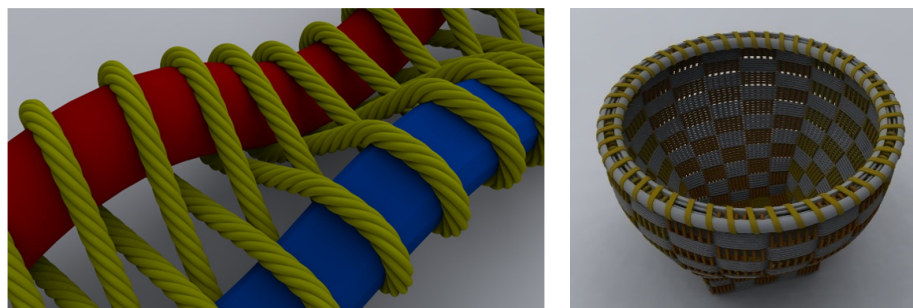


Figure 8. Two wrapping structures.

Plaiting structures help to model plaited flexible ropes. In addition to the alternately wound plaited structure, the model must be mechanically realistic and reasonable, just like the wrapping structures. The tensed ropes shown in Figure 9 represent a combined application of wrapping and plaiting tools.

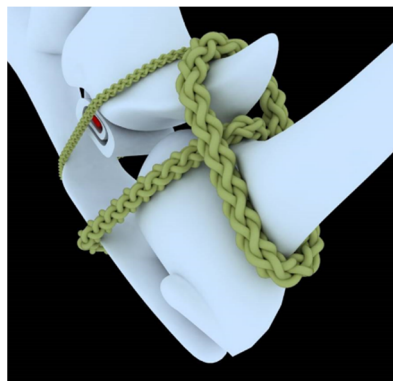


Figure 9. Plaiting structure.

Knotting structures build 3D knot models. Knots made of materials such as bamboo and rattan are generally not complicated in order to prevent breaking. The program employs a simple modeling method of planar knots, whereby knots are expressed as tightly tensed over-under structures in a free weaving style (Figure 10).

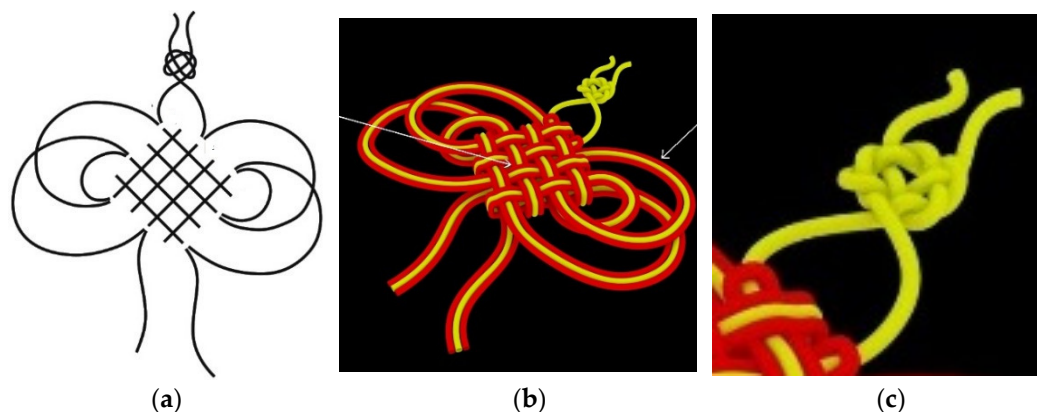


Figure 10. Knotting structure. (a) 2D draft; (b) generated 3D model from the draft; (c) detail of the knot.

5. Practice and Influence on the Sustainability of the Bamboo Basketry Industry

The proposed design tools were provided to bamboo basketry artists and designers for trial and improvement and to determine further needs. As practitioners of user innovation theory in design technology, we also need proof to encourage us to continue.

5.1. Practice in Pet Nest Design

The proposed software was first applied to the design of woven pet beds made of bamboo or willow. The company we worked with has been engaged in the OEM business for a long time and intends to develop original designs for their foreign customers to improve profits. However, it is difficult to provide their clients with realistic images of new designs that can be communicated through the internet without building samples.

