

SketchChair: An All-in-one Chair Design System for End Users

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ABSTRACT

SketchChair is an application that allows novice users to control the entire process of designing and building their own chairs. Chairs are designed using a simple 2D sketch-based interface and design validation tools, and are then fabricated from sheet materials, cut by a laser cutter or CNC milling machine. This paper presents the concepts and details of *SketchChair*, and both miniature and full-sized chairs are designed using the application. We conclude with results and insights from a workshop in which novice users designed their own model chairs.

Author Keywords

User-generated Design, Rapid Prototyping, User Interface, Sketch-based modeling, Fabrication, Customization.

ACM Classification Keywords

I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling; H.1.2 User/Machine Systems; J.6 Computer-aided engineering (computer aided design).

General Terms

Design, Experimentation.

INTRODUCTION

Recently, there have been significant advances in digital manufacturing technologies. Tools, such as 3D printers, laser cutters, and computer-controlled milling machines, have become cheaper and more accessible to consumers. These ‘desktop manufacturing’ or ‘personal fabrication’ [5] processes are providing the means for people who might normally be consumers to become creators. Just as desktop printers and desktop publishing software have enabled users to design and produce their own printed material, desktop manufacturing allows people to create their own products at home, quickly and precisely.

However, CAD (computer aided design) systems that enable novice users to design their own products have lagged behind. In many instances, inexperienced users are

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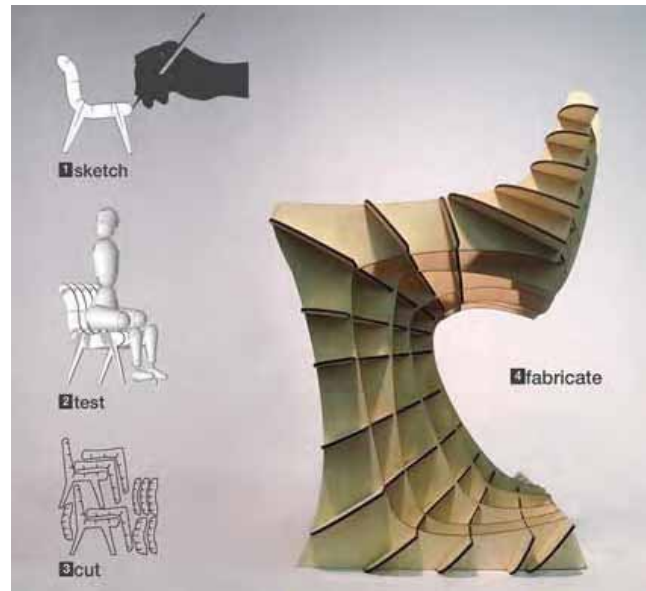


Figure 1. Process diagram for designing a chair using our system.

faced with complex programs intended for experts, such as SolidWorks [3] and AutoCAD [1]. Moreover, these tools are usually only part of the design process. Before a functional product can be developed, other steps may need to be performed outside the CAD system (e.g., sketching, prototyping, testing).

There are generally constraints on creating functional 3D products within a given fabrication process. For example, a laser cutter can only construct objects from planar materials. Most CAD systems do not permit users to incorporate constraints of specific fabrication processes into a design. Instead, they produce generic 3D models, leaving it to the user to translate the designs into patterns that can be used to create actual products.

If a product is designed poorly, it may not function correctly. For example, a chair designed in a CAD system may be unbalanced and fall over when it is actually constructed. Most CAD systems do not provide the average user with a way of assessing such potential problems.

All of these obstacles ultimately make it difficult for ordinary users to avail themselves of simple CNC manufacturing techniques and become creators.

We introduce a system that brings us one step closer to realizing the goal of personal fabrication. Our system is appropriate for the design and fabrication of furniture. In this paper, we focus on the design and fabrication of chairs, because there is a strong relationship between the user and the desired form of a chair. The advantage of our *SketchChair* software is that it allows even a novice user to control the entire process of creating an actual chair. This process includes concept development, refinement, testing, and fabrication. The system uses a simple 2D sketch interface that can easily be learned by novice users, but also includes more powerful tools for experienced users to fine-tune their designs. We provide several tools that enable users to sketch and refine chair designs. We also provide tools for testing the ergonomics of a design, including a physical simulation of a seated human figure that can be sized to match the height of the intended user. With the aid of these tools, users can refine their designs until the desired results are achieved. Our system then automatically generates 2D profiles of the individual pieces required to construct the chair. We use a laser cutter to produce the pieces, and assemble them to create the actual chair.

