Upcycle-Chic: A Software Tool for Ideating Furniture Upcycling Design

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Figure 1: Design examples with Upcycle-Chic: (a) two bookcases turned into a bed; (b) a desk added with a shelf; (c) a dresser turned into a seat; (d) a table turned into a cart.

ABSTRACT
Upcycling design seeks solutions to repurpose existing furniture with new spatial, aesthetic, or functional values, which provides both financial and environmental benefits. However, design and ideation for furniture upcycling is extremely hard for most people in the current maker community without a strong design background. In this paper, we present Upcycle-Chic, a design and visualization environment that allows a user to view possible upcycling solutions for a given piece of old furniture and explore varying design variations. These possible solutions are generated based on design strategies drawn from over 1000 examples on web and books shared by professionals and hobbyist furniture makers. Through a design competition and a DIY workshop, we demonstrated the effectiveness and usefulness of Upcycle-Chic in helping novice designers come up with insightful design solutions.

Author Keywords
Upcycling; interactive design; creative tool; furniture; ideation; DIY communities; sustainability.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): User Interface.

INTRODUCTION
The prevalent culture of newness and perceived obsolescence has led to un-sustainable creation of new furniture to replace old ones that are usually stashed away or even discarded, making the volume of waste grow. A good solution to this problem is through *upcycling*, which seeks a transitional solution by repurposing existing pieces of furniture and adding new spatial, aesthetic, or functional values to them [24]. The benefits are not only financial, but also environmental. However, furniture upcycling is still in its infancy among the masses [10] because of the difficulty nature of both upcycling design and craft. This paper focuses on the former.

Ideation, as a premiere upcycling design process is critical, but uniquely challenging compared to designing a furniture from scratch. It requires creatively utilizing a furniture's existing material, structure, and referencing new functions, genres, and styles to create designs that satisfy a person's goal [22]. The well-established shape and structures add a lot more constraints to people to think outside-the-box and imagine the possibilities that upcycling can create for a given piece of old furniture. For example, an old dinning chair can be repurposed to a bench, shelf, or hammock, which can be all outside one's imagination. Therefore, the power of furniture upcycling is largely overlooked. Unfortunately, the current practice to explore possible design options through trial-and-error on physical furniture is time consuming and costly. Tools created for the design of new furniture [36, 44] do not take these challenges into consideration, thus can be hard to use for upcycling.

While challenges exist, the "upcycle culture" has gradually spread among professionals and hobbyist furniture makers, whose designs and creations have been shared with the Do-It-Yourself (DIY) communities via popular sites like IKEA

Hackers [16], BHGs [2], online blogs [7, 18, 29], social websites (e.g., Pinterest, Facebook) [8, 31], and even books [22, 24]. Such sources of information provide opportunities for new comers (e.g., people with basic crafting skills but not so much design background) to learn furniture upcycling from examples and get inspired. However, just looking at those examples is insufficient for idea *concretization*, *adaptation* and *customization* to a given furniture, which are important ideation process and of more practical value to the learners.

To better support the ideation of furniture upcycling design, we present Upcycle-Chic, a visualization environment that allows a user to view possible upcycling solutions for old furniture and explore design variations for selected solutions with 3D representations of the furniture. It alleviates the burden of 3D modelling skills on users by enabling simple select and click metaphors. The software incorporates design strategies of seven categories of furniture including table chairs, bar chairs, bookcases, dressers, bedside cabinets, tables and desks. The knowledge of furniture upcycling approaches and operations were obtained via summarizing over 1000 examples from the online DIY communities. With Upcycle-Chic, a user can quickly explore and view suggested and customized design that, for example (Figure 1), turns bookcases to bed box, adds a shelf and wheels to a desk, makes a seat from a dresser, turns a table into a cart, and get inspirations from them.

To demonstrate the expressiveness of Upcycle-Chic, and validate its usefulness in helping the user in formalizing design ideas, we first run a furniture upcycling design competition with 10 students from design department of a local university. The students were divided into two groups, and alternatively completed 6 design tasks with/out the tool. The results showed that Upcycle-Chic was effective and efficient in helping the students quickly come up and finalize insightful design solutions. Moreover, a second study was run with 6 hobbyist makers. They were asked to design and craft 4 old furniture with Upcycle-Chic. The results helped us examine the software's effectiveness, as well as challenges in practical use.

The paper's contribution is three-fold: i) A software tool to support ideation of furniture upcycle design, by allowing users to view and explore variances of possible design with 3D representations; ii) A summary of design strategies from over 1000 examples, including common furniture upcycling approaches and operations that are incorporated in Upcycle-Chic; iii) Two studies evaluated Upcycle-Chic's effectiveness and usefulness in design and craft activities.

RELATED WORK

Our work is inspired by prior research in example-based design, exploratory design user interface, and sustainable design. We review related work in these areas.

Design with Examples

In design practice, examples are important resources in scoping what is already available, and inspiring new design ideas [9, 38, 42, 45]. Previous work has demonstrated three major ways of using examples to elicit creative design.

