

3D PRINTING METHOD FOR PRODUCING AN ARTICLE MADE OF CONCRETE OR MORTAR AND HAVING A THROUGH-OPENING

The invention relates to a method for producing an article made of concrete or mortar by means of 3D printing and an article thus produced.

The 3D printing of articles made of concrete or mortar is known per se. In this process, a concrete or mortar composition corresponding to the shape of the article to be produced is deposited in the form of tracks in layers on top of one another. From the raw article produced with the desired shape, the article is created by hardening the concrete or mortar composition. Merely by way of example, reference is made to EP1587995A2, US2015072068A1, EP3260258A1, and EP3284879A1.

Using 3D printing, articles made of concrete or mortar can be produced with high design flexibility. However, the 3D printing process reaches its limits when articles with through-openings are to be produced, as is the case, for example, with concrete walls with window or door openings or through-openings for cable ducts, drain pipes, water lines, or the like. No tracks of the concrete or mortar composition can be deposited above such a through-opening because they require stabilization in the not yet hardened state. Stabilization is provided by the underlying tracks, which are absent in the case of the through-opening. In 3D printing of plastic articles, it is common in such cases to print a pillar or meshlike support structure, which is, however, not possible with the 3D printing of articles made of concrete or mortar since such comparatively delicate structures cannot be produced.

Consequently, there is a need for improved methods for 3D printing of articles made of concrete or mortar that enable the production of an article with a through-opening. The object of the present invention is to provide such a method.

According to the invention, the object of the invention is accomplished by a method in accordance with the independent claim 1. Preferred embodiments emerge from the dependent claims.

In 3D printing of articles made of concrete or mortar, tracks of a concrete or mortar composition are deposited in layers on top of one another. The invention is based on adding a support structure to create a through-opening during the 3D printing that is suitable for

supporting the portions of the article situated above the support structure during the hardening of the concrete or mortar composition. The support structure can be a temporary support structure that is removed when the concrete or mortar composition has hardened enough that the region above the through-opening no longer needs mechanical support. However, the support structure can also be intended to remain in the article and to have a through-opening itself, which then forms the through-opening of the article. For example, elements such as cable ducts, conduits, or window inserts can be integrated into the article during the 3D printing. The method can be used very flexibly in response to the requirements of the specific application. These are major advantages of the present invention.

In a first step of the method according to the invention for producing an article made of concrete or mortar by means of 3D printing, a lower portion of the article is printed. For this purpose, at least one track of a concrete or mortar composition is applied; preferably, multiple tracks are applied in layers on top of one another, thereby producing said lower portion. In the context of the invention, this lower portion of the article is referred to as the "base portion".

The upward-facing surface of the base portion (i.e., the uppermost track of the base portion) can be divided conceptually into a through-opening region and a wall region. The through-opening region is that region, above which a through-opening through the article is provided. The wall region is that region, above which concrete or mortar composition adjacent the through-opening is to be applied. In a second step, a support structure is arranged on the through-opening region. The support structure covers the entire through-opening region. The through-opening region and the support structure extend from one side face of the article (i.e., of the base portion as part of the article produced up to that point) to another side face, preferably all the way to the opposite side face of the article, thus producing a continuous through-opening through the article. The support structure can also be referred to as a support member.

The wall region is adjacent the through-opening region on one side when the through-opening is directly adjacent a side face of the article. Otherwise, the wall region is divided into two sub-regions separated from each other by the through-opening region, and the wall region is adjacent the through-opening region on both sides. In a third step, at least one further track of the concrete or mortar composition is applied to the wall region; preferably, multiple further tracks of the concrete or mortar composition are applied in layers on top of one another, producing a wall portion adjacent the support structure on one side or producing

two wall portions of the article adjacent the support structure on both sides. In the context of the invention, the wall portions are those portions of the article that are arranged laterally adjacent the through-opening and delimit it laterally. The height of the wall portion or the wall portions substantially corresponds to the height of the support structure such that the support structure and the wall portion(s) are substantially flush at the top.

Subsequently, in a fourth step, at least one further track of the concrete or mortar composition is applied on the wall portion or the wall portions on the one hand and the support structure on the other; preferably, multiple further tracks of the concrete or mortar composition are applied in layers on top of one another. This produces a portion of the article situated above the wall portions and the through-opening, referred to in the context of the invention as the “cover portion”.

The concrete or mortar composition is typically applied by means of a printing head that includes a nozzle. The concrete or mortar composition is fed to this nozzle via a supply line using a pump.