We provide examples of both scaled and full-sized chairs created with our system. The scaled models were made of paper or plywood, while the full-sized ones were constructed from plywood. The time required for sketching the chairs was 1-10 min. It took 10 min to cut and assemble the scaled chairs, and 90 min to cut and assemble the full-sized chairs. We also present results and insights obtained from a workshop in which novice users designed and constructed their own scaled chairs, including what worked and what could be improved.

BACKGROUND

An example of the benefits of custom design is furnished by the pianist Glenn Gould. When Gould was quite young, his father modified a folding chair for him, allowing him to sit at his piano at just the right height without obstructing his elbows while he played. Gould used this chair at virtually every concert for the rest of his career [2].

Digital fabrication processes that facilitate the production of custom one-off designs are becoming more commonplace. Various manufacturing cycles are being altered by digital fabrication, which has dramatically lowered the cost of producing certain products by eliminating the need for specialized machines and molds. Services such as Ponoko [13] take advantage of this by allowing people to upload designs for their own laser-cut products, which are then sold online and produced on demand.

The popularity of DIY communities that share plans and designs for projects, such as instructables.com [7] and makezine.com [10], has been growing steadily as more people find the right tools and resources to build things.

Several researchers have recently introduced systems for personal fabrication [9]. Plushie [11] is an interactive

system for designing plush toys. It provides an interface and a set of tools for plush toy design. The algorithm automatically computes a 2D cloth pattern that corresponds to the user input. Spatial Sketch [17] allows the user to sketch immersively in a 3D real-world space. The 3D user sketch is converted to a set of planar slices, from which a real object can then be fabricated using a laser cutter. Our work also brings us a step closer to the larger goal of personal fabrication, in the specific case of chair design using a 2D sketch interface.

There are many systems [6, 18] for creating 3D models from 2D user sketches. These systems make it easy for novice users to create 3D models with a familiar 2D screen interface. Another approach allows users to sketch directly in 3D space. The Sketch Furniture [4] system enables rapid prototyping of 3D shapes resembling furniture. The Surface Drawing [14] system facilitates the creation of 3D surfaces and shapes that are appropriate for artistic expression. Our system provides a 2D sketch-based interface for creating 3D chairs. The user controls the entire process, from initial concept design to the eventual production of an actual chair.

OVERVIEW

The *SketchChair* system is a custom computational design environment written in Java™, enabling a user to design chairs via a 2D sketch interface (Fig. 2). A chair can be custom-tailored to the user's size (ergonomics). The system also permits users to design different styles of chairs (stools, office chairs, etc.). To create a chair, the user sketches the profiles with a mouse or a tablet PC. The system then extrudes these profiles to produce a frame made from interlocking planes. Legs are added by sketching their profiles with a leg tool. The resulting chair design is then tested in a physical simulation. A virtual figure representing the user is placed on the chair, in an appropriate posture, to check the ergonomics of the chair and to verify that the final design is stable enough to stand.

The profiles and slots to be fitted together are automatically generated by the system. These can be cut using a laser cutter, a CNC milling machine, or by hand. The user can then construct the chair.

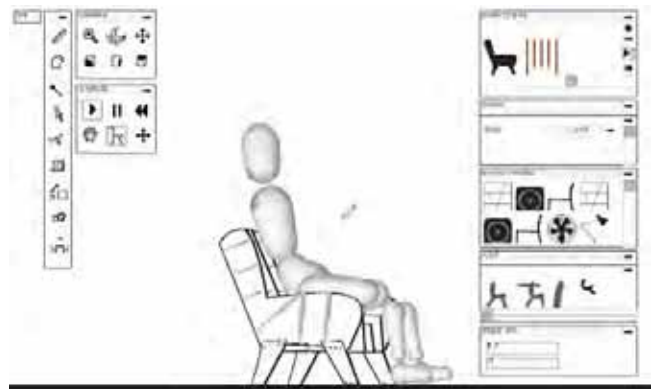


Figure 2. Screen shot of our system.