The software partly solved their problem. The 3D modeling of various cross-weaving products provides a good medium for discussion for communication between designers and customers, as shown in Figure 11.

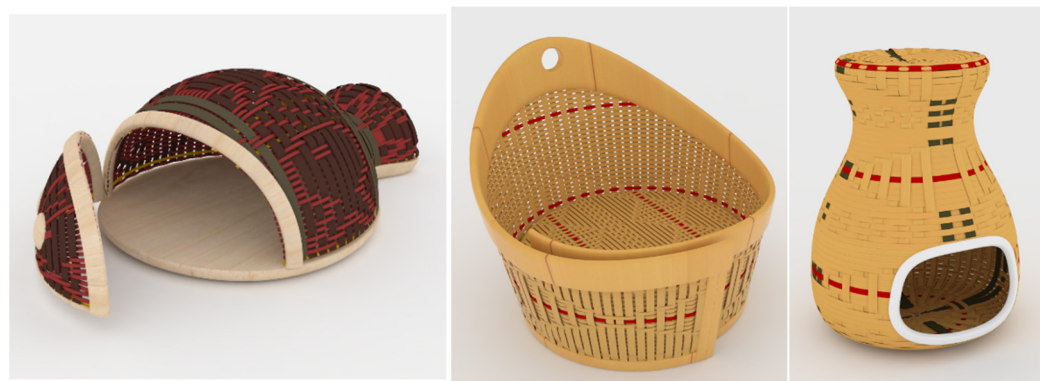


Figure 11. Pet nest designs for communication with customers.

By applying the proposed technology, the company considerably increased the designs available to their customers.

5.2. Training of Professional Designers

The *National Arts Fund of China* is a national program intended to support the cultivation of artistic creation and innovative talents. In 2019, it funded a project to train bamboo basketry designers, recruiting approximately 40 members with design or manufacturing experience to participate in a two-month training. The members included bamboo basketry craftsmen, professional designers and university teachers in a design program. Our team invited to teach the principles of CAD technology for bamboo basket design (Figure 12).



(a)



(b)

Figure 12. Bamboo woven ICH product design and making course and the resulting works. (a) Trainees at work; (b) the work of trainees on exhibit.

Many of the members were introduced to design technologies for the first time and showed considerable interest. The three types of members presented with different requirements based on their professional backgrounds.

Craftsmen are eager to preview and evaluate their ideas or designs with the help of software. In the past, most craftsmen worked with only rough sketches or literal descriptions of desired changes relative existing products. In order to evaluate innovative new designs, they usually make samples. The proposed technology is just what they need.

Professional designers aim to test ideas and explore possibilities by creating unique personal designs, benefitting from the functions of software. The efficiency of the proposed software makes it possible to create bamboo basket designs as a part-time job.

Some university teachers realized the R&D potential of the technology. They hope to participate in development work and develop academic projects to apply for official funding.

Three independent trends emerged from this training session: division of the manufacturing unit, external design resources, university-level R&D.

5.3. Technology Extension in Other ICH Products

The charm of bamboo basketry mainly lies in the unique complexity and sense of rhythm of weaving structures, which make it a visual symbol and is widely used in many other ICH visual art forms. For example, we identified demands for weaving patterns for paper-cutting art and folding fan products.

Paper-cutting art and folding fans are both national ICHs in China. Their design is basically graphic design, and the main demand is to draw a visual form of a weaving structure similar to the interwoven structure in Celtic patterns [67].

One of the demands for weaving patterns proposed for paper-cutting art is to express gray tones; traditional paper-cutting involves silhouette, and grayscale is usually expressed by borrowing strokes from woodcutting practice, employing strip with varying widths. Because certain mechanical properties must be guaranteed for paper objects, the strips cannot be too long or too thin in order to avoid deformation and fracture.

The tools for basket design were revised according to the demand to build strips with varying widths and visually interweaving structures for artistic effect, as shown in Figure 13, in which two Chinese characters (with the meaning of *bamboo wind*) are hidden.