Examples as References: This method uses examples to guide a user when sketching new ideas. Tsang et al. [43] integrated an existing 2D image to guide a user when sketching 3D models. Passos et al. [30] provided an example-based synthesis approach that allowed the user to sketch silhouettes of mountains via real world terrain models. Other tools were designed to support creating 3D contents over examples. For instance, using contextual information in prototyping could tightly fit 3D virtual objects into the real world [20].

Examples as Remixing Resources: In this case, examples are remixed as resources to inspire new designs. Remixing is an efficient design approach that allows users to extract valuable components from the existent designs and hack them together. The idea has been explored and exploited in multiple disciplines. For example, Hartmann et al. [11] presented a framework of opportunistic design for ubiquitous computing to hardware and software practices. Lee et al. [21] discussed the role that example galleries can play in web design. Rewire [38] automatically infers a vector representation of screenshots to be reused in new interface design. In the field of 3D modeling, Funkhouser et al. [9] developed a tool that allowed the user to compose a new shape from the existing parts of furniture models. This was named "modeling by example". Later, Schulz et al. [34] extends this concept by creating an assembling based modelling system for fabrication via parameter templates. The "remixing culture" [27] has appeared prominently in online maker communalities such as Thingiverse [40]. Recently, Roumen et al. [33] created a tool to support users' creation of 3D printed objects by extracting and remixing mechanical parts from a library of existing models.

Examples as Guidelines: Examining a categorization of examples may provide insights into many aspects of design, such as principles, guidelines, strategies, and common approaches taken by experts. This approach has been shown effective in many disciplines. Reprise [5] derived a library of adaptation strategies from an existing tool to assist users in the design and customization of daily objects. Similarly, Medley [3] drew principles from everyday embeddables' to support custom designs with various material properties. Merrell et al. [25] developed a system that suggests furniture layout based on identified interior design guidelines. TAC [1] is a design tool that suggests a variety of candidate circuits based on users' high-level intentions.

Inspired by the previous work, we draw design strategies from existing furniture upcycling examples to help users quickly explore and compose design ideas.

Exploratory Design Interface

Many interface paradigms have been proposed to lower the burden of 3D modeling in supporting exploring varying design options. Igarashi et al. [14] proposed a suggestive interface for 3D modeling based on hints provided by users. Umetani et al. [44] exploited the idea and implemented a system to guide the user to explore physically valid shapes. Many researches discussed in the previous section also leveraged this approach. For instances, Merrell et al. [25] suggests candidate furniture layouts in their system. Both Reprise [5] and Medley [3] provide suggestions on design choices and let the users to adjust their own designs based on the suggestions.

Recent development of generative design has strengthened this approach. For instances, DreamSketch [17] allows users to express ideas by sketching and select synthesized design solutions that are generated from topology optimization. With Forte [6], the user can explore optimized topology of 3D objects by sketching their intentions. DreamLens [23] looks at divergent generative design, where large scale collections of solutions to solve the same problem are visualized. TAC [1] exploits the similar idea in circuit prototyping.

The key message delivered from these works is that providing the user with valid design options is an efficient approach for inspiration and ideation. Although not following the exact approach such as those used in generative design, Upcycle-Chic shares the value and supports users to explore valid design solutions and then customize the design upon suggestions.

Sustainable Design

The existing work aiming to repurpose, reuse, remake, reinvent, or reconfigure existing objects also employs the concept of upcycling. For example, Ramakers et al. [32] introduced a framework to retrofit physical interfaces with actuators, sensors, and enclosure designed by the system. Koyama et al. [19]'s system can perform geometric and force analysis on input objects and suggest ways to connect the two of objects. Chen et al. [4] designed print-over, print-to-affix, print-through techniques to augment everyday object with attachment. Teibrich et al.'s work allows users to edit and print directly on existing objects [39]. Song et al. [37] presented a tool to assist the design and construction of reconfigurable furniture from a given set of 3D designs. These approaches have demonstrated promising ways in augmenting existing objects using new functions. Upcycle-Chic is different in that it focuses on upcycling furniture by suggesting potential solutions to add new functional values to old furniture.

UPCYCLING DESIGN STRATEGIES

The "upcycle culture" has gradually spread among professionals and hobbyist furniture makers. For example, BHGs [2] collect creations and design of upcycled furniture from hobbyist makers in almost every category, from living room furniture to kitchen furniture. There are also personal bloggers who share collections of their favorite projects such as IKEA dresser makeover [18]. Additionally, books like [22, 24] have more detailed step to step recipes, from idea generation to hand-on operations.

Such sources of information provide valuable insights for furniture upcycling ideas and strategies. To obtain this part of knowledge, we carefully examined over 1000 examples of furniture upcycling design from the sources, including cases of 260 chairs, 53 bookcases, 271 cabinets, 198 dressers, 147 tables and 112 desks. A space of design strategies that are commonly found from the examples is summarized, including design approaches and operations.

