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3D PRINTED FURNITURE AND METHOD OF MAKING THE SAME

Abstract

A three-dimensional (3D) printed multi-component structure includes a first component and a second component. The first component has a first surface and a second surface opposite the first surface. The first component is formed to define a channel that extends into the first surface toward the second surface. The second component has an outer edge, a mating edge configured to mate with the channel of the first component to couple the first component to the second component, and a body extending between the outer edge and the mating edge.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 63/555,218, filed 19 Feb. 2024, the disclosure of which is now expressly incorporated herein by reference.

FIELD OF THE DISCLOSURE
[0002] The present disclosure relates generally to furniture, and more specifically to 3D printed furniture and methods of the making the same.
BACKGROUND
[0003] Disposing of some objects, such as furniture or décor, may be difficult. Furniture waste is becoming increasingly problematic as furniture is generally made of multiple different materials, many of which are difficult to recycle. Further, taking apart furniture to process each type of material separately is time-consuming and expensive.
[0004] Three-dimensional (3D) printing may be used to make three-dimensional objects. 3D printing is achieved using additive processes during which an object is created by laying down successive layers of material until the object is created. There remains interest in using 3D printing to reduce furniture waste.
SUMMARY
[0005] The present disclosure may comprise one or more of the following features and combinations thereof.
[0006] A method of three-dimensional (3D) printing multi-component furniture may comprise providing a first furniture component having a first surface and a second surface opposite the first surface. The method may comprise removing material from the first surface of the first furniture component to form a channel in the first surface of the first furniture component. The method may comprise depositing at least one first layer of molten material in the channel to form a mating edge of a second furniture component having a contour of the channel. The method may comprise depositing at least one second layer of molten material onto the at least one first layer of molten material while the at least one first layer of molten material is molten to form a body of the second furniture component on the mating edge of the second furniture component. The method may comprise cooling the at least one first layer of molten material and the at least one second layer of molten material to cause the at least one first layer of molten material and the at least one second layer of molten material to solidify and form the second furniture component comprising the body and the mating edge having the contour that mates with the channel of the first furniture component.
[0007] In some embodiments, the channel of the first furniture component may be formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall. A width of the channel between the first sidewall and the second sidewall may remain constant or may increase as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first furniture component.
[0008] In some embodiments, a first angle may be formed between the first sidewall and the base wall. A second angle may be formed between the second sidewall and the base wall. The first angle and the second angle may each be 90 degrees.
[0009] In some embodiments, a first angle may be formed between the first sidewall and the base wall. A second angle may be formed between the second sidewall and the base wall. The first angle and the second angle may each be greater than 90 degrees. The method may further comprise, after

cooling, separating the second furniture component from the first furniture component.
[0010] In some embodiments, the channel of the first furniture component may be formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall. A width of the channel between the first sidewall and the second sidewall may decrease as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first furniture component. A first angle may be formed between the first sidewall and the base wall. A second angle may be formed between the second sidewall and the base wall. The first angle and the second angle may each be less than 90 degrees.
[0011] In some embodiments, a first angle may be formed between the first sidewall and the base wall. A second angle may be formed between the second sidewall and the base wall. The first angle may be 90 degrees, and the second angle may be less than 90 degrees.
[0012] In some embodiments, providing a first furniture component may include 3D printing the first furniture component with at least one third layer of molten material. Removing material from the first surface of the first furniture component may include milling the material from the first surface of the first furniture component to form the channel in the first surface of the first furniture component.
[0013] According to another aspect of the present disclosure, a method of three-dimensional (3D) printing multi-component structures may comprise providing a first component having a first surface and a second surface opposite the first surface. The method may comprise forming a channel in the first surface. The method may comprise depositing a first layer of material in the channel. The method may comprise depositing a second layer of material onto the first layer of material while the first layer of material is molten. The method may comprise cooling the first layer of material and the second layer of material to cause the first layer of material and the second layer of material to form a second component having a contour of the channel.
[0014] In some embodiments, forming a channel in the first surface may include milling material from the first surface of the first component to form the channel in the first surface of the first component. The first layer of material may form a mating edge of the second component having the contour of the channel and the second layer of material may form a body of the second component. The mating edge of the second component may mate with the channel to couple the first component to the second component. The first component may be removably coupled with the second component.
[0015] In some embodiments, the channel of the first component may be formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall. A width of the channel between the first sidewall and the second sidewall may remain constant or may increase as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component. The mating edge of the second component may be captured in the channel of the first component.
[0016] In some embodiments, the channel of the first component may be formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall. A width of the channel between the first sidewall and the second sidewall may decrease as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component.
[0017] According to another aspect of the present disclosure, a three-dimensional (3D) printed multi-component structure may include a first component and a second component. The first component may have a first surface and a second surface opposite the first surface. The first component may be formed to define a channel that extends into the first surface toward the second surface. The second component may have an outer edge, a mating edge configured to mate with the channel of the first component to couple the first component to the second component, and a body extending between the outer edge and the mating edge. The mating edge may be formed to have a contour that matches a contour of the channel.