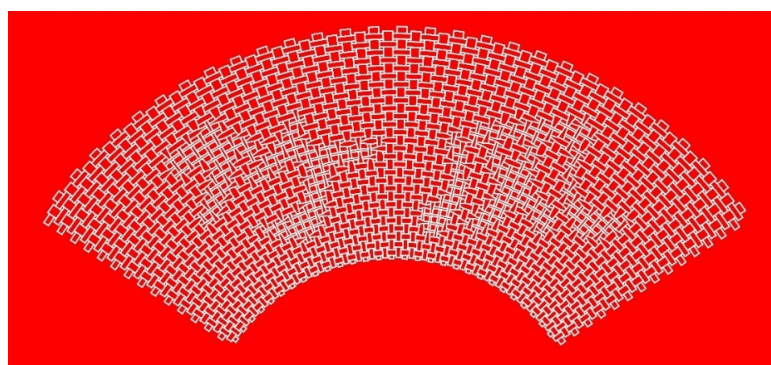


Figure 13. Interweaving pattern in paper-cutting art.

Weaving patterns are applied to folding fans to decorate hollowed-out bamboo fans with bones made of carved bamboo strips. The fan requires a large area of hollow background with sufficient strength. Weaving patterns can meet both requirements, as shown in Figure 14. The basic technical principle is similar to that of paper cutting.

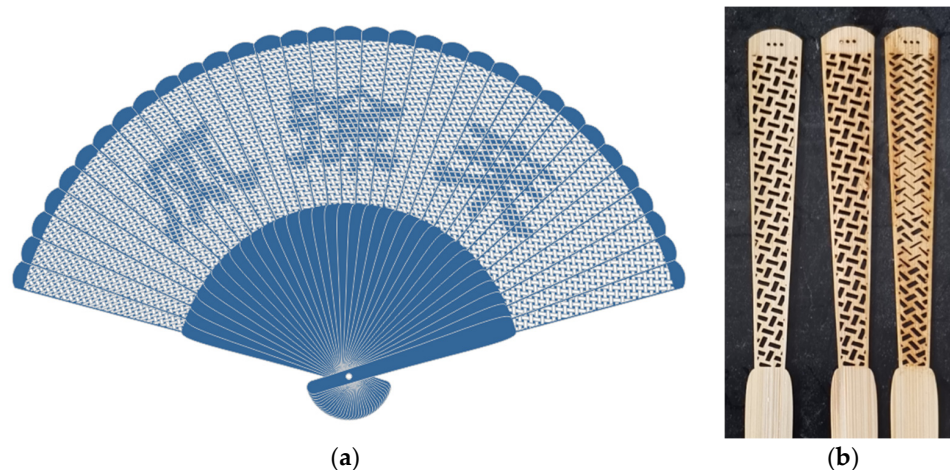


Figure 14. Interweaving pattern of a bamboo fan (The three Chinese characters hidden in it is the Brand of the product). (a) The design; (b) sample of bones.

Weaving structures or their visual patterns are widely used in traditional products. Therefore, the technology proposed in this paper can meet the demands of various ICHs.

However, clear technical requirements are rarely available for most ICHs; therefore, technological interventions need to be proposed by people who are familiar with both design and programming.

5.4. Sustainability of Technical Development and Ecology Building

Although the proposed technology is interesting and exciting, our team has received only approximately USD 20,000 in funding since our research began from 2004 because the market is too small to secure substantial investment to support long-term commercial development. User innovation is an important factor to guarantee the sustainability of the ICH industry. With enough participants, the development of technical tools is likely to become a normalized demand, with numerous existing and novel weaving patterns waiting to be modeled and for further innovation.

The development concept presented in Section 4.2.1 is not conventional for commercial software. However, considering the low frequency of use and small number of users, the sustainability of the design technology itself is equally important as that of the products. The combination of user innovation and open-source development may be an appropriate option. Most CAD software provides a secondary development platform and function libraries, and Rhinoceros even provides a user-oriented programming-free development platform known as Grasshopper. These user innovation toolboxes are helpful in developing the R&D ecosystem.

We have attempted to encourage industrial design graduate students to participate in development and have achieved some satisfying results. With a background in design and art rather than software engineering, these graduates mastered programming skills after short training periods and developed their own plug-ins, which considerably stimulated their research interests. Some students even set up their own bamboo basketry design studios after graduation because they realized the personal advantages in this niche product area with the help of their new-found development skills.

It is often difficult to obtain investment for initial technical research that usually begins in the university setting due to the unclear commercial interests; however, it is possible to obtain start-up funds from the government with proof of early achievements. This is the best starting point for ecological environmental construction.

