Supplementary Video Legends

Supplementary Video 1

“Capillary container” and “drainage container”. The capillary and drainage containers are composed of connected frame units with different connection modes. When slowly lifting the connected frame units from water (1.7 mm/s), the single-rod connected frames (capillary container) can continuously capture water; however, the double-rod connected frames (drainage container) keep draining water. The frame units have a side length of 3 mm and a diameter of 400 μm. The vertical connecting rods between the frame units are 1 mm in length and 800 μm in diameter, while the inclined connecting rods are 6.2 mm in length and 400 μm in diameter.

Supplementary Video 2

“Drainage container” with different double-rod connection methods. As shown in the video, different double-rod connection methods don’t change the drainage behavior of the drainage containers.

Supplementary Video 3

Capillary and drainage container arrays. The 3D liquid array is prepared using a capillary container array, while the drainage container array still drains the liquid. For the drainage container array, there are no connections under the last row of frames, which are capillary containers and can capture the liquid. This liquid trapping can be avoided by designing the last row of frame structures, such as adding double rod connections below the frames, increasing the frame size beyond the capillary scale, or printing only half of the frame structure.

Supplementary Video 4

The detailed drainage process of the drainage containers. When drainage containers are slowly lifted from water (0.3 mm/s), a liquid film forms between the double-rod connection, and water in the frame gradually shrinks inward and ruptures at a critical rising height, indicating that water in the frame is continuously drained into the bulk water below.

Supplementary Video 5

Numerical simulation of the rising uniform and non-uniform capillary tubes. During the rising of the uniform capillary tube, the height of capillary rise is almost constant. For the nonuniform tube, the height of capillary rise varies with the rising. Based on Jurin's law, the rising meniscus has a smaller radius of curvature at a narrower location in the tube, resulting in a larger Laplace pressure, which can support a larger liquid height. Therefore, the maximum liquid height occurs where the meniscus reaches the minimum radius of curvature (where the tube diameter is the smallest).

Supplementary Video 6

Numerical simulation of the rising capillary and drainage container. The containers are first immersed in water with a constant contact angle of 60°. Instead of moving the containers upwards as in the experiment, we let the water flow downwards instead (1.7 mm/s). For capillary containers, the water is always trapped in the frames due to the large capillary force. For drainage containers, the water is first trapped in the cubes, and then it is drained out due to continuous gravitational flow.

Supplementary Video 7

Drainage phenomenon of drainage containers with different geometries. The drainage processes of drainages containers with different geometries all can be divided into three stages (Supplementary Discussion 3). Drainage stages I and II can drain most of the liquid in the frame, but their drainage proportions vary in frames with different geometries. Stage I occupies a larger drainage proportion in cubic and pentahedral frames, while stage II contributes more to icosahedral, dodecahedral, and truncated icosahedral frames. In the video, the second pentahedral frame is a capillary container because of the single-rod connection underneath it.

Supplementary Video 8

Converting drainage containers into capillary containers by piercing the liquid film. The liquid film between the double-rod connections is the key to inducing the drainage of the drainage containers. The video suggests that once the liquid film is punctured with a cotton swab, the frame stops draining and traps the remaining liquid. That is, breaking the liquid film can switch the drainage containers into capillary containers.

Supplementary Video 9

Converting drainage containers into capillary containers by reducing the lifting speed. By reducing the lifting speed from 1.7 mm/s to 0.1 mm/s, the liquid film between the double-rod connections would rupture within tens of seconds due to evaporation. Before the liquid film ruptures, the drainage is not completed, and the remaining liquid can be trapped in the frame, so the drainage container becomes a capillary container.

Supplementary Video 10

Release liquids by the droplet-to-droplet contact. The droplet-to-droplet contact of dispersed liquids in the frames can form continuous liquids with continuous hydrostatic pressure, consequently, the liquid will be drained by gravity. The video shows that more than 90% of the liquid can be drained within 3 s, indicating high drainage efficiency.

Supplementary Video 11

Release liquids with liquid films. The soap film plays the same role as the liquid film between the double rod connections. Therefore, the soap film can convert the capillary containers into drainage containers, which can release more than 90% of the liquid within 6s.

Supplementary Video 12

Release liquids at different liquid film heights. The condition for complete liquid drainage of the capillary container is $L_1 > h_{max}$, where L_1 is the distance from the contact point to the bottom of the film. If L_1 is less than h_{max}, only part of the liquid in the capillary container can be drained, as shown in the first part of the video. If L_1 is larger than h_{max}, the liquid can be drained completely, as shown in the second part of the video.

Supplementary Video 13

Release liquids at designated locations with pre-designed liquid films. Using pre-designed soap films can selectively release the liquids in the capillary container, the liquids in the soap film contact areas are released, and the liquids in the non-soap film contact areas are retained.

Supplementary Video 14

Release 3D liquid array with the soap film array. All liquids in the 3D capillary container array can be completely released with the soap film array. Therefore, by combining capillary container arrays and soap film arrays, large-scale liquid capture and release can be achieved.

Supplementary Video 15

The basic principle of 3D programmable liquid patterning. By designing the connection modes between the frame units, the 3D spatial arrangement of capillary and drainage containers can be programmed to acquire the desired liquid patterns. As shown in the video, the frames are all connected with single rods, which can continuously capture liquid; alternately connected with double rods and single rods, which can capture liquid intermittently; all use double rod connections, which do not capture liquid.

Supplementary Video 16

Patterning of 2D letter patterns of "U", "W", and "O". Based on the digital codes of the target pattern, we can deduce the spatial arrangement of single-rod and double-rod connections between the frame units, and the expected liquid pattern can be obtained after printing the pre-designed model. This video presents 2D letter patterns of "U", "W", and "O" successfully created using pre-programmed capillary and drainage containers.

Supplementary Video 17

Patterning of the hourglass-like 3D liquid pattern. By disassembling 3D patterns into layer-by-layer 2D patterns, we can obtain the digital codes of target 3D patterns. This video exhibits the creation process of the hourglass-like 3D liquid pattern using pre-programmed capillary and drainage containers.

Supplementary Video 18

Patterning of other pre-designed 3D liquid patterns. Using the same programmable 3D liquid patterning method, this video exhibits the preparation process of other pre-designed 3D liquid patterns using pre-programmed capillary and drainage containers.

Supplementary Video 19

Demonstration of 3D programmable binary liquid patterning. The video shows the detailed process of 3D binary liquid patterning. Capillary containers first capture red-dyed gellan gum solution. After the gellan gum is cooled and fully gelled, these solidified liquid interfaces break the liquid continuity and block the drainage process of the adjacent drainage containers, converting the drainage containers into capillary containers that can capture blue-dyed water or green-dyed gellan gum solution, finally forming the 3D binary liquid pattern with alternating red and blue pixels and 3D binary liquid pattern with alternating red and green layers.