[0018] In some embodiments, the channel of the first component may be formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall. A width of the channel between the first sidewall and the second sidewall may remain constant or may increase as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The detailed description particularly refers to the accompanying figures in which:

[0020] FIG. **1** is a diagrammatic view of a method for three-dimensional (3D) printing a multi-component structure showing that the method includes (i) providing a first furniture component, (ii) milling the first furniture component to form a channel in the first furniture component, (iii) aligning a nozzle of a printer with the channel formed in the first furniture component, (iv) depositing at least one first layer of molten material into the channel to form a mating edge of a second furniture component, (v) depositing at least one second layer of molten material on the at least one first layer of molten material to form a body of the second furniture component, and (vi) cooling the molten material to form the second furniture component coupled with the first furniture component;

[0021] FIG. **2**A is a diagrammatic view of a method for three-dimensional (3D) printing the multi-component structure showing that the method includes 3D printing the first furniture component prior to milling the channel in the first furniture component;

[0022] FIG. **2**B is a continued diagrammatic view of the method of FIG. **2**A;

[0023] FIG. **3**A is a perspective view of the multi-component structure formed with the method of FIGS. **1**-**2**B showing that the first furniture component is coupled with the second furniture component to form a multi-component table;

[0024] FIG. **3**B is a sectional view of the multi-component table of FIG. **3**A;

[0025] FIG. **4** is a perspective view of the first furniture component of FIG. **1** showing that the at least one first layer of molten material is deposited into the channel of the first furniture component to form the mating edge of the second furniture component that matches a contour of the channel;

[0026] FIG. **5** is a sectional view of a portion of the first furniture component of FIG. **1** showing that the channel has a generally constant width along a height of the channel so that the first furniture component and the second furniture component may be separated from one another without damage to the first furniture component, the second furniture component, or the mating edge of the second furniture component;

[0027] FIG. **6** is a sectional view of a portion of the first furniture component of FIG. **1** formed to include an alternative channel showing that the channel has an increasing width along a height of the channel so that the first furniture component and the second furniture component may be separated from one another without damage to the first furniture component, the second furniture component, or the mating edge;

[0028] FIG. **7**A is a sectional view of a portion of a multi-component structure including the first furniture component and a second furniture component showing that at least one first layer of molten material is deposited into a free geometry channel of the first furniture component to form a hinge so that the second furniture component is in a first position relative to the first furniture component and free for movement relative to the first furniture component;

[0029] FIG. **7**B is a sectional view of the multi-component structure of FIG. **7**A showing that the second furniture component is in a second position after pivoting of the second furniture component relative to the first furniture component;

[0030] FIG. **8** is a sectional view of a portion of the first furniture component formed to include an

alternative channel showing that the channel has a decreasing width along a height of the channel to cause a mating edge of the second furniture component to be captured in the channel of the first furniture component so that the first furniture component and the second furniture component may not be separated from one another without damage to the first furniture component, the second furniture component, or the mating edge;

[0031] FIG. **9** is a sectional view of a portion of the first furniture component formed to include an alternative channel showing that the channel has a decreasing width along a height of the channel to cause a mating edge of the second furniture component to be captured in the channel of the first furniture component so that the first furniture component and the second furniture component may not be separated from one another without damage to the first furniture component, the second furniture component, or the mating edge;

[0032] FIG. **10** is a sectional view of a portion of the first furniture component formed to include an alternative channel showing that the channel has a decreasing width along a height of the channel to cause a mating edge of the second furniture component to be captured in the channel of the first furniture component so that the first furniture component and the second furniture component may not be separated from one another without damage to the first furniture component, the second furniture component, or the mating edge;

[0033] FIG. **11**A is a sectional view of a multi-component structure including the first furniture component and a second furniture component showing that at least one first layer of molten material is deposited into the captive geometry channel of the first furniture component to form a hinge so that the second furniture component is in a first position relative to the first furniture component and free for movement relative to the first furniture component;

[0034] FIG. **11**B is a sectional view of the multi-component structure of FIG. **11**A showing that the second furniture component is in a second position after pivoting of the second furniture component relative to the first furniture component;

[0035] FIG. **12** is a diagrammatic view of a method for forming a multi-component structure showing that the method includes (i) providing a first furniture component and a second furniture component, (ii) milling the first furniture component and the second furniture component to form a channel in the first furniture component and the second furniture component, (iii) aligning the channel formed in the first furniture component with the channel formed in the second furniture component, (iv) depositing molten material into the channel of the first furniture component and the second furniture component to form a mating edge that couples the first and second furniture components together and cooling the molten material to form the multi-component structure;

[0036] FIG. **13**A is a top perspective view of the multi-component structure formed with the method of FIG. **12**; and

[0037] FIG. **13**B is a bottom perspective view of the multi-component structure formed with the method of FIG. **12**.