Design Approaches

The design space is drawn from most seen examples of seven interior furniture. This includes table chair, bar chair, bookcase, dresser, bedside cabinet, table and desk. The sketch of the furniture demonstrating the shape and structure attributes are shown in Figure 2. In the following discussions, we use "*a#*" to annotate summarized upcycling design approaches from the examples.

Figure 2. Sketches of furniture categories

Chair: A quick and easy way to update a chair is to *give it a new color (a1)* by painting it. Paint is almost always useful to make an old furniture look clean and current. With different painting techniques (e.g., spray paint and traditional paint) could potentially change the style of the piece (Figure xa[1]). Similarly, wrapping a chair and its part (e.g., chair seat) could have the same effect such as to *provide new texture* (*a2*, Figure xb[2]). These two approaches are also available for other categories of furniture, but could be more difficult due to their sizes and structures.

Figure 3. (a) Making a new color; (b) Adding fabrics

Painting and wrapping are efficient ways to make an old furniture look new. However, these would not add new functional values to the furniture. With a chair, one could take the back part and attach it with either a plate, and/or

[1] https://girlinthegarage.net/2014/08/weathered-bench-makeover-chalk-paint/

[2] https://girlinthegarage.net/2016/01/vintage-white-chair-makeover-themed-furniture/

hooks (Figure 4a[3]). It *becomes a wall shelf (a3)* if hung on a wall. A chair can be flipped upside down, to *add or create storage spaces* (*a4*, Figure 4b[4]). A user can also *make a swing* from the chair (*a5*). As chairs are usually small in size and easy to move, there are design that align a couple of chairs and *make a bench* (*a6*) by adding a long cushion on top of them (Figure 4c[5]). Chairs can be aligned in either parallel way, or opposite way. Bar chairs can be stacked to make an *aesthetically pleasing design* (*a7*, Figure 4d[6]).

Figure 4. Chair(s) can be turned to (a) a wall shelf; (b) create storage space; (c) a bench; (d) make visual pleasing design.

Bookcase: A bookcase's size is suitable for being a foothold and many examples used bookcases in this way. Specifically, a bookcase is laid down and added a long cushion on top of it, turning the bookcase into a bench (marked as *a6,* Figure 5a[7]). Another possibility is having two bookcases laid down and aligned, *working as a bed box* (*a8*) to hold a mattress on top of them. Additionally, attaching a board on top of several bookcases easily turns them *into a table* (*a9*, Figure 5b[8]).

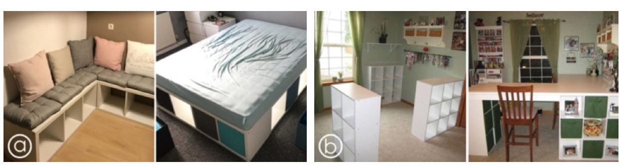

Figure 5. making bookcase(s) to (a) bench or bed; (b) table

Dresser: A dresser usually comes with many drawers and thus provides a relatively rich space to work with. By removing (part of) the drawers, a dresser can be turned *into a chair* (*a10*, Figure 6a[9]). Replacing the drawers with flatter ones can turn a blah side table *into one with specimen drawers* (*a11*, Figure 6b[10]). Different accessories can be added to the inner and outer space of the dresser. For

Figure 6. Turning a dresser into (a) a chair; (b) specimen drawers; (c) with extra racks; (d) a small closet.

example, racks can be attached to the side of the dresser, to *create extra storage space* (marked as *a4*, Figure 6c[9]). A rod can also be added inside, to make it *a small cloth closet* (*a12*, Figure 6d[9]). Other design choices include adding a bigger plate on top of the dresser to *make it a table* (marked as *a9*), and adding a sliding curtain to *alter its way to use while keeping its original function* (*a13*).

Figure 7. Making a cabinet (a) taller; (b) into a table.

Bedside Cabinet: Bedside cabinet is similar to dressers but with smaller sizes. It shares many common design strategies with a dresser while maintaining some unique design options. For instance, one could add legs or wheels to the cabinet to *make it taller* (*a14*, Figure 7a[11]) or to *make it moveable* (*a15*). Two beside cabinets of suitable sizes can be aligned to *form a table* (marked as *a9*, Figure 7b[12]).

Figure 8. (a) stacked tables; (b) using the desk as rubbish bin

Table: Tables have comparably simpler structures (e.g., a board with four legs). Common design examples including those adding boards or drawers to *create extra storage spaces* (marked as *a4*), or adding wheels beneath the legs such that it can *be easily moved* (marked as *a15*). As its simple structure, tables of various sizes can be stacked to *create a cabinet* (*a16*) to fulfill a user's need (Figure 8a[13]).