6. Discussion

The contribution we aim to make to the sustainability of the ICH industry is to introduce two types of key stakeholders that are often lacking or absent in many ICH industries. The first is the leading user defined by von Hippel [57], i.e., the designer who can develop design tools for self-use. The second is the designer who is interested in bamboo baskets design with the help of design tools. We hope that a portion of the second group can be converted into members of the first group. Thus, a continuous human resource supply loop will be established, which is a basic prerequisite for sustainability.

Because the proposed technology is still primitive, its impact on the ICH industry of bamboo basketry can only be predicted based on our limited practical experience. So far, through the digital models generated by proposed tools, the communication between designers and manufacturers has proven smooth and efficient, and designers from design agencies can design successful products without having to weave them themselves.

In this paper, we presented an example of user innovation in ICH product design. Von Hippel provided many examples of successful implementation of user innovation theory, also implying the premise that the users should be *leading users*, i.e., users with the ability to develop a product they want to use, with the user innovation toolbox as a premise.

In this case, the user refers to the user of the design technology, namely the designer, whereas the product refers to the design technology or software. User innovation occurs when designers begin to develop their own design tools. After having been trained in basic

programming skills, designers already meet Von Hippel's definition of leading users, and the user-oriented secondary development tools provided by CAD platforms also basically conform with the concept of user innovation toolbox. We have also run a course to teach designers how to develop their own personalized tools, proving the feasibility of this concept.

However, with approximately 12 years of experience running this course, we have found that the user innovation style has some limitations, as follow:

- (1) Robustness of the software: Designers can write code but lack experience in software development, so the user interaction of the software they write is usually poor. Therefore, software developed by designers serves best as a prototype with low commercial value. However, the designer's innovative concept is at least realized.
- (2) The problem of universality: Bamboo basket design is associated with a variety of structures, so design software needs to provide a certain degree of versatility. This requires an ability to abstract with respect to the technology's functions. A common problem is that when a designer comes across a new structure, instead of modifying the code to make it more versatile, they usually write a new program.
- (3) Application of user innovation outputs: People who are interested in writing design tools for their own use are generally less inclined to share or sell their program, lest they lose their advantage. This results in repeated programming of similar functions. Therefore, the techniques published in the literature on bamboo basket design are similar, almost all of which involve basic cross-weaving. A developer community is necessary, just like the open-source software community.

As for the third limitation, universities can play the role of organizers in the ecological environment building of developers, which can also help to solve the first two limitations. We are encouraged by professional programmers and software companies beginning to show an interest after experiencing the proposed tools. These software prototypes and their outputs made them feel that it is completely feasible to redevelop such tools on a new platform and in a more efficient programming language. Demonstrations of these prototypes can also help to convince investors to provide their support. As evidence, an entrepreneur project based on our early achievements has successfully obtained government funding.

7. Conclusions

The sustainability of bamboo basketry not only has the general characteristics of ICH products but also has involves personalized features. Through the work presented in this paper, we aim to target the bottleneck of design technology to improve the ICH industry to help it adapt to modern society.

We believe that the work presented in this paper will contribute to the sustainability of ICH industries as follows:

- (1) The sustainability of ICH products depends on the sustainability of the ICH industry. Modern society is a diversified world, including a variety of preference groups, and the Internet allows many niche products to quickly find their markets. Adaptive industries have some common features, including stakeholder structure.
- (2) The sustainability of the ICH industry depends on a complete range of stakeholder types. The bamboo basketry industry lacks a designer group, which is a key role, as well as closely related stakeholders in market research, user research, and technical development, which are key to the sustainability of industry; such stakeholders will only participate on the condition that designers are already engaged in the industry.
- (3) The proposed design technology for bamboo basketry offers promise to encourage the participation key stakeholders, i.e., designers, either through external recruitment or by developing talent within the industry. Design technology can serve to catalyze modernization of the industry.
- (4) The technical system itself also needs to be sustainable. A good ecological environment is necessary and will generate spillover effects and benefit other types of ICH products.

User innovation has been proven to be a suitable method, even if the output is only prototypes.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su141912058/s1>, Video S1: Bamboo and Rattan Product Modeling Tools.

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