DETAILED DESCRIPTION

[0038] For the purposes of promoting an understanding of the principles of the disclosure, reference will now be made to a number of illustrative embodiments illustrated in the drawings and specific language will be used to describe the same.

[0039] A three-dimensional (3D) printed multi-component structure **10** in accordance with the present disclosure includes a first furniture component **12** and a second furniture component **14**, as shown in FIGS. **1**-**3**A. The first furniture component **12** and the second furniture component **14** are coupled with one another without using adhesives and/or fasteners, such as interlaminar adhesion, glue, bolts, screws, rivets, nails, or other similar adhesives or fasteners. Instead, the first furniture component **12** and the second furniture component **14** are coupled with one another via a 3D printed mechanical connection. The absence of adhesives and/or fasteners allows for direct recycling and/or reuse of the first furniture component **12** and/or the second furniture component **14**.

[0040] The first furniture component **12** includes a first surface **16** and a second surface **18** opposite the first surface **16**, as shown in FIGS. **1**, **3**A, and **3**B. The first furniture component **12** is formed to define a channel **20** that extends into the first surface **16** toward the second surface **18**. In some embodiments, the first furniture component **12** is 3D printed, as shown in FIG. **2**A. In some embodiments, the first furniture component **12** is not 3D printed. For example, the first furniture component **12** may include wood, metal, non-printed polymeric material, ceramic, stone, engineered materials, etc.

[0041] The second furniture component **14** includes an outer edge **22**, a mating edge **24**, and a body **26** extending between the outer edge **22** and the mating edge **24**, as shown in FIGS. **1**, **3**A, and **3**B. The mating edge **24** extends into and mates with the channel **20** of the first furniture component **12** to couple the first furniture component **12** with the second furniture component **14**. Illustratively, the mating edge **24** forms the 3D printed mechanical connection. The mating edge **24** is formed to have a contour that matches a contour of the channel **20**. The mating edge **24** allows for connection of the first furniture component **12** and the second furniture component **14** via friction and/or material fastening. In some embodiments, the second furniture component **14** is 3D printed. In some embodiments, the second furniture component **14** is not 3D printed. In some embodiments, the first furniture component **12** and the second furniture component **14** are formed of different materials. In some embodiments, the first furniture component **12** and the second furniture component **14** are formed of the same materials.

[0042] The second furniture component **14** is removably coupled with the first furniture component **12** in the illustrative embodiment. In some embodiments, the second furniture component **14** is coupled with the first furniture component **12** such that the components **12**, **14** may not be separated without damaging one or more of the components **12**, **14**.

[0043] A method **200** of three-dimensional (3D) printing the multi-component structure **10** is shown in FIGS. **1**, **2**A, and **2**B. FIGS. **2**A and **2**B shows a bottom view of the multi-component structure **10** in each step and a sectional view of the multi-component structure **10** through the dashed line in each step. In step **202**, the first furniture component **12** is provided, for example, by 3D printing material or by providing a formed component of other material. In some embodiments, as shown in FIG. **2**A, the step **202** of the method **200** includes step **202**A of setting a print path for a nozzle **28** of a 3D printer to deposit at least one layer of molten material and step **202**B of 3D printing the first furniture component **12**. In some embodiments, the first furniture component **12** is not 3D printed and may be a wooden, metal, plastic, etc. material and made by traditional processes.

[0044] In step **204**, the channel **20** is formed in the first surface **16** of the first furniture component **12**. In the illustrative embodiment, the first furniture component **12** is fully cured or is in a rigid state. In other words, the channel **20** is formed in a rigid component and not made during an additive manufacturing process of forming the first furniture component. To form the channel **20**, material from the first surface **16** is removed. In some embodiments, the channel **20** is formed by milling. In some embodiments, the channel **20** is formed by turning, drilling, grinding, cutting, lasering, or any other subtractive process. In some embodiments, the channel **20** is formed by an additive process of making the first furniture component **12**. The channel **20** may by continuous, as shown in FIG. **2**A. In other words, the channel **20** may form a circle, an oval, a rectangle, a square, or any other shape that is continuous.

[0045] In step **206**, the nozzle **28** of the 3D printer is positioned above the first furniture component **12**. The nozzle **28** is positioned at a nozzle height relative to the channel **20**. The nozzle height may locate the nozzle **28** above the first surface **16**, aligned with the first surface **16**, or below the first surface **16** (i.e., in the channel **20**). In step **206**, a flow rate of the material being deposited into the channel **20** from the nozzle **28** is set. The nozzle height and the flow rate may be set based on a shape of the channel **20**, the material being deposited into the channel **20**, and/or a desired connection type between the first furniture component **12** and the second furniture component **14**.