The concrete or mortar composition includes at least one aggregate, a binder, and mixing water. The aggregate can be of natural or synthetic origin. Cement or lime is preferably used as the binder. Optionally, the concrete or mortar composition can contain concrete additives and/or concrete admixtures. The concrete or mortar composition is flowable and can thus be deposited by the printing head. After deposition, the concrete or mortar composition begins to harden, losing its flowability as a result of chemical processes (in particular the incorporation of the mixing water as crystallization water: hydration) and evaporation of mixing water. The cement paste is transformed into cement stone. In particular, the hardening first includes stiffening; subsequently, initial solidification, and again, subsequently, final setting of the concrete or mortar composition. Stiffening is the first phase of hydration, wherein the concrete or mortar composition can still be processed. During the subsequent initial solidification (setting) phase, a significant increase in viscosity occurs. During the final phase of setting, hydration is completed.

Complete hardening can take several months. It is not necessary to wait for completion of the entire hardening phase before the support structure can be removed, if such a removal is intended. In the context of the invention, setting therefore includes in particular the phases of stiffening and initial solidification such that the raw article has lost its flowability and has

sufficient stability that undesirable plastic deformation of the concrete or mortar composition no longer occurs, for example, under the influence of gravity.

Concrete additives are pulverized or liquid additives that affect certain properties of the concrete or mortar composition. Concrete additives used can be mineral fines (for example, rock flour, fly ash, tuff, trass, and/or silica dust), organic materials (for example, synthetic resin dispersions, in particular to improve workability and adhesion), color pigments, and/or fibers (in particular steel, glass, or plastic fibers). Concrete admixtures are agents dissolved or suspended in water that are admixed with the concrete or mortar composition to change its properties, for example, workability, solidification behavior, setting, or durability, by physical and/or chemical actions. Concrete admixtures used can be, for example, concrete plasticizers, flow improvers, stabilizers, air pore forming agents, solidification accelerators, setting accelerators, solidification retarders, setting retarders, and/or sealants. Concrete admixture content is preferably less than 4 wt.-% of the concrete or mortar composition, particularly preferably at most 4 wt.-%, for example, from 0.2 wt.-% to 2 wt.-%.

The nozzle can be implemented as a simple tube with a constant cross-section in the flow direction of the concrete or mortar composition, or can also have a tapering or widening cross-section. The discharge opening of the nozzle can have any shape in order to achieve a suitable discharge cross-section in the specific application. The shape of the nozzle, in particular its discharge opening, is preferably adapted to the width and thickness of the track of concrete or mortar composition to be produced. The concrete or mortar composition is fed to the nozzle via a supply line, that comprises, in particular, pipes and/or hose lines.

During deposition of a track of the concrete or mortar composition, the printing head is moved in a direction referred to in the context of the invention as "direction of movement of the printing head" or "deposition direction". A track is a contiguous layer of the concrete or mortar composition, which is produced by movement of the printing head along the direction of movement. The track can be straight or can also have any other shape desired. The track can also form a closed shape by bringing its end back to the beginning. In the context of the invention, the dimension of a track in the deposition direction is referred to as the length of the track. The dimension perpendicular thereto in the plane of the track is referred to as the width of the track. After a track has been produced, the next track is deposited as a layer above this track. In the context of the invention, the direction in which the tracks are deposited in layers on top of the one another is referred to as the "direction of growth". The article is

thus built up in layers “from bottom to top” in the direction of growth by 3D printing. In the context of the invention, the dimension of a track in the direction of growth (perpendicular to the length and width) is referred to as the thickness of the track. The total accumulated thickness of the tracks yields the height of the article.

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The width and thickness of the tracks can, in particular, be adjusted by the design of the nozzle, the consistency of the concrete or mortar composition, and the delivery rate of the concrete or mortar composition. The thickness and the width of all tracks are preferably the same and constant. This is advantageous in terms of fast and technically simple deposition because the tracks can then be produced by a uniform movement of the printing head without having to make interim adjustments of delivery speed or nozzle shape. The length of all tracks of the base portion and of the cover portion can be constant such that all tracks are arranged flush at their beginning and at their end. The same is true for the sum of the length of the tracks of the same plane of the wall portion or wall portions and the length of the support structure. Thus, an article with a consistent dimension is produced. However, it is also easily possible for a track to have a shorter length than the underlying track such that the underlying track is not completely covered by the track. For example, an article can be produced that tapers overall or in sections from the bottom to the top. The length, width, and thickness of the tracks can be freely selected by the person skilled in the art according to the requirements of the application. The width is, for example, from 10 mm to 500 mm, in particular from 20 mm to 100 mm; the thickness, for example, from 5 mm to 100 mm, in particular from 10 mm to 50 mm, which is easily producible with typical nozzles. The maximum achievable height of the article is depends on the design of the robot and the print bed (print support). The maximum achievable height can, for example, be increased by mounting the print bed to move vertically and moving it downward during printing.