Figure 3. Sketching a path, editing, elongating, and retracting.

USER INTERFACE

In this section, we describe the *SketchChair* design tools.

Draw Tool

The draw tool allows users to quickly and intuitively sketch and edit appropriate curves for a seating contour (Fig. 3). The user selects a slice plane and draws the contour as if using a paintbrush or pen. The system automatically computes the offset outline. Any shape drawn on a plane is automatically merged with overlapping shapes.

All strokes drawn with the pen tool can be subsequently edited by dragging the stroke's path. If a middle point is selected and dragged, the surrounding points will be moved to maintain a smooth path. New points are added to lengthen a stroke when necessary. A stroke can be shortened by dragging an end point back toward the preceding points, and elongated by dragging an end point away from the preceding points.

Leg Tool

The leg tool allows legs to be added to a chair. The user clicks and drags a stroke to add a leg (Fig. 5). A supporting plane traversing the form is automatically added to the leg to strengthen it. The user is then able to edit the outline of the leg to ensure that it will rest flat against the floor.

Layers Panel

The layer panel allows the user to select and edit different slice planes. By editing slice planes separately, the user is able to create chairs with curved contours along the z-axis. For example, a chair can be given a curved bucket seat by moving profiles in the middle of the seat downwards. Curved slice planes in the z-direction are then automatically generated across the seat.

By editing 2D planes separately, users can design a wide range of chairs (Fig. 4). The system automatically creates cross-sections of the chair, and also checks for collisions between planes and removes invalid planes. Thus an interface is provided in which anything that can be drawn can be produced.



Figure 4. Slice control panel for selecting different slice planes in a chair.

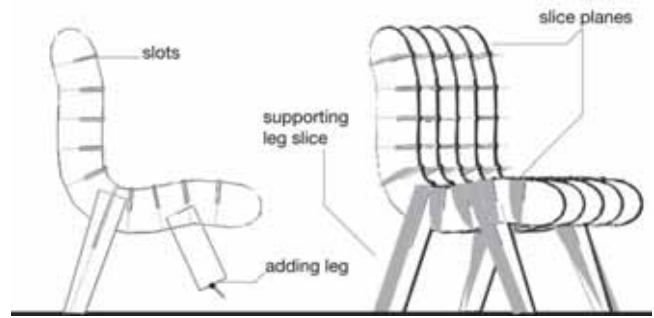


Figure 5. A leg being added to a chair.

Path Tool

The path tool allows the user to create far more varied chairs by drawing paths in a manner similar to many illustration programs. The user first draws a polyline via successive clicks. The shape of this line can be modified, and finely controlled curves can be created by adding Bezier points to the path. This tool allows the user to precisely specify the shape of a path with only a few control points.

Measure Tool

This tool allows the user to measure any part of the chair by clicking and dragging a selection box over the area. Dimensions are shown on the sides of the selection box. This is important for verifying the real dimensions of a chair or part of a chair, because it is easy to misjudge these in a virtual interface.

DESIGN AID TOOLS

To assist users in creating their own chairs, some design aid tools are also built into the editing environment.

Exploring Design Variations with Showroom and Hibernation

Experienced designers often start the design process with a sketch. Sketching provides a quick way of exploring many different ideas. CAD modeling is often not appropriate at this stage, because it is often slow and constrained, and the results are stored as a file on the user's computer, making it hard to compare designs visually.

Some novice users may prefer not to begin the design process with a hand-drawn sketch, and may have difficulty translating such a sketch into a 3D design in a CAD system. We address this issue by providing a simple sketch interface that allows a user to quickly sketch different chairs and then test them. Designs that are saved appear next to previously saved chairs in a showroom panel. The chairs in the showroom can be compared visually and loaded into the program for refinement.

When a new chair is created in the design environment, any existing chairs are 'hibernated,' and an image of each hibernated chair appears in its place. Right clicking on the

image of a chair will load the corresponding design, replacing the image. In this way, the user can quickly explore many different possibilities before deciding on a particular design.