Desk: Desks are with drawers and/or closets. Designing with a desk is similar to that with a cabinet. For example, a

[3] https://www.confessionsofaserialdiyer.com/repurposed-chair/

[4] www.coco01.today/post/420903

[5] https://anoregoncottage.com/make-french-styled-bench-from-old-chairs/

[6] martinogamper.com/project/a-100-chairs-in-a-100-days/

[7] https://picsrooms.online/kallax-regal-eckbank/

[8] https://www.pinterest.com/pin/748019819330220688

[9] www.foliver.com/diy/40-awesome-makeovers-clever-ways-with-tutorials-to-repurpose-old-furniture/

[10] thepaintedhive.net/2014/07/re-love-project-before-after/

[11] https://www.bhg.com/decorating/makeovers/furniture-makeovers/fabulous-furniture-makeovers/

[12] https://www.ikeahackers.net/2015/08/rast-dresser-desk.html

[13] https://ikeahackers.net/2016/01/bedside-table-stacked-lack.html

desk can be added with different accessories to get new functions. A door on the desk, for example, can open vertically that *alters its way to use* (marked as *a13*) by moving its hinges from side to bottom edges. In this way, the storage space is turned to be a rubbish bin (Figure 8b[14]).

Design Purposes

The examination of the examples helped us identify several common upcycling design purposes. Many design cases aimed to refurbish the old furniture with new stylish and modern looking. Upcycling design of this kind put more focus on the appearance change while keeping the furniture's original functions. For instance, one can polish an old piece of table, and turn its color into soft blue by painting or wrapping it, to make it better suited to a user's preference and her living environment. One may also add four stands to a cabinet, giving it an outstanding skinny look. Upcycling ideas like these are simple but can bring immediate changes to old furniture.

Many other work were looking for design options that can make more space for storage, or to better leverage existing storage spaces. It requires people to carefully examine the structures of the furniture and see possible upcycling options that remove, split, or replace part of it. These are usually efficient ways to create desired storage spaces with little efforts. One can also insert boards and accessories to creatively segment the open space that is inside/outside the furniture to add storage functions to it.

What is more interesting about upcycling design is repurposing a furniture, that enables new functions of a user's need. Many upcycling ideas fall into this category. Taking the chairs as example, the chair back can be used as a wall shelf for books and flowers, or to hang things with added hooks. The chair seat can be flipped and acts as a rubbish bin. Two abandoned chairs can be made into a bench, used either in one's garden or in public place. Other than this, a couple of bookcases can be laid down and spaced apart, to become a bed frame with storages. These are interesting upcycling ideas that add not only functional, but also decorative values, as their original style contributes unique visual elements when being used in alternative ways.

Design Operations

It is noticed that many design approaches are shareable among different categories of furniture, and the approaches are formalized with a series of elementary design operations in certain sequences. Here the concept of operations is akin to those toolbars in many design software, where users choose and apply design operations to target objects without worrying about their underneath implementation details. The operations shall be easy to understand and intuitive to use. We expect that with these operations, users can express their own design thoughts, such as to customize a design suggested by the system, or to compose an upcycling design from scratch. To this end, we summarized

Figure 9. Changing (a) with (b) painting and (c) wrapping

these basic operations that are used as elementary design components in upcycling design processes.

Refinishing Operations: To make a furniture look new or to make a quick change to its style, one could choose the operations of *paint* and *wrap* (Figure 9). These often give a furniture a new look with modern stylish, but they do not change a furniture's existing structures and functions.

Additive Operations: We found many examples where people add things to a furniture. These could be constructing components that alter the furniture's structure, or accessories that enable certain functionality. Most common additive operations include those to add a *door*, a *curtain*, a *board*, a *drawer*, a *rod*, as well as accessories such as *stands*, *wheels*, *hooks* and *racks* (Figure 10). While many operations have dedicated ways of actions, some take totally different effects when being applied in different ways, e.g., position matters. For instance, a board added to the top of a furniture may turn it into a table, while a board added to inner space of a furniture may create a storage layer or segment its original storage spaces. A rod may make a hanger if added inside a furniture, and make a handrail if added to the side.

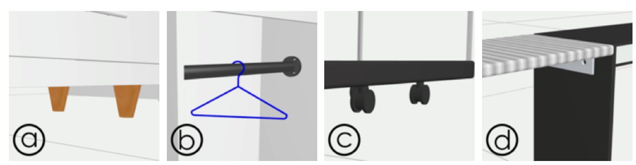

Figure 10. Examples of additive operations.

Subtractive Operations: Opposite to the additive operations, subtractive operations are to *remove* things on a furniture. It may require various levels of workload to carry out a remove operation. For instance, drawers are easy to remove while boards connected to the furniture body with glue or nails need extra efforts to get removed. Moreover, in corresponding to the remove operation, one may need to *cut* a piece of the furniture first (Figure 11a-b).

Figure 11. Subtractive operations with (a) cut and (b) remove; (c) position operation.