In an advantageous embodiment, the tracks are applied with an alternating deposition direction such that successive tracks are deposited with an opposite direction of movement of the printing head. The beginning of one track thus coincides with the end of the underlying track. This is advantageous in terms of time-saving buildup of the article, because the printing head does not have to be moved back from the end of the track to the beginning before the next track is deposited. During the transition from one track to the track above it, the discharge of the concrete or mortar composition from the nozzle can be interrupted such that the tracks are separated from one another. Alternatively, the discharge of the concrete or mortar composition can also be continued such that adjacent tracks are not separated from

one another, but are, instead, connected to one another by the concrete or mortar composition in the manner of an accordion fold. In principle, it is, of course, also possible to apply the tracks with the same deposition direction. The statements apply for tracks that do not form closed shapes and whose beginning and end are, consequently, spaced apart from one another. If the tracks form a closed shape, all tracks are preferably applied with the same deposition direction.

The tracks of the concrete or mortar composition are preferably deposited by means of a robot, in particular an industrial robot that moves the printing head. The 3D printing is advantageously automated using CAD processing, wherein the CAD data of the article are provided to a processing machine and the processing machine deposits the tracks to produce the article using the CAD data. The printing head is particularly preferably mounted on a robot arm. However, industrial robots, which have fewer degrees of freedom of movement than a robot arm, can also be used. The movement of the printing head is preferably computer-aided using the CAD data (computer-aided design). The tracks can thus be deposited with high precision and speed and low labor intensity to produce the article.

In the context of the invention, terms such as “bottom” and “top”, “above” and “below”, “upper surface”, “lateral”, and the like refer to the growth direction of the article, with a track that was deposited later than another track situated above that other track.

The article (and likewise each track and each portion of the article) has an upward-facing upper surface and a downward-facing lower surface and four side faces. The four side faces are two end faces and two transverse side faces extending therebetween. The end faces extend along the width dimension and are formed by the beginning and the end of the tracks. The transverse side faces extend along the length dimension and are formed by the lateral boundaries of the tracks. Typically, the transverse side faces are the longer side faces and the end faces are the shorter side faces of the article. If the tracks form a closed shape, the end faces are omitted since the end of the tracks is brought back to the beginning and connected to it. Since the tracks typically have production-related rounded side edges, the side faces do not have flat surfaces but, instead, have bulges with indentations between them.

According to the invention, the through-opening region and the support structure arranged thereon extends from a first side face of the article all the way to a second side face so as to

produce a continuous through-opening through the article. In an advantageous embodiment, the through-opening region and the support structure arranged thereon extend from one side face all the way to the opposite side face such that a straight through-opening is created, as will be required in most applications. These two opposing side faces can be the end faces of the article such that the through-opening region and the support structure extend longitudinally relative to the direction of extension of the tracks, i.e., in the long dimension of the tracks. The through-opening region and the support structure are then arranged on the base portion over its entire length. However, the two opposing side faces can also be the transverse side faces of the article such that the through-opening region and the support structure extend transversely, in particular perpendicular to the direction of extension of the tracks, i.e., in the width dimension of the tracks. The through-opening region and the support structure are then arranged on the base portion over its entire width. The direction of extension of the tracks corresponds to the direction of movement of the printing head. In principle, the two said side faces can, however, also be adjacent side faces such that the through-opening runs at an angle, as it were, and the through-opening region and the support structure extend partially longitudinally and partially transversely relative to the direction of extension of the tracks.

According to the invention, tracks of the concrete or mortar composition are arranged in layers on top of one another on the wall region and thus create the wall portion or the wall portions. In a possible embodiment, the further tracks of the concrete or mortar composition are applied to the wall region and the support structure. The concrete or mortar composition is then deposited through the nozzle in the same way as in the base portion and in the cover portion and each track covers the wall region and the support structure. An interim interruption of the supply of concrete or mortar composition is not necessary. Subsequently, the concrete or mortar composition applied on the support structure is removed again such that only the concrete or mortar composition remains on the wall region. The removal of the concrete or mortar composition be done track-by-track such that the concrete or mortar composition of one track is removed before the next track is applied. However, it is also possible to first deposit several or all of the tracks and then remove them together. The removal of the (still flowable) concrete or mortar composition can, for example, be done by blowing, scraping, wiping, or rinsing. It is also conceivable to provide the support structure with an inclined upper surface such that the concrete or mortar composition deposited thereon slides down.

However, it is also possible to apply the concrete or mortar composition exclusively on the wall region such that the support structure is not impinged on by the concrete or mortar composition. In the case of a through-opening between the transverse side faces (i.e., transverse to the direction of extension of the tracks) that is directly adjacent an end face of the article, the 3D printing can simply be continued, with the length of the tracks merely having to be shortened in accordance with the length of the wall region adjoining the through-opening region on one side. In the case of a through-opening between the transverse side faces that is not directly adjacent an end face of the article such that the wall region adjoins the through-opening region on both sides, the following embodiments are conceivable, for example:

- The movement of the printing head is continued over the entire length of the article, interrupting the supplying of concrete or mortar composition in the region of the support structure such that no concrete or mortar composition is deposited thereon. If the support structure obstructs the movement of the printing head along the track, the printing head (with interrupted supplying of concrete or mortar composition) can be lifted over the support structure or guided laterally past the support structure.
- The two wall portions are printed separately from one another. The printing head continues to be moved regularly, in particular with an alternating deposition direction, with the length of the tracks shortened in accordance with the length of the respective wall portion. The two wall portions can be printed successively with the same printing head, with the supplying of concrete or mortar composition preferably being interrupted when the printing head is moved from one wall section to the other. Alternatively, it is also possible to print the two wall portions simultaneously with two printing heads.