To prepare a tighter fit between the components **12**, **14**, the flow rate may be increased so that more molten material is deposited into the channel **20** and/or the nozzle height may be decreased so that the nozzle **28** is closer to the channel **20**. A print path for the nozzle **28** is also set in step **206**. The print path is the path the nozzle **28** travels along the channel **20** to ensure the channel **20** is appropriately filled with the molten material.

[0046] In step **208**, at least one first layer of molten material is deposited into the channel **20** to form the mating edge **24** of the second furniture component **14**, as shown in FIGS. **1**, **2**B, and **4**. The nozzle **28** deposits the molten material into the channel **20** such that the channel **20** is partially or completely filled with the molten material. Depending on the shape of the channel **20**, the material being deposited into the channel **20**, and/or a desired connection type between the first furniture component **12** and the second furniture component **14**, the molten material may be deposited into the channel **20** in a single pass or in multiple passes. For example, if a single pass is insufficient to fill the channel **20** with molten material, the molten material may be deposited into the channel **20** in multiple passes, as suggested in FIG. **4**. Because the molten material is deposited into the channel **20** to form the mating edge **24** of the second furniture component **14**, the mating edge **24** conforms to the shape of the channel **20** such that the mating edge **24** has a contour of the channel **20**. The mating edge **24** conforming to the shape of the channel **20** may save production time as the mating edge **24** of the second furniture component **14** does not require machining to match the shape of the channel **20**.

[0047] In step **210**, at least one second layer of molten material is deposited onto the at least one first layer of molten material (i.e., the mating edge **24**) while the at least one first layer of molten material is molten, as shown in FIGS. **1** and **2**B. The at least one second layer of molten material forms the body **26** of the second furniture component **14**. Additional layers of molten material may be deposited onto one another in step **210** until the desired shape of the second furniture component **14** is achieved. The body **26** is formed on the mating edge **24**, and the outer edge **22** is formed on the body **26** opposite the mating edge **24**. In step **212**, the layers of molten material are cooled to cause the layers of molten material to solidify. In some embodiments, the molten material shrinks as the molten material cools in step **212**. The shrinking of the molten material may prevent motion between the first furniture component **12** and the second furniture component **14**.

[0048] As shown in FIG. **5**, the channel **20** is formed to include a base wall **30**, a first sidewall **32**, and a second sidewall **34**. Each wall **30**, **32**, **34** may be substantially flat or straight. The first sidewall **32** extends upwardly from the base wall **30** to the first surface **16** of the first furniture component **12**. The second sidewall **34** extends upwardly from the base wall **30** to the first surface **16** of the first furniture component **12**. In some embodiments, the first sidewall **32** and the second sidewall **34** are substantially parallel to one another and perpendicular to the base wall **30**. As shown in FIG. **5**, a width W**1** of the channel **20** between the first sidewall **32** and the second sidewall **34** remains constant as the first sidewall **32** and the second sidewall **34** extend upwardly from the base wall **30** to the first surface **16** of the first furniture component **12**. In other words, the width W**1** of the channel **20** may be defined as a function of a height H**1** of the channel **20** (with the height H**1** equal to zero at the base wall **30**) where the width W**1** does not decrease as the height H**1** of the channel **20** increases. Instead, the width W**1** remains constant as the height H**1** of the channel **20** increases.

[0049] A first angle A**1** is formed between the first sidewall **32** and the base wall **30**, as shown in FIG. **5**. A second angle A**2** is formed between the second sidewall **34** and the base wall **30**. In some embodiments, the first angle A**1** and the second angle A**2** are both about 90 degrees. The shape of the channel **20** allows the second furniture component **14** to be removably coupled with the first furniture component **12**. In other words, the connection between the first furniture component **12** and the second furniture component **14** via the mating edge **24** is a temporary connection due to the free geometry of the channel **20**. Free geometry channels, such as those shown in FIGS. **5** and **6**, help to align and/or orient the first furniture component **12** and the second furniture component **14**