14 www.diyhowto.org/diy-trash-can-cabinet-projects/

Position, Orientation and Alignment Operations: These are the operations to support a furniture's spatial *translation* and *rotation* without actually changing or modifying the furniture's shape or structure, that introduce new functional values and usage ways. For instance, a table can be placed against a wall to become a wall cabinet (Figure 11c). A chair can be flipped upside down to become a rubbish bin. For multiple furniture, they are often *aligned*, in parallel or opposite way, or *stacked* for further design.

SYSTEM OVERVIEW AND IMPLEMENTATION

The knowledge of the design space and operations are embedded in the system of Upcycle-Chic. With a 3D furniture model, the software supports users to view and examine possible design solutions, and explore customized design operations.

Upcycle-Chic is implemented using ThreeJS [41], a JavaScript framework that handles WebGL rendering. OpenJSCAD [28] is used in the system to handle 3D modelling and editing functions such as shape creating and cutting. Upcycle-Chic is run on a local web server.

Scenario Walkthrough

Lisa has an old chair in her garage. She would like to explore what are the Upcycle possibilities of the chair using Upcycle-Chic. To start, Lisa takes a photo of the chair with her phone, manually brushes and segments the chair from the background on the touchscreen, and uploads it to Upcycle-Chic (Figure 12a-b). The software receives the photo, and suggests three most matched 3D models to Lisa via a search of a pre-defined furniture dataset (Figure 12c), including its category information (e.g., table chair). Lisa picks the most similar one and the model gets imported.

Upcycle-Chic starts with a simulated house environment as the background in the scene (Figure 1). This is to i) help users better estimate the size of the furniture and its design outcomes; ii) provide suitable visual elements, such as a wall, a window to support the exhibition of a design outcome. When the model gets imported to the scene, the software estimates its size and orientation, via reading the relevant information from the 3D model file, and makes necessary adjustments of the model's scale, rotation and position when rendering it to the scene. The scene's camera

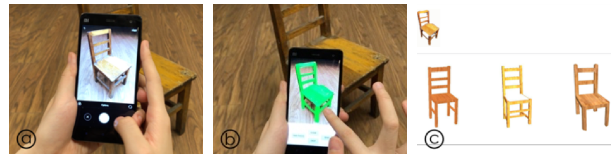

Figure 12. A user (a) takes a photo of the chair, (b) segments the chair, and (c) gets three recommended chair models.

adjusts its position (e.g., auto zoom) and presents a suited view of the chair to Lisa for her exploration.

Annotation: Upcycle-Chic requires users to manually annotate the furniture model with a few simple and intuitive operations. To annotate the chair, Lisa clicks on the chair and presses "E", that invokes the explosive view of the chair (Figure 13a). This is possible as many of these models come already decomposed into multiple components. When Lisa clicks on a component, a toolbar pops up and Lisa selects "Label - Seat" from the menu. She can also perform a "Group" command to assemble several parts into one and then label it, e.g., the "back" part. Upon the label selection, a 6-dimensional axis is shown on the component such that Lisa can select the "normal" direction of the part by clicking on it (Figure 13b). This tells the system the loaded orientation information of the model and its parts.

Exploration of Suggested Design: Once the chair is correctly labeled (i.e., back and seat), Lisa explores possible upcycling design suggested by the system. She clicks "Suggested Design" button on the left panel, and a list of five design options are provided, including *a1 – a5* in this case. To view a design, Lisa clicks on one of the buttons, and the corresponding design will be automatically applied to the chair. She can iteratively explore how the design looks like when it is applied to the chair (Figure 13e-i).

There might be cases where Lisa has two such chairs in her garage. With the current chair model labeled, she first clicks the "Duplicate" button to make a copy of the chair in the scene. Then she clicks the "Suggested Design" button, that shows two new design suggestions (i.e., *a5-a6*, Figure 13k-j). Following the same procedure, Lisa may explore suggested design for other categories of furniture.