In the case of a through-opening between the end faces (i.e., lengthwise along the direction of extension of the tracks), the following embodiment is possible, for example: The wall portion or the wall portions are printed with a nozzle that has a reduced width compared to the nozzle for the base portion and the cover portion such that tracks with the width of the (respective) wall portion are produced.

The shape of the support member depends on the requirements in the individual case, in particular on the purpose of the through-opening produced. The support member can, for example, have a rectangular, triangular, circular, or oval cross-section (perpendicular to the direction of extension through-opening to be produced). In an advantageous embodiment, the support member has a planar base surface, which is arranged on the base region facing

the base region, and a width that remains constant or decreases as it progresses from the bottom to the top. Thus, particularly stable wall portions can be produced because there are no “shadow” regions for the 3D printing. In a particularly advantageous embodiment, the support structure has a rectangular cross-section. Support members with a rectangular cross-section are required for most applications and can be integrated particularly well into the article with approx. cuboid tracks.

In one embodiment of the invention, a support structure that is only temporary is provided, which is removed again after the printing of the cover section and complete or partial hardening of the concrete or mortar composition. The support structure is, so to speak, a placeholder for the desired through-opening created by removal of the support structure. This embodiment is particularly suitable for producing through-openings transverse to the direction of extension of the tracks, because then the support structures can be removed more easily due to their smaller extension. However, it can also be used for producing through-openings along the direction of extension of the tracks. The flowability of the concrete or mortar composition must have decreased before the removal of the support structure and its dimensional stability increased such that the through-opening remains without the region of the cover section arranged directly above it sagging into the through-opening under the influence of gravity. This region is sufficiently stabilized by the hardening of the concrete or mortar composition such that it no longer requires support from the support structure, which can then be removed. It is not necessary for the phase of the initial solidification and (or even the final setting) to be fully completed. Likewise, it suffices for the base portion, the wall portion, and a portion of the cover section situated directly thereabove to be sufficiently stabilized. However, since the 3D printing of the article can extend over several hours depending on its size, it is thus possible to remove the support structure already before the uppermost tracks of the cover section have hardened (i.e., while they are still flowable).

The temporary support structure can be designed in various ways. In one embodiment, the support structure is provided as a prefabricated component and placed on the through-opening region of the base portion. The support structure is preferably made of wood, metal (in particular foamed metals or metal alloys), ceramics or plastics (in particular foamed plastics, such as, expanded polystyrene (“styrofoam”)). The particular advantage of foamed metals and foamed plastic resides in their low weight, as a result of which the base region is stressed only a little. The support structure can be solid or frame-like. In the case of a frame-

like support structure, a through-opening extends through the support structure parallel to the track planes. After the hardening of the concrete or mortar composition, the support structure can simply be pushed out or first dismantled, for example, sawed or cut up, and then removed piece by piece. Removal of the support structure by machining processes such as milling, drilling, planing, or chiseling is also conceivable.

In a further embodiment, the support structure is inflatable. It is then easy to store and can, for example, be inflated with compressed air in order to be used as a support structure. In an advantageous embodiment, the support structure is inflated during the 3D printing of the wall portions, and in particular such that it is, in each case, essentially flush at the top with the latest printed track; the height of the support structure thus always corresponds to the current height of the wall section under construction. The overlying track can then be printed as a level track and the concrete or mortar composition situated on the support structure can subsequently be removed or slide down as a result of the further inflation of the support structure.

In a further embodiment, the temporary support structure is produced by means of 3D printing onto the through-opening region of the base portion. The production of the support structure can be completed before the printing of the at least one wall portion is begun. However, it is also possible to print the support structure and the at least one wall portion simultaneously. It is particularly advantageous for the regular movement of the printing head not to be interrupted or slowed down during the transition from the base portion into the wall portion, but, rather, for the regular movement of the printing head to remain constant during the entire production of the article, with the printing of the support structure beginning when the through-opening region of the uppermost track of the base portion has been produced. The 3D-printed support structure can, for example, be made of plastic. Particularly preferably, the support structure is printed from construction foam because this forms only a slight bond to the concrete or mortar composition and can be easily removed. The removal of the 3D-printed support structure can be carried out, for example, by chemical dissolution or by machining production processes, such as milling, drilling, planing, or chiseling.