relative to one another.
[0050] The shape of the channel **20** allows the first furniture component **12** and the second furniture component **14** to be disassembled and separated without damaging the first furniture component **12**, the second furniture component **14**, or the mating edge **24**. Because the width W**1** of the channel **20** does not decrease as the height H**1** of the channel **20** increases, the mating edge **24** is free to be removed from the channel **20** without damage to the mating edge **24** or the components **12**, **14**.
[0051] In some embodiments, the first furniture component **12** is formed to include channel **20′**, as shown in FIG. **6**. The channel **20′** is formed to include a base wall **30′**, a first sidewall **32′**, and a second sidewall **34′**. Each wall **30′**, **32′**, **34′** may be substantially flat or straight. The first sidewall **32′** extends upwardly from the base wall **30′** to the first surface **16** of the first furniture component **12**. The second sidewall **34′** extends upwardly from the base wall **30′** to the first surface **16** of the first furniture component **12**. As shown in FIG. **6**, a width W**2** of the channel **20′** between the first sidewall **32′** and the second sidewall **34′** increases as the first sidewall **32′** and the second sidewall **34′** extend upwardly from the base wall **30′** to the first surface **16** of the first furniture component **12**. In other words, the width W**2** may be defined as a function of a height H**2** of the channel **20′** (with the height H**2** equal to zero at the base wall **30′**) where the width W**2** does not decrease as the height H**2** of the channel **20′** increases. Instead, the width W**2** increases as the height H**2** of the channel **20′** increases.
[0052] A third angle A**3** is formed between the first sidewall **32′** and the base wall **30′**, as shown in FIG. **6**. A fourth angle A**4** is formed between the second sidewall **34′** and the base wall **30′**. In some embodiments, the third angle A**3** and the fourth angle A**4** are both greater than 90 degrees. In some embodiments, one of the third angle A**3** and the fourth angle A**4** is equal to 90 degrees and the other of the third angle A**3** and the fourth angle A**4** is greater than 90 degrees. The shape of the channel **20′** allows the second furniture component **14** to be removably coupled with the first furniture component **12**. In other words, the connection between the first furniture component **12** and the second furniture component **14** via the mating edge **24** is a temporary connection due to the free geometry of the channel **20′**. The shape of the channel **20′** allows the first furniture component **12** and the second furniture component **14** to be disassembled and separated without damaging the first furniture component **12**, the second furniture component **14**, or the mating edge **24**.
[0053] With the channels **20**, **20′**, the first furniture component **12** and the second furniture component **14** may be separated from one another and reused or recycled. For example, the second furniture component **14** shown in FIG. **3**A may be removed from the first furniture component **12**, and a different first furniture component may be coupled with the second furniture component **14** (or vice versa), thereby allowing interchangeability of components **12**, **14**.
[0054] As one example, the components **12**, **14** may be separated to change the first furniture component **12** between a fixturing surface for computer numerical control (CNC) operation and a printing surface. As another example, the components **12**, **14** may be separated to change the first furniture component **12** to a different first furniture component having a different aesthetic (i.e., to change the look of the first furniture component **12**). Additionally, for shipping purposes, the second furniture component **14** and the first furniture component **12** may be separated from one another for shipping, and the components **12**, **14** may be assembled once the destination is reached. As another example, the second furniture component **14** and the first furniture component **12** may be used to create a removeable panel. The force needed to separate the components **12**, **14** is a function of the coefficient of static friction between the materials of the first furniture component **12** and the materials of the mating edge **24** and the bonding that may be present. The force required to separate the components **12**, **14** from one another may be at least partially dependent on the height H**1**, H**2** of the channel **20**, **20′** and the angle A**1**, A**2**, A**3**, A**4** between the base wall **30**, **30′** and the sidewalls **32**, **34**, **32′**, **34′**.
[0055] In some embodiments, the first furniture component **12** is formed to include channel **20″**, as

shown in FIGS. **7**A and **7**B. The channel **20**″ has a semi-circular cross-sectional shape. A width W**3** of the channel **20**″ increases as the channel **20**″ extends upwardly from a base **30**″ of the channel **20**″ to the first surface **16** of the first furniture component **12**. In other words, the width W**3** may be defined as a function of a height H**3** of the channel **20**″ (with the height H**3** equal to zero at the base **30**″) where the width W**3** does not decrease as the height H**3** of the channel **20**″ increases. Instead, the width W**3** increases as the height H**3** increases. The shape of the channel **20**″ is formed with a free geometry. The channel **20**″ is illustratively formed as a linear channel **20**″. In other words, instead of forming a continuous shape (like the channel **20** of FIG. **2**A), the channel **20**″ forms a linear shape having ends that do not connect with one another.

[0056] At least one first layer of molten material is deposited into the channel **20**″ to form a hinge **24**″ of a second furniture component **14**″, as shown in FIGS. **7**A and **7**B. At least one second layer of molten material is deposited onto the at least one first layer of molten material (i.e., the hinge **24**″) while the at least one first layer of molten material is molten. Additional layers of molten material may be deposited onto the at least one second layer of molten material. The at least one second layer of molten material forms the body **26**″, and the outermost additional layer of molten material forms the outer edge **22**″ of the second furniture component **14**″.

[0057] Due to the shape of the channel **20**″, the hinge **24**″ is free for rotation within the channel **20**″ about an axis A such that the second furniture component **14**″ is movable relative to the first furniture component **12**, as shown in FIGS. **7**A and **7**B. For example, as shown in FIG. **7**A, the second furniture component **14**″ is in a first position relative to the first furniture component **12**. As shown in FIG. **7**B, the second furniture component **14**″ is pivotable relative to the first furniture component **12** about the axis A to assume a second position. To pivot the second furniture component **14**″, the hinge **24**″ rotates within the channel **20**″. Additional rotation of the second furniture component **14**″ will be blocked by the first furniture component **12** due to engagement of the body **26**″ of the second furniture component **14**″ with the first surface **16** of the first furniture component **12**.