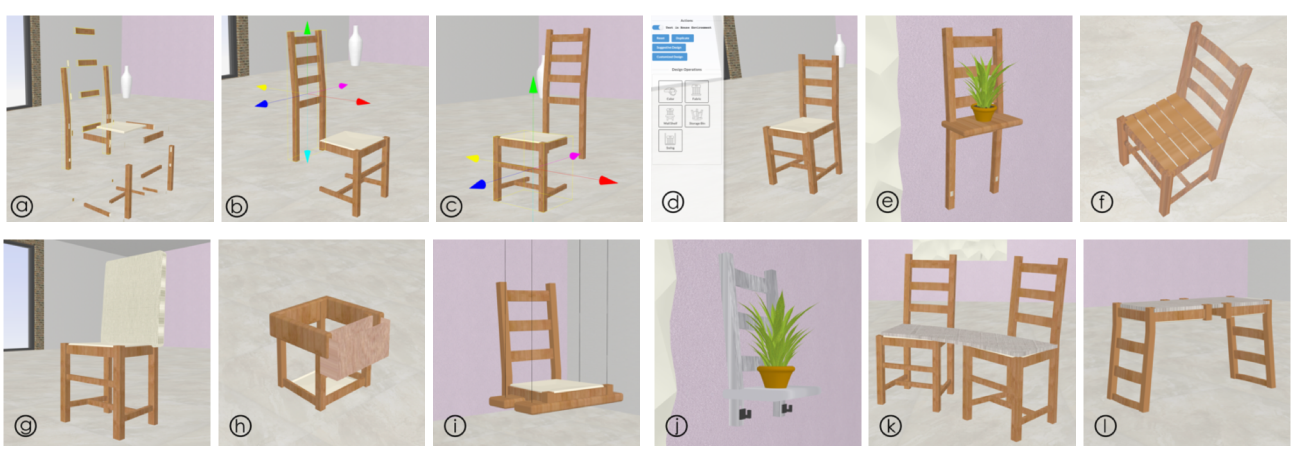

Figure 13: (a – c) Annotation procedures; (d - i) exploring suggested design of a chair; (j - l) customized design.

Design Customization: Upcycle-Chic allows users to apply customized changes to a suggested design. In this example, Lisa is interested in the design that turns the chair to a wall shelf (Figure 13e). However, she is not satisfied with the color and wants to decorate the shelf. To make a change, Lisa switches to "Customized Design" panel, where the corresponding design operations are available to use. She first cuts out the lower part of the legs, and paints the shelf with gray color. Finally, she attaches a couple of hooks to underneath the shelf plate (Figure 13j).

It is worth to note that a user may also start her upcycling design and express her own ideas without loading suggested ones once she is familiar with the design space and operations. Upcycle supports such operations while it may require more creative skills from the users. For most others, we expect them to follow a suggested + customized design method while using Upcycle-Chic. The following subsections describe more technical details.

3D Furniture Model Search

Online repositories such as ShapeNet [35], ObjectNet3D [26], IKEA Dataset [15] provide rich set of furniture 3D models. For example, ShapeNet covers over 23,000 chairs and over 26,000 tables. Users could search via the website or leverage 3D model search engines such as "heymesh.com" [12] to obtain a model that matches or similar to the target furniture. This, however, may be tedious and time-consuming. We designed and implemented a 3D furniture model retrieval framework that allows model searching in a more user-friendly way: the user takes a photo of the furniture, manually crops out the background, and uploads it to the Upcycle-Chic server, which processes the image and searches through a pre-defined 3D furniture model dataset, and suggests the top 3 most matched models to the user. Here we briefly describe the implementation details.

With a pre-downloaded dataset, each furniture model is automatically loaded to a 3D web view. Snapshots are taken from eight different view angles of the model and saved as 2D images with tags. The images are cropped along the bounding box of the furniture, and resized to 64 x 64 scale. These data are saved into a furniture library.

Upon receiving the photo from the user, the software does the resizing operations. The system then iteratively calculates the image distance/similarity between the photo and images in the furniture library using a state-of-the-art method [46]. It uses a pre-trained convolutional neural network to extract the deep features of two images, and then calculate the perceptual loss of two feature maps to get the perceptual similarity between them. Based on the results, the top three most matched images are selected and their corresponding 3D models are suggested to the user in Upcycle-Chic.

To test the feasibility and performance of the approach, 500 furniture models were collected and saved to the library. The number was evenly distributed across the 7 categories

Figure 14. Example testing results of furniture model search

of the furniture discussed in this paper. For each category, 10 photos of different furniture were downloaded from online search and used as the testing set. The photos were manually searched such that each furniture shown in the photo had at least one similar 3D model in the library. This is to make sure that if the algorithm works, it must return the correct model to the user.

All the photos were tested, and the system suggested 1, 3, or 5 3D models after examining the similarity. Then we checked whether the "correct" one was listed among the suggested ones. The results showed that when 3 suggested models were given, the chance to find the good match was 96.77%, while with 1 suggested model, it dropped to 87.10% and with 5 suggested model, it achieved 100% accuracy. Figure 14 listed example furniture photos and the matched 3D models that were found from the library. Using this method, we decided to suggest 3 models to users in Upcycle-Chic. Users also have the option to load a model manually from their local disks.

Obtain Component's Shape

There are many operations that require to gather the information of a component's shape, such as when wrapping a chair's back with fabric, and when adding a board on top of aligned chairs. In most cases, it is sufficient to use the positions of a component's corners, obtained from its bounding box, while some operations need more detailed information like contours. To this end, we collect the components' vertices, and project them to the left and back faces of its bounding box. The 2D contours are calculated respectively based on a JS library [13] (Figure 15). With these, the 3D shape of the component is retrieved by calculating the intersection of the extruded geometries

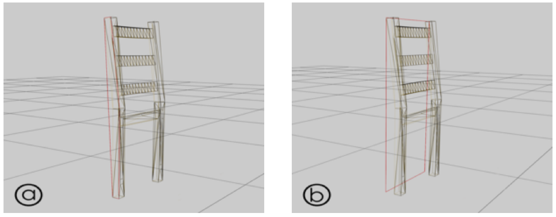

Figure 15. Computing the convex hull of the components.

from the contours, which is then rendered with a fabric texture (Figure 9c).