It can be advantageous to arrange a separating layer between the concrete or mortar composition and the surface of the support structure facing it. The separating layer prevents the formation of a bond between the concrete or mortar composition and the support structure such that the support structure can be more easily removed. The separating layer

can, for example, be implemented as a plastic film, as a metal foil, as a paper or cardboard layer, or as a layer of a soap solution.

In an advantageous embodiment, the temporary support structure is equipped with at least one support leg. The at least one support leg is suitable and intended for stabilizing the support structure such that it can stand freely at the required height and position that it assumes on the through-opening region. The at least one support leg can advantageously prevent the base portion from being adversely affected by the pressure exerted by the support structure and the tracks of the concrete or mortar composition deposited thereabove as a result of gravity on the underlying base portion before it has hardened. The at least one support leg extends, starting from the support structure all the way to the ground or subsoil. It does not run through the base portion, but is arranged laterally thereto (runs laterally past the base region), in particular in front of one of the side faces between which the through-opening region with the support structure runs.

The support leg is in particular advantageous for support structures that are provided as prefabricated components since these typically have a comparatively high weight. The support structure can already be provided with the at least one support leg when it is arranged on the through-opening region. However, the support leg can also be attached later. However, even inflatable support members can be supported by separate support legs. Likewise, it is possible to provide a 3D printed support member with support legs. The support legs can either be attached later or provided in advance such that the subsequently printed support structure is connected to them.

In one embodiment, the support structure is equipped with exactly one support leg that runs past the base region on one side or with multiple support legs that run past the base region on one side (i.e., all support legs are arranged in front of the same side face of the base region). In order to ensure sufficient stability despite the laterally offset support structure, the at least one support leg should be equipped with a support foot that is sufficiently wide and heavy or is weighted with a separate weight (weighting). The weight of the support foot or the weighting attached thereon is selected such that the center of gravity of the entirety comprising the support leg and the support structure is situated within the support foot or the weighting or directly above it, not offset laterally therefrom. Sufficient stability is then ensured. If said center of gravity is arranged directly above the support foot, its orthogonal projection to the ground is within the base surface of the support foot. The advantage of this variant is

that the support structure together with support leg(s) can be removed simply after the hardening of the concrete or mortar composition without having to dismantle the at least one support leg. The at least one support leg can be formed in one piece with the support structure or can be connected to the support structure via a detachable connection, for example, a screw, clamp, or plug connection.

In a further embodiment, the support structure is equipped with at least two support legs that run past the base region on both sides. Thus, at least one support leg is arranged in front of each of the side faces between which the through-opening region with the support structure runs. It is sufficient if there is exactly one support leg on each side. These support legs should then be equipped with a support foot that is sufficiently wide and heavy or weighted with a separate weight such that the support structure can stand freely with the two support legs. In a preferred embodiment, the support structure is equipped with at least three support legs. The three support legs ensure sufficient stability without the need for special support feet. At least one support leg is arranged in front of one side face of the base region; and at least two, in front of the other side face. Particularly preferably, the support structure is equipped with at least four support legs, with at least two support legs arranged in front of one side face of the base region and at least two in front of the other side face. At least the support leg or the support legs in front of one of the two side faces of the base region should be attached to the support structure with a detachable connection, for example, a screw, clamp, or plug connection such that they can be easily dismantled after the hardening of the concrete or mortar composition in order to remove the support structure. Alternatively, it is also conceivable to attach the support legs pivotably on the support structure such that they can be flipped up for removal of the support structure.

In a further embodiment of the invention, a permanent support structure that remains permanently in the article is provided. In that case, the support structure has a through-opening that forms the through-opening of the article. The permanent support structure can be made, for example, of wood, metal, plastic, ceramic, or also of concrete or mortar. Preferably, the component for which the through-opening is intended is integrated directly into the article during the 3D printing as a permanent support structure. The permanent support structure can be, for example, a cable duct, a conduit, a door frame, or a window frame, in particular a window frame.

Even the permanent support structure can be equipped with one or more support legs that run past the base region on one side or on both sides. The statements above concerning the support leg or the support legs in connection with the temporary support structure apply here mutatis mutandis. The support leg or the support legs should, however, then be attached to the permanent support structure with a detachable connection, for example, a screw, clamp, or plug connection, such that they can be easily dismantled after the hardening of the concrete or mortar composition.

The support structure can be implemented in one piece or also in multiple pieces. In one embodiment of the invention, the support structure is designed in multiple pieces comprising multiple sections that are arranged one after another on the through-opening region. Each section is arranged on a region of the through-opening region such that the adjacent sections make direct contact with each other. This embodiment is particularly suitable for the case that the through-opening region runs along the direction of extension of the concrete or mortar tracks, in particular when prefabricated components are used as a temporary or permanent support structure. Since, typically in this case, comparatively large support structures are required, it can be easier to assemble them from multiple sections instead of using a one-piece support member. Preferably, the sections are, starting from one side edge of the article (or of the base portion), arranged directly adjacent one another in each case until the other side edge is reached. However, the embodiment can also be used for producing through-openings along the direction of extension of the tracks. The arrangement of the sections of the support structure is preferably automated, in particular by means of a (further) robot, that can grip and place the sections. The movement is preferably computer-assisted using CAD data (CNC, Computerised Numerical Control). Alternatively, however, manual placing of the sections is also possible.