Ergonomics

When designing a chair (especially for a specific person), it is important to make sure that the chair fits the user’s body. A chair should hold its occupant in a comfortable pose, with the feet typically resting on the floor. When designing products in a virtual environment, it is easy to lose track of scale and design products that are too small or too large. Prior to any actual production, professionals generally make a full-sized cardboard mockup of a product to verify that the proportions are correct. However, constructing a full-sized prototype chair can be difficult for novices, so our system provides a virtual human figure that can be resized to match any specified height (Fig. 6, 7). The figure can be virtually seated on a chair, thus making it possible to directly assess whether the chair will be suitable for the intended user. If the chair does not fit the user, it can be edited with the virtual figure sitting on it to provide reference.

The system supports users of different ages. In the design environment, a user’s age and height can be specified. The virtual figure is then resized to match this height, and its proportions are changed to fit a user of the given age (for example, the heads of babies and children are larger in proportion to the rest of their bodies than those of adults [16]).

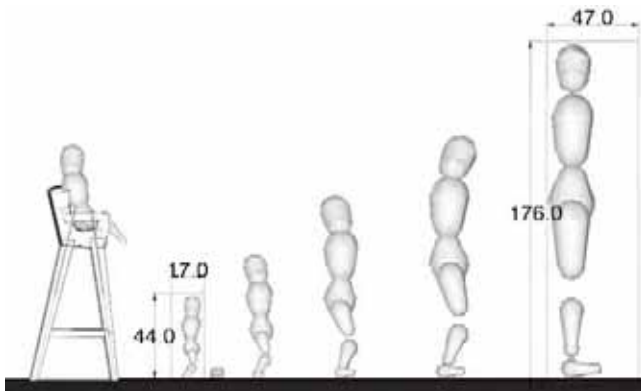


Figure 6. Resizing the figure, right. Highchair for a baby, left.



Figure 7. Using the virtual figure to adjust a chair so that the figure’s feet rest on the floor.



Figure 8. Testing and correcting an unbalanced chair.

Simulation

The rigid-body physics simulation jBullet [8] is included in the design environment. It enables the user to test the effect of gravity on a chair and occupant before actually producing the chair. Simulation in the design environment allows a user to quickly correct mistakes that might cause a chair to fail (for example, an unbalanced chair, as shown in Fig. 8). Simulation makes it possible to work with the constraints of designing an actual chair, instead of discovering them at a later stage. This reduces the time required to design a viable chair, and helps the user understand the limitations of chair design.

The physics of the chair is controlled with the play, pause, and rewind buttons. It is important to note that a chair or figure can be created or edited with the simulator running, and any changes made to the chair will be updated in the simulator without restarting.

Reference Geometry

When buying a piece of furniture, we generally consider whether it is compatible with other furniture in the home (e.g., a new chair for the dining table or a chair to sit on while playing the piano). One of the advantages of custom furniture is that it can be designed for compatibility with other furniture in the home. To facilitate this, our system provides a series of reference images that can be dragged into the design environment and resized to approximate the furniture in a user’s home. Users can also load their own custom reference images into the program (for example, a photo of a table to which a new chair is to be matched).

Images or sketches of other chairs can be used as reference images to help the user design similar chairs. Photos taken by the user can be input to the program by adding them to the environment directory. This makes it possible to design a chair that matches the style of other furniture found in the user’s home (Fig. 9).



Figure 9. Reference geometry used to help design a chair.

FABRICATION

Production is considered in the interface; that is, the system allows the user to work within the construction constraints. *SketchChair* will only create designs that can be fabricated from flat components.

Material usage and cost are calculated in the design interface in real time. This can be used to price chairs, and also to produce chairs that use material more efficiently.

Designing for flat materials offers a number of advantages. Products can be packed flat for cost-effective shipping. They can also be made from a range of materials, using a variety of production equipment, including laser cutters, CNC mills, and hand saws.

Designs can also readily be constructed on different scales, using materials, such as paper and cardboard, and this makes the system appropriate for prototyping designs, as well as for creating scale models that can be used as toys. The capacity to print directly to a paper cutter is included in the *SketchChair* system. This means that designs can be created in the sketch interface, printed to a paper cutter, and fabricated for further testing within 10 min (Fig. 10).

To produce laser-cut profiles that are larger than the cutting bed of a laser cutter, we manually cut each oversized profile into smaller pieces. These pieces can then be tightly packed onto a sheet of material for further cutting. Once cut, the pieces are fit back together and glued in layers to provide strength at the joints. This approach allows chairs of any size to be manufactured using the smaller, more common CNC machines.