Positioning on Model

In the software, users often need to attach or add things (e.g., wheel, rod, board) to the furniture model. The positioning is calculated by using a raycasting method. For identifying a single positioning point, the system calculates the intersection point on the model using a raycaster that is originated from the cursor, and with the scene camera's look-at direction. When adding a rod to the furniture, another raycaster is originated from the intersection point, and with the direction that is akin to the component face's normal vector. A red dot is rendered in the scene to visualize the current intersection point and selected surface (Figure 16a). If collision is detected between the raycaster and the model, the rod is positioned (Figure 16b).

Figure 16. (a-b) Adding a rod between the table's legs; (c) cutting a chair's component.

Cut Model Component

To cut a component, the user invocates the cut command, and a yellow plane is rendered to visualize the cutting position and direction on the model (Figure 16c). The position is determined by the intersection of the cursor and the model, while the direction of the cutting plane is changed by mouse wheel scrolling. The current system supports to set the cutting plane to the three axis directions, which satisfies the need of most design cases.

Get Size of Model

Users may want to measure the model's size when a design approach is applied to better estimate whether it fits to the room. To do so, the user selects a furniture or its component in the scene, and clicks "Get Size" command, which marks the length, width and height values in the unit of meter

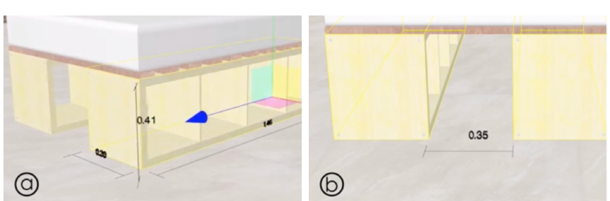

Figure 17. size of (a) a component, (b) between components

(Figure 17a). If two objects are selected, the system shows their spacing value (Figure 17b).

EVALUATIONS

To demonstrate the expressiveness of Upcycle-Chic and validate its usefulness in helping users in formalizing design ideas, we first run a furniture upcycling design workshop with 10 students from the design department of a local university. We further invited 6 hobbyist makers to participate a DIY workshop, where they used Upcycle-Chic to design and create new ones with four old furniture.

Design Workshop

All the students (avg. age = 19.8, 5 females) received training the day before the design workshop was held. They were introduced the goal of the project, Upcycle-Chic's functions and how to use them. They practiced to use the software until they got familiar with the functions and operations.

Procedure: The students were randomly chosen into two groups, five members each (A and B). There were two design sessions. The two groups were asked to compose upcycling ideas and sketch them out with 3 given furniture (a chair, a table, a dresser), one group with and the other without using Upcycle-Chic (Figure 18a-b) in the first session, and swapped in the next session with 3 different furniture (a different chair, a desk, a cabinet). 20 minutes were given for each furniture, and they were allowed to hand in their sketch if the sketch was completed in shorter time.

Figure 18. (a) A student doing the design with the assistance of Upcycle-Chic; (b) designing without using the software; (c) design output - sketches; (d) evaluation of the design.

After the sessions, the students were asked to fill a survey about their experiences of using Upcycle-Chic. Specifically, we asked them to write down their feedback on how helpful of using Upcycle-Chic was in their composition process. Then the students were asked to vote for three most favorite design of each furniture (6 in total) anonymously based on how "creative", "interesting", and "useful" the design was, including the design from both groups, and they were not allowed to vote their own design (Figure 18d).

Results: Summarizing the top three most voted design for each furniture, 13 out of the 18 best design (72.2%) were from the students when they used Upcycle-Chic. This showed that Upcycle-Chic was effective in helping the participants compose new and good ideas. We also compared the average task completion time, and found that the students spend an average of 11.08 mins to complete the design when using Upcycle-Chic, compared to an average of 12.68 mins when not using the software. However, no significant effect was found between them after running a One-way ANOVA ($p > 0.5$). This indicated that Upcycle-Chic was efficient in ideating new design, but this may vary to different people and based on different design tasks.

Feedback: The students were generally in favor of using Upcycle-Chic. They like the simple and intuitive operations of the software and the 3D visualization of the design approaches. More importantly, the students found Upcycle-Chic is useful in inspiring design ideas with the given furniture. By exploring the suggested design approaches, they could quickly draw inferences about other cases and formalize the new design on top of them, while it was non-trivial to propose an upcycling idea without guidance. Some students expected to see more suggested design approaches.

With Upcycle-Chic, the students found themselves more orientated towards designing the functions via modifying the furniture's structures, such as a chair can be turned into a bench or wall shelf. Meanwhile, the students found the stylish change via painting and wrapping was also an efficient and creative upcycling approach after trying them out using the software.

Nonetheless, the students expressed their concerns on how well the design approaches and operations follow the principles of crafting process, especially on material properties and connections between pieces of the components. This part of knowledge is not included in the current implementation of Upcycle-Chic. However, we expect the upcycling approaches and operations introduced in the software have a certain level of do-ability values as they are all referred from concrete real-life design examples.