[0058] As shown in FIG. **8**, in some embodiments, the first furniture component **12** is formed to include an alternative channel **320**. The channel **320** includes a base wall **330**, a first sidewall **332**, and a second sidewall **334**. Each wall **330**, **332**, **334** may be substantially flat or straight. The first sidewall **332** extends upwardly from the base wall **330** to the first surface **16** of the first furniture component **12**. The second sidewall **334** extends upwardly from the base wall **330** to the first surface **16** of the first furniture component **12**. As shown in FIG. **8**, a width W**4** of the channel **320** between the first sidewall **332** and the second sidewall **334** decreases as the first sidewall **332** and the second sidewall **334** extend upwardly from the base wall **330** to the first surface **16** of the first furniture component **12**. In other words, the width W**4** may be defined as a function of a height H**4** of the channel **320** (with the height H**4** equal to zero at the base wall **330**) where the width W**4** decreases as the height H**4** of the channel **320** increases.

[0059] A fifth angle A**5** is formed between the first sidewall **332** and the base wall **330**, as shown in FIG. **8**. A sixth angle A**6** is formed between the second sidewall **334** and the base wall **330**. In some embodiments, the fifth angle A**5** and the sixth angle A**6** are both less than 90 degrees.

[0060] The shape of the channel **320** captures the mating edge **24** of the second furniture component **14** in the channel **320**. In other words, the connection between the first furniture component **12** and the second furniture component **14** via the mating edge **24** is a permanent connection due to the captive geometry of the channel **320**. The shape of the channel **320** allows the first furniture component **12** and the second furniture component **14** to be disassembled and/or separated only by damaging at least one of the first furniture component **12**, the second furniture component **14**, and the mating edge **24**.

[0061] In some embodiments, the first furniture component **12** is formed to include channel **320**′, as shown in FIG. **9**. The channel **320**′ is formed to include a base wall **330**′, a first sidewall **332**′, and a second sidewall **334**′. Both sidewalls **332**′, **234**′ may be curved, while the base wall **330**′ may

be substantially flat or straight. The first sidewall **332**′ extends upwardly from the base wall **330**′ to the first surface **16** of the first furniture component **12**. The second sidewall **334**′ extends upwardly from the base wall **330**′ to the first surface **16** of the first furniture component **12**. As shown in FIG. **9**, a width W**5** of the channel **320**′ between the first sidewall **332**′ and the second sidewall **334**′ decreases as the first sidewall **332**′ and the second sidewall **334**′ extend upwardly from the base wall **330**′ to the first surface **16** of the first furniture component **12**. In other words, the width W**5** may be defined as a function of a height H**5** of the channel **320**′ (with the height H**5** equal to zero at the base wall **330**′) where the width W**5** decreases as the height H**5** of the channel **320**′ increases. Each of the first sidewall **332**′ and the second sidewall **334**′ curve toward one another as the sidewalls **332**′, **334**′ extend upwardly away from the base wall **330**′. In this way, an angle between each of the sidewalls **332**′, **334**′ and the base wall **330**′ may be about 90 degrees.

[0062] The shape of the channel **320**′ captures the mating edge **24** of the second furniture component **14** in the channel **320**′. In other words, the connection between the first furniture component **12** and the second furniture component **14** via the mating edge **24** is a permanent connection due to the captive geometry of the channel **320**′.

[0063] In some embodiments, the first furniture component **12** is formed to include a channel **320**″, as shown in FIG. **10**. The channel **320**″ is formed to include a base wall **330**″, a first sidewall **332**″, and a second sidewall **334**″. Each of the walls **330**″, **332**″, **334**″ may be substantially flat or straight. The first sidewall **332**″ extends upwardly from the base wall **330**″ to the first surface **16** of the first furniture component **12**. The second sidewall **334**″ extends upwardly from the base wall **330**″ to the first surface **16** of the first furniture component **12**. As shown in FIG. **10**, a width W**6** of the channel **320**″ between the first sidewall **332**″ and the second sidewall **334**″ decreases as the first sidewall **332**″ and the second sidewall **334**″ extend upwardly from the base wall **330**″ to the first surface **16** of the first furniture component **12**. In other words, the width W**6** may be defined as a function of a height H**6** of the channel **320**″ (with the height H**6** equal to zero at the base wall **330**″) where the width W**6** decreases as the height H**6** of the channel **320**″ increases. The first sidewall **332**″ is perpendicular to the base wall **330**″. A seventh angle A**7** is formed between the first sidewall **332**″ and the base wall **330**″, as shown in FIG. **10**. The seventh angle A**7** may be about 90 degrees. An eighth angle A**8** is formed between the second sidewall **334**″ and the base wall **330**″. In some embodiments, the eighth angle A**8** is less than 90 degrees.