CONSTRUCTION DETAILS

Cover

Chairs designed with *SketchChairs* can be upholstered with layers of felt and palm fiber matting. This provides a soft seating platform, and also distributes the user's weight across the laser-cut slats. It is more comfortable for the user, and prevents too much stress from being placed on any one part of the frame.

The layer of fiber is lashed to the frame with a soft cotton lace similar to a shoelace (Fig. 11). This lace also holds the frame together and provides strength. It can be untied and unthreaded by the user, allowing the frame to be disassembled for storage or transport.

Frame braces

Optional aluminum corner braces can be added to the frame for additional strength. These are small sections of square extruded aluminum, about 50 mm long, with four slots cut into them. The *SketchChair* program generates extra slots at the junctions of each chair frame, permitting these braces to be inserted into the frame. This holds the frame together and supports the joints, preventing the chair from collapsing.

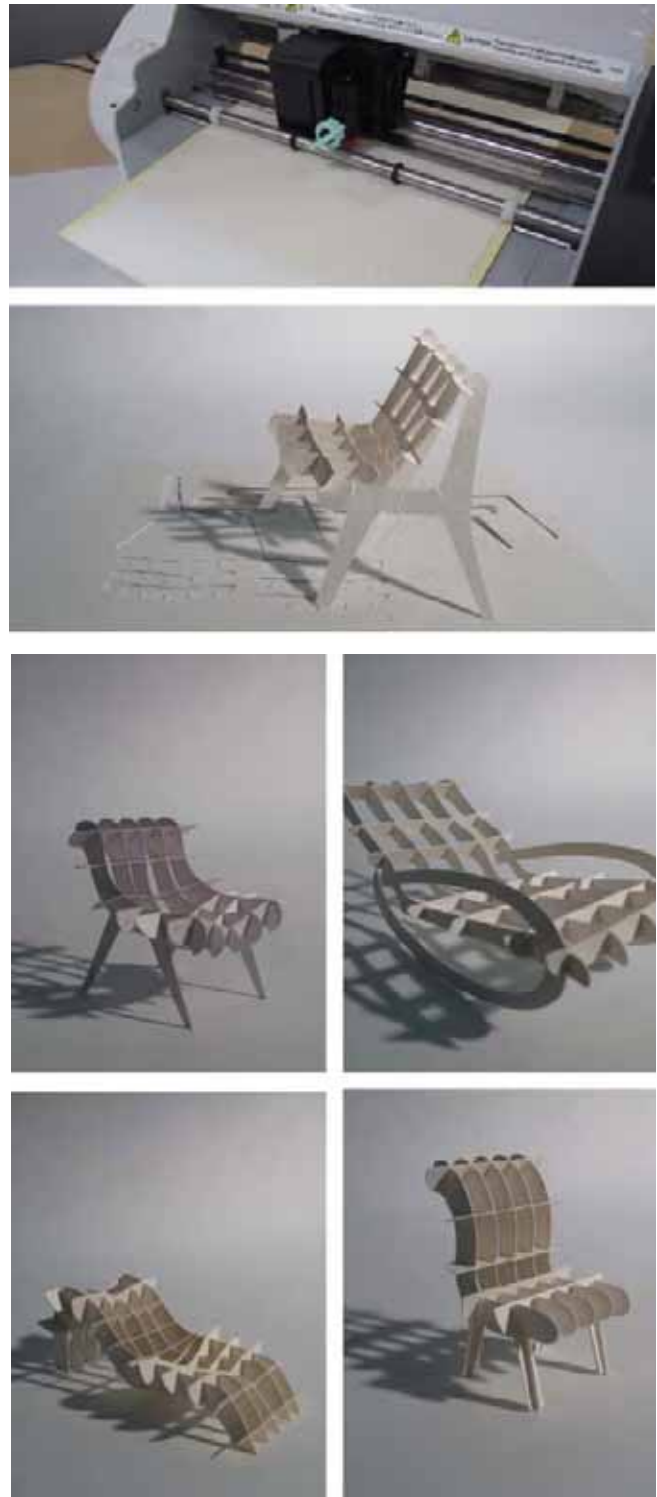


Figure 10. Paper chairs created using the system and cut with a cutter plotter (each chair is about 70 mm in height).