DIY Workshop

To better understand how Upcycle-Chic could help users in actual furniture crafting activities, we run a DIY workshop.

Procedure: Six hobbyist makers were invited from a local community. They have basic crafting skills but do not have much experience in design. They formed four groups based on their self-estimated skill level, 2 groups with only 1 member each, and 2 groups with 2 members each. Four furniture were provided including two chairs, a closet shelf, and a table, and each group picked one. The 3D models of the furniture were pre-loaded to use in Upcycle-Chic.

After a short tutoring session, the six participants learnt how to use Upcycle-Chic. They explored the suggested design solutions and operations based on the given furniture (Figure 19a). We observed that the participants frequently

Figure 19. (a) A participant explores the design using Upcycle-Chic; and (b) crafts the furniture; (c) Another group crafts a different furniture.

compared the design with the furniture. After making the design decision, they started working on the furniture (Figure 19b-c). Two professional wood-makers were invited to supervise them on using the tools and machines, but they did not participate the design phase.

On average, each group spent about 2 hours to complete their final design, and they all successfully produced the upcycled furniture. After the workshop, we interviewed each group on their experiences of using the software.

Feedback: The participants found it was extremely helpful in getting upcycling ideas. Looking on the visualization of the design approaches, especially when the design was simple yet interesting, they felt more confident to work on the given furniture. However, some participants more or less hesitated to decide their final approach due to self-evaluation of the crafting skills needed by the design. Instead of discussing until getting a final design solution and then moving to work on the furniture, they preferred to try out some operations (e.g., disassemble the furniture) and use the software to generate the design iteratively. These participants expected to have more detailed guidance on implementations, such as how best to connect two components with nails. Such problem was not met for the participants who had done similar crafting work before.

DISCUSSION AND FUTURE WORK

Instead of stashing away or discarding old furniture, upcycling provides a sustainable way to turn them into new ones that are stylish and functional. It brings both economic and environmental benefits. Upcycle-Chic is to ease and inspire the ideating process as design something where one has to use an old piece of furniture with established shape and structure is quite hard and challenging. Good design ideas shall be encouraged as essential part of the upcycling process. The paper demonstrates a viable way to this end by incorporating design knowledge from existing examples into a 3D visualization environment, which supports the design exploration and customization.

Examples from those online DIY communities are rich but of various formats, which makes it time-consuming to review and summarize. However, it turns out to be beneficial to the project in many aspects. Design cases could be varying from case to case, but the design strategies including those approaches and operations are in most time consistent and similar. Reviewing the examples helped us quickly explore the upcycling design space in a high-leveled and structured way. In the current implementation, we summarized the most common approaches of seven categories of furniture. Including more examples is expected to be able to enrich Upcycle-Chic's expressiveness and generalizability.

Although Upcycle-Chic has been shown to be expressive and intuitive to use, there are many ways to improve it: i) The current 3D model search framework is only validated with the prepared furniture library. It is possible to extend the search framework and integrate a more advanced search engine such that the server could grab a better matched furniture model from online datasets; ii) Those downloaded 3D furniture models often come with different formats and different levels of details. This adds difficulties to make the encoded design approaches and operations applicable to any loaded model. Requests of the design on the model's properties and qualities shall be added; iii) Based on the concerns of i and ii, looking for a 3D reconstruction method using a depth camera is another option; iv) When applying the same design approach to a different furniture, the result could be more adaptive and diverse, by analyzing the furniture's style and aesthetic properties; v) To help a user better understand the design process, it might be good to provide step-wise visualization of the operations in a design approach. In this way, the user can step back and forward to get more hints on the design process.

It is also desirable to enrich Upcycle-Chic's functionalities to check if a designed furniture is comfortable, durable and how well it serves a user's specific purpose. There always exists a gap between the design and craft. When crafting a furniture, a user has to be aware of the material properties, structure properties, his own crafting skills, as well as available resources and tools. All these determine the practicability of the design and the feasibility of turning the design into reality. One future work direction of Upcycle-Chic is to digitalize and embed those knowledge and information to the system, such that any design proposed by the system has to follow the principles of process. This would be valuable to inspire more people to get hands-on and upcycle furniture themselves.

CONCLUSION

Upcycling design is a sustainable way to repurpose old furniture with new spatial, aesthetic, or functional values, but its ideation process is hard. This paper presents a software approach for ideating furniture upcycling design. Upcycle-Chic incorporates design knowledge (i.e., approaches and operations) from over 1000 DIY examples into a 3D visualization environment, and supports users to view possible upcycling solutions for a given piece of old furniture and explore design variations. A design competition workshop and a DIY workshop were held to evaluate the expressiveness of the software and its usefulness in inspiring upcycling ideas. The results showed that Upcycle-Chic is easy and intuitive to use, while being effective and efficient in helping users in composing new upcycling ideas.

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