[0064] The shape of the channel **320**″ captures the mating edge **24** of the second furniture component **14** in the channel **320**″. In other words, the connection between the first furniture component **12** and the second furniture component **14** via the mating edge **24** is a permanent connection due to the captive geometry of the channel **320**″.

[0065] With the channels **320**, **320**′, **320**″, the first furniture component **12** and the second furniture component **14** may be permanently connected with one another. Though permanently connected, the first furniture component **12** and the second furniture component **14** may be disassembled and separated from one another by damaging at least one of the first furniture component **12**, the second furniture component **14**, and the mating edge **24**. After separation, the undamaged pieces may be reused, and the damaged pieces may be recycled. For example, if only the mating edge **24** is damaged, the first furniture component **12** and the second furniture component **14** may be reused after the creation of a new mating edge to replace the damaged mating edge **24**.

[0066] In some embodiments, the first furniture component **12** is formed to include a channel **320**′″, as shown in FIGS. **11**A and **11**B. The channel **320**′″ has a cross-sectional shape of more than half a circle. A width W**7** of the channel **320**′″ at the first surface **16** is smaller than a maximum width of the channel **320**′″. The maximum width may be defined at a mid-way point of the channel **320**′″ between a base **330**′″ of the channel **320**′″ and the first surface **16**. The shape of the channel **320**′″ is formed with a captive geometry. The channel **320**′″ is illustratively formed as a linear channel **320**′″. In other words, instead of forming a continuous shape (like the channel **20** of FIG. **2**A), the channel **320**′″ forms a linear shape having ends that do not connect with one another.

[0067] At least one first layer of molten material is deposited into the channel **320**‴ to form a hinge **324**‴ of a second furniture component **314**‴, as shown in FIGS. **11**A and **11**B. At least one second layer of molten material is deposited onto the at least one first layer of molten material (i.e., the hinge **324**‴) while the at least one first layer of molten material is molten. Additional layers of molten material may be deposited onto the at least one second layer of molten material. The at least one second layer of molten material forms the body **326**‴, and the outermost additional layer of molten material forms the outer edge **322**‴ of the second furniture component **314**‴.
[0068] Due to the shape of the channel **320**‴, the hinge **324**‴ is free for rotation within the channel **320**‴ such that the second furniture component **314**‴ is movable relative to the first furniture component **12**, as shown in FIGS. **11**A and **11**B. For example, as shown in FIG. **11**A, the second component **314**‴ is in a first position relative to the first component **12**. As shown in FIG. **11**B, the second furniture component **314**‴ pivots relative to the first furniture component **12** about an axis A to assume a second position. To pivot the second furniture component **314**‴, the hinge **324**‴ rotates within the channel **320**‴.
[0069] Any channel geometry that is not a free geometry is defined as a captive geometry. For example, the first sidewall **332**, **332**′, **332**″ and/or the second sidewall **334**, **334**′, **334**″ of the channel **320**, **320**′, **320**″ may be formed to include a saw tooth pattern. The failure strength for the permanent connection between the components **12**, **14** is the lowest material strength between the material of the first furniture component **12** and the material of the mating edge **24**, accounting for stress concentrations.
[0070] The creation of the permanent connection between the components **12**, **14** may be useful for combining the components **12**, **14** into a permanent multi-component structure **10** that does not have a need for separation. For example, the permanent connection may be used to couple a foot to a planter or may be used to combine multiple components into a permanent assembly. As another example, the permanent connection may be used to permanently attach a tabletop to a base. As another example, the permanent connection may be used to permanently attach two pieces of a wooden desk together. As another example, the permanent connection may be used to create designated failure points. As another example, the permanent connection may be used to create a hinge using a circular channel.
[0071] An alternative method **400** of forming a multi-component structure **410** is shown in FIG. **12**. In step **402**, a first furniture component **412** and a second furniture component **414** are provided. The first furniture component **412** and the second furniture component **414** are illustratively not 3D printed; however, the first furniture component **412** and the second furniture component **414** are coupled together via 3D printing. In step **404**, a channel **420** is formed in a first surface **416** of the first furniture component **412** and a first surface **417** of the second furniture component **414**. To form the channel **420**, material from the first surfaces **416**, **417** is removed. In some embodiments, the channels **420** are formed via milling. In step **406**, the channels **420** of each component **412**, **414** are aligned and a print path for the nozzle **28** is set.
[0072] In step **408**, at least one first layer of molten material is deposited into the channel **420** to form a mating edge **424** between the first furniture component **412** and the second furniture component **414**. In step **409**, the at least one first layer of molten material is cooled to cause the at least one first layer of molten material to solidify and fix the first furniture component **412** to the second furniture component **414**, as shown in FIGS. **13**A and **13**B, to form the multi-component structure **410**.
[0073] A printed mechanical connection is a connection between two or more components, where print material is used to join the two or more components permanently or temporarily. The printed mechanical connection is the dominant force with either friction and/or material fastening, where the load is transferred directly through contact with the other component or components. There may be some interlaminar adhesion, but it is not the primary mechanism for bonding. The printed mechanical connection, thus, is different from normal connections within a printed part where the

connection is primarily interlaminar adhesion (i.e., the molecular chains of the printed polymer connecting one layer to the next). As the printed mechanical connection does not rely on the movement of polymer chains across the components being connected, as in a normal print, it allows components of other materials to be joined together to the printed component without the use of adhesive or other fasteners and for the connection of two printed parts where the connection would not reach a temperature allowing for polymer chain movements to create a bond.