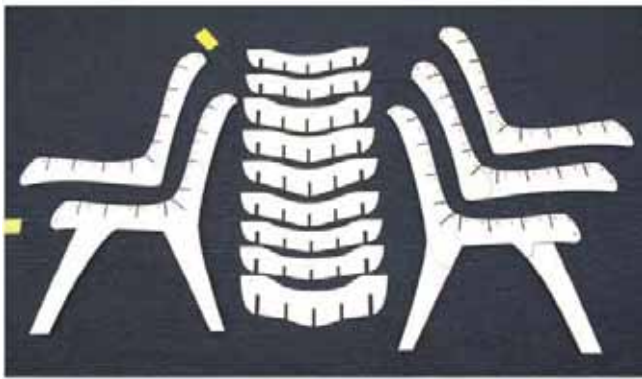


Figure 11. (Top) Felt cover and palm matting tied to a frame with cotton laces. (Bottom) Laser-cut plywood profiles for a finished chair.

RESULTS

Workshop

We organized a workshop in which seven participants, from 12 to 53 years old, were invited to design and build scale models using *SketchChairs*. During a short presentation, the participants were first introduced to the idea of designing furniture, and then to the features of the program. They were then given 30 min to practice with the software. During the practice session, the participants were given a range of images of different chair designs, and asked to reproduce similar designs using the *SketchChair* system. After the practice session, participants were asked to design a chair. Each chose a design and saved the cutting profiles for the design. The designs were then cut, and the participants constructed their chairs from the cut profiles. Finally, the participants were asked to fill out a short survey on their experience with the system and the idea of designing their own products.

All participants successfully produced miniature chairs, and all reported enjoying the experience of designing their own chairs. The concept of designing one's own furniture was

well received, and all but one participant expressed a preference for their own designs over the chairs sold in stores. Furthermore, participants stated that they would place more value on chairs they had built themselves, and would consider them less disposable. One participant even articulated a wish to pass such a chair down to his/her children, to keep it in the family. This seems to indicate that products designed by the user have the potential to be more sustainable than their mass-produced equivalents, because people may be inclined to retain them for longer periods.

It was observed that a majority of the participants preferred to use the draw tool and the leg tool to design their chairs, reporting that these tools were more intuitive. Users who were more experienced with CAD systems enjoyed the control that the path tool gave them. Most users preferred to work only with one layer, and did not use the layers panel to alter their chairs in the z-direction. Three participants declared that they would like the option to “start with a template chair designed by a designer” and then “modify that one.”

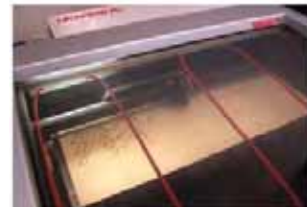


Figure 12. Scale chairs designed by users during the workshop.

Full-sized Chairs

Figures 1 and 13 show full-sized chairs designed using the system. They were designed in 20-min modeling sessions, cut with a laser cutter (taking 60 min), and produced with materials bought from a local hardware store.

8. DISCUSSION AND FUTURE WORK

We introduced a chair design software as an example of a system that enables users to design their own products. It allows users to move successfully through the entire process of designing and fabricating a full-sized chair. The simple interface permits the user to sketch different concepts quickly and compare them visually. Designs can then be tested in a physical simulation to verify that they are balanced and will not fall over. A virtual human figure, scaled to match the size of the user, is placed on the chair to test the ergonomics and ensure a correct fit. Reference images can be added to the design environment to determine whether a newly designed chair will be compatible with existing furniture. Design patterns are produced by the system, and can be fabricated via rapid manufacturing techniques (e.g., with a laser cutter or by hand).

In the future, we plan to add the following features to the system: a strength of materials simulation to ensure that designs are strong enough to be used as chairs, automatic division of profiles to fit them onto smaller sheets (this is currently done manually), automatic measurement of the ergonomics of a chair, based on the seating of a virtual figure, and the pressure applied at different parts of the figure's body. Development of a plug-in version for a generic 3D CAD software will also be important for further development and dissemination.



Figure 13. Finished chairs designed using the SketchChair system.

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