In a particularly advantageous embodiment, the support structure is suitable for accelerating the curing of the surrounding concrete or mortar composition. This is, in particular, advantageous for temporary support structures because these can then be removed more quickly as the stability of the surrounding regions required for this is reached more quickly. As a prefabricated component, the support structure can, for example, be equipped with a heating device to heat the concrete or mortar composition and to accelerate the hardening as a result. A support structure as a prefabricated component or as a 3D-printed structure can also, for example, secrete chemicals that accelerate hardening. During hardening, a

permanent support structure can also, for example, be equipped with a heating device arranged in the through-opening.

5 The invention also includes an article made of concrete or mortar with a through-opening, produced by means of 3D printing in accordance with the method according to the invention.

10 The invention also includes the use of the article according to the invention made of concrete or mortar as a component of the masonry of a building. The through-opening is preferably a window or door opening or is a cable duct or a conduit (in the case of temporary support members) or is provided as a cable duct or conduit (in the case of permanent support members) cable duct or a conduit.

In the following, the invention is explained in detail with reference to drawings and exemplary embodiments. The drawings are a schematic representation and not to scale. The drawings in no way restrict the invention.

5 They depict:

Fig. 1 a side view of the 3D printing of an article made of concrete or mortar during various phases,

Fig. 2 a cross-section of an article made of concrete or mortar during various phases of its production in an embodiment of the method according to the invention,

10 Fig. 3 a cross-section through an embodiment of an article according to the invention,

Fig. 4 a cross-section through a further embodiment of an article according to the invention,

Fig. 5 three views of a base region with a support structure arranged thereon in accordance with an embodiment of the method according to the invention,

15 Fig. 6 three views of a base region with a support structure arranged thereon in accordance with a further embodiment of the method according to the invention,

Fig. 7 a cross-section of an article during various phases of its production in a further embodiment of the method according to the invention,

Fig. 8 a cross-section through a base region with a support structure arranged thereon in accordance with a further embodiment of the method according to the invention,
20 and

Fig. 9 a flow chart of an embodiment of the method according to the invention.

Fig. 10 two views of a base region with a support structure arranged thereon in accordance with a further embodiment of the method according to the invention,

25 Fig. 11 two views of a base region with a support structure arranged thereon in accordance with a further embodiment of the method according to the invention,

Fig. 1 depicts a side view of the 3D printing of an article made of concrete or mortar, the
30 already produced portions of which can be seen in cross-section. A concrete or mortar composition 1 in the form of tracks 2 is stacked in layers on top of one another. The concrete or mortar composition 1 is applied by means of a printing head 3 that is attached to a robot arm 7 and is moved with the associated robot. The printing head 3 contains a nozzle 4 that is designed, for example, as a steel tube with a suitably shaped discharge opening. A supply
35 line 6, via which the nozzle 4 is supplied with the concrete or mortar composition 1 by

means of a pump (not shown), is connected to the nozzle 4. The printing head 3 is moved, with computer assistance using CAD data, along the precalculated shape of the tracks 2, with concrete or mortar composition 1 emerging from the nozzle 4 and forming the tracks 2. The direction of movement R of the printing head 3 is indicated by a gray block arrow. The thickness of the tracks 2 is, for example, 2 cm.

Fig. 1a depicts the method during the deposition of the first (lowest) track 2. Another track 2 is subsequently deposited thereon (Fig. 1b). During the deposition of the second track 2, the direction of movement R of the printing head 3 is opposite that of the first track 2. The method is continued (Fig. 1c), with the tracks 2 being stacked on top of one another in the direction of growth A (likewise indicated by a gray block arrow) until the article has reached the desired height.

Fig. 2 depicts a cross-section of an article according to the invention at various times during its production in one embodiment of the method according to the invention. First, by means of 3D printing, as depicted in Fig. 1, a lower base portion S is produced (Fig. 2a). The upper surface of the uppermost track 2 of the base portion 2 can be conceptually divided into a through-opening region B and a wall region B' arranged on both sides thereof. Directly above the through-opening region B, the final article is to have a through-opening; and directly above the wall region B', two wall portions delimiting this through-opening are to be printed. For this purpose, a support structure 5 is arranged on the through-opening region B (Fig. 2b). Two wall portions W are subsequently printed adjacent the support structure 5 (Fig. 2c). Then, a complete track 2 is printed, covering the wall region B' and the support structure 5, and the region of this track 2 arranged on the support structure 5 is then removed such that the concrete or mortar composition 1 remains exclusively on the wall regions B'. The wall portions W are completed when they have reached the height of the support structure 5. After that, a cover portion D is printed above the wall portions W and the support structure 5 (Fig. 2d).