[0074] While the disclosure has been illustrated and described in detail in the foregoing drawings and description, the same is to be considered as exemplary and not restrictive in character, it being understood that only illustrative embodiments thereof have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected.

Claims

1. A method of three-dimensional (3D) printing multi-component furniture, the method comprising providing a first furniture component having a first surface and a second surface opposite the first surface, removing material from the first surface of the first furniture component to form a channel in the first surface of the first furniture component, depositing at least one first layer of molten material in the channel to form a mating edge of a second furniture component having a contour of the channel, depositing at least one second layer of molten material onto the at least one first layer of molten material while the at least one first layer of molten material is molten to form a body of the second furniture component on the mating edge of the second furniture component, and cooling the at least one first layer of molten material and the at least one second layer of molten material to cause the at least one first layer of molten material and the at least one second layer of molten material to solidify and form the second furniture component comprising the body and the mating edge having the contour that mates with the channel of the first furniture component.

2. The method of claim 1, wherein the channel of the first furniture component is formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall, and wherein a width of the channel between the first sidewall and the second sidewall remains constant or increases as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first furniture component.

3. The method of claim 2, wherein a first angle is formed between the first sidewall and the base wall, a second angle is formed between the second sidewall and the base wall, and the first angle and the second angle are each 90 degrees.

4. The method of claim 2, wherein a first angle is formed between the first sidewall and the base wall, a second angle is formed between the second sidewall and the base wall, and the first angle and the second angle are each greater than 90 degrees.

5. The method of claim 2, further comprising, after cooling, separating the second furniture component from the first furniture component.

6. The method of claim 1, wherein the channel of the first furniture component is formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall, and wherein a width of the channel between the first sidewall and the second sidewall decreases as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first furniture component.

7. The method of claim 6, wherein a first angle is formed between the first sidewall and the base wall, a second angle is formed between the second sidewall and the base wall, and the first angle and the second angle are each less than 90 degrees.

8. The method of claim 6, wherein a first angle is formed between the first sidewall and the base wall, a second angle is formed between the second sidewall and the base wall, the first angle is 90 degrees, and the second angle is less than 90 degrees.

9. The method of claim 1, wherein providing a first furniture component includes 3D printing the

first furniture component with at least one third layer of molten material.

10. The method of claim 1, wherein removing material from the first surface of the first furniture component includes milling the material from the first surface of the first furniture component to form the channel in the first surface of the first furniture component.

11. A method of three-dimensional (3D) printing multi-component structures, the method comprising providing a first component having a first surface and a second surface opposite the first surface, forming a channel in the first surface, depositing a first layer of material in the channel, depositing a second layer of material onto the first layer of material while the first layer of material is molten, and cooling the first layer of material and the second layer of material to cause the first layer of material and the second layer of material to form a second component having a contour of the channel.

12. The method of claim 11, wherein forming a channel in the first surface includes milling material from the first surface of the first component to form the channel in the first surface of the first component.

13. The method of claim 11, wherein the first layer of material forms a mating edge of the second component having the contour of the channel and the second layer of material forms a body of the second component.

14. The method of claim 13, wherein the mating edge of the second component mates with the channel to couple the first component to the second component.

15. The method of claim 14, wherein the first component is removably coupled with the second component.

16. The method of claim 15, wherein the channel of the first component is formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall, and wherein a width of the channel between the first sidewall and the second sidewall remains constant or increases as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component.

17. The method of claim 14, wherein the mating edge of the second component is captured in the channel of the first component.

18. The method of claim 17, wherein the channel of the first component is formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall, and wherein a width of the channel between the first sidewall and the second sidewall decreases as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component.

19. A three-dimensional (3D) printed multi-component structure, the multi-component structure comprising a first component having a first surface and a second surface opposite the first surface, the first component being formed to define a channel that extends into the first surface toward the second surface, and a second component having an outer edge, a mating edge configured to mate with the channel of the first component to couple the first component to the second component, and a body extending between the outer edge and the mating edge, the mating edge being formed to have a contour that matches a contour of the channel.

20. The multi-component structure of claim 19, wherein the channel of the first component is formed to include a base wall, a first sidewall extending upwardly from the base wall, and a second sidewall extending upwardly from the base wall, and wherein a width of the channel between the first sidewall and the second sidewall remains constant or increases as the first sidewall and the second sidewall extend upwardly from the base wall to the first surface of the first component.