Fig. 3 depicts an article G according to the invention that was produced with the method of Fig. 2. In this case, the support structure 5 was intended to remain in the article G. The support structure has a continuous through-opening, which then forms the through-opening O through the article G. The support structure 5 can, for example, be a cable duct or a window frame that is integrated directly into the article G during the 3D printing.

Fig. 4 depicts a further article G according to the invention that was produced with the method of Fig. 2. In this case, the support structure 5 was provided only temporarily in order to stabilize the portions of the cover section D situated above. After the hardening of the concrete or mortar composition 1, the support structure 5 was removed. The support structure 5 can, for example, be made of wood or metal in a frame-like manner and can be pushed out of the article G after hardening, thus creating a through-opening O through the article G. A cable duct or a window frame, for example, can later be inserted into this through-opening O.

Fig. 5 depicts three views of a base region S with a support structure 5 arranged thereon in an embodiment of the method according to the invention. Fig. 5a depicts a side view looking at the transverse side face; Fig. 5b, a side view looking at the end face; and Fig. 5c, a plan view ("view from above"). The through-opening region B and the support structure 5 arranged thereon extend from one transverse side face to the opposite transverse side face. This produces a through-opening O along the width dimension of the tracks 2 or of the article G, as also depicted in Fig. 2.

Fig. 6 depicts three views of a base region S with a support structure 5 arranged thereon in a further embodiment of the method according to the invention. In this case, Fig. 6a depicts a side view looking at the transverse side face; Fig. 6b, a side view looking at the end face; and Fig. 6c, a plan view ("view from above"). The through-opening region B and the support structure 5 arranged thereon extend from one end face to the opposite end face. This produces a through-opening O along the longitudinal dimension of the tracks 2 or of the article G. The support structure 5 is formed from multiple sections 5'. The sections 5' were arranged one after another on the through-opening region B, with, starting from one end face, each section 5' is placed directly adjacent the preceding section 5' by means of a robot. The support structure 5 on the through-opening region B directly adjoins a transverse side face such that the wall region B' adjoins the through-opening region B on one side only. The through-opening O produced by means of the support structure 5 can be provided, for example, as or for a cable duct that is then accessible via the transverse side face to which the through-opening region B is adjacent. Thus, it is possible either to produce the through-opening O into which the cable duct is later inserted with a temporary support structure 5, or to integrate the cable duct as a permanent support structure 5 directly during the 3D printing.

Fig. 7 depicts cross-sections of an article according to the invention G during the printing of the wall portions W. The support structure 5 is inflatable and is inflated during the printing of the wall portions W by the introduction of compressed air. In each case, the support structure 5 ends flush at the top with the latest printed track 2 such that a substantially flat base is provided for the printing of the next track 2.

Fig. 8 depicts a cross-section of a base region S with a support structure 5 arranged thereon in a further embodiment of the method according to the invention. The support structure is formed from construction foam, which was produced on the through-opening region B by 3D printing after completion of the base region. After completion of the wall regions W and the cover region D and after the hardening of the concrete or mortar composition 1, the support structure 5 can easily be removed, for example, mechanically or chemically.

Fig. 9 depicts an exemplary embodiment of the method according to the invention by means of a flow chart.

Fig. 10 depicts two views of a base region S with a support structure 5 arranged thereon in a further embodiment of the method according to the invention. In this case, Fig. 5a depicts a side view looking at the transverse side face, and Fig. 5b, a side view looking at the end face. This is a further development of the embodiment of Fig. 5. The through-opening region B and the support structure 5 arranged thereon extend from one transverse side face to the opposite transverse side face.

The support structure 5 is equipped with a single support leg 8, which extends from the support structure 5 to the ground and runs laterally past the base region. The support structure 5 with the support leg 8 can stand freely such that the support structure is situated at the required height. The gravitational force of the support structure 5 and the tracks of the cover region D later deposited above it is absorbed by the support leg 8 such that no pressure is exerted on the base region S situated below it. This prevents the base region S from being deformed before the concrete or mortar composition 1 is hardened.

As a result of the support leg 8 being attached on one side, the support structure 5 can be easily removed after the hardening of the concrete or mortar composition 1. In order to nevertheless ensure sufficient stability, the support leg 8 is designed wide and provided with a support foot that is weighted down with an additional weight 9.

Fig. 11 depicts two views of a base region S with a support structure 5 arranged thereon in a further embodiment of the method according to the invention. In this case, Fig. 5a depicts a side view looking at the transverse side face and Fig. 5b, a side view looking at the end face. This is a further development of the embodiment of Fig. 5. The through-opening region B and the support structure 5 arranged thereon extend from one transverse side face to the opposite transverse side face.

The support structure 5 is equipped with four support legs 8, which extend from the support structure 5 to the ground. Two support legs 8 are arranged on each side of the base region S (in front of each of the two transverse side faces). The four support legs 8 ensure sufficient stability without requiring weighted support feet. At least the two support legs 8 on one of the two sides of the base region S are, for example, bolted to the support structure such that, they can easily be dismantled in order to remove the support structure 5 after the hardening of the concrete or mortar composition 1.

List of Reference Characters:

- (G) 3D printed article made of concrete or mortar
(S) base portion of the article G
5 (W) wall portion of the article G
(D) cover portion of the article G
(B) through-opening region of the base portion S
(B') wall region of the base portion S
(O) through-opening durch den article G
10
(1) concrete or mortar composition
(2) printed track of the concrete or mortar composition 1
(3) printing head
(4) nozzle
15 (5) support structure
(5') portion of a multipart support structure 5
(6) supply line
(7) robot arm
(8) support leg of the support structure 5
20 (9) weight for weighting down the support leg 8

(R) direction of movement of the printing head 3
(A) direction of growth of the article G'

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CLAIMS

1. Method for producing an article (G) made of concrete or mortar by means of 3D printing, wherein
 - (A) tracks (2) of a concrete or mortar composition (1) are deposited in layers on top of one another, thereby producing a base portion (S) of the article (G),
 - (B) a support structure (5) that extends from one side face of the article (G) to a further side face is arranged on a through-opening region (B) of the base portion (S),
 - (C) further tracks (2) of the concrete or mortar composition (1) are deposited, in layers on top of one another, onto a wall region (B') adjoining the through-opening region (B) on one side or on both sides, thereby producing a wall portion (W) of the article (G) adjoining the support structure (5) on one side or two wall portions (W) adjoining the support structure (5) on both sides, with the height of the wall portion(s) corresponding to the height of the support structure (5),
 - (D) further tracks (2) of the concrete or mortar composition (1) are deposited, in layers on top of one another, onto the wall portion (W) or the wall portions (W) and the support structure (5), thereby producing a cover portion (D) of the article (G).
2. Method according to claim 1, wherein the concrete or mortar composition (1) is deposited by means of a printing head (3) comprising a nozzle (4), to which the concrete or mortar composition (1) is supplied via a supply line (6) by means of a pump.
3. Method according to claim 2, wherein the printing head (3) is moved by an industrial robot, preferably by means of a robot arm (7).
4. Method according to one of claims 1 through 3, wherein the support structure (5) is equipped with at least one support leg (8) that extends from the support structure (5) to the ground and is arranged laterally relative to the base portion (S).
5. Method according to one of claims 1 through 4, wherein the support structure (5) is removed after step (D) and complete or partial hardening of the concrete or mortar composition (1), thereby creating a through-opening (O) through the article (G).
6. Method according to claim 5, wherein the support structure (5) is placed as a prefabricated component on the through-opening region (B) of the base portion (S) and

is preferably made of wood, metal, or plastic, particularly preferably of a foamed metal, a foamed metal alloy, or expanded polystyrene.

5 7. Method according to claim 5, wherein the support structure (5) is designed to be inflatable and is preferably inflated during step (C), in particular such that the height of the support structure (5) always corresponds to the current height of the wall portion (W).

10 8. Method according to claim 5, wherein the support structure (5) is produced by means of 3D printing onto the through-opening region (B) of the base portion (S) and is preferably made of construction foam.

15 9. Method according to one of claims 1 through 4, wherein the support structure (5) has a through-opening and remains in the article (G) such that the through-opening of the support structure (5) forms a through-opening (O) of the article (G).

10. Method according to claim 9, wherein the support structure (5) is a cable duct, a conduit, a door frame, or a window frame.

20 11. Method according to claim 6 or 9, wherein the support structure (5) is implemented in multiple parts from a plurality of sections (5') that are arranged one after another on the through-opening region (B), preferably by a robot.

25 12. Method according to one of claims 1 through 11, wherein the concrete or mortar composition (1) contains at least an aggregate, a binder, preferably cement or lime, and mixing water, as well as, optionally, concrete additives and concrete admixtures.

30 13. Method according to one of claims 1 through 12, wherein the support structure (5) is suitable for accelerating the hardening of the surrounding concrete or mortar composition (1), wherein the support structure (5) is preferably equipped with a heating device, in order to heat the concrete or mortar composition (1) and to thus accelerate the hardening or is suitable for secreting chemicals that accelerate the hardening.

35 14. Article (G) made of concrete or mortar with a through-opening (O), produced by means of 3D printing according to the method according to one of claims 1 through 13.

15. Use of an article (G) according to claim 14 as part of the masonry of a building, wherein the through-opening (O) is preferably a window opening or door opening or is provided for a cable duct or conduit.