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# DEPICTION OF SUPPORT STRUCTURES IN TECHNICAL DRAWINGS

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## Abstract

To ensure uniform documentation of support structure information, a concept is presented that enables a standardized depiction of support structures in technical drawings based on ISO 128-3. To this end, requirements for a uniform depiction are defined and a procedure for drawing entry is presented. The drawing entry should contain all production-relevant support structure information. The standardized documentation of support structure information in technical drawings is intended to ensure a simple, clear and safe exchange of information between business units or different companies along the value chain. As a result a possible drawing entry of support structures was developed. To distinguish between different support structure types, a standardized depiction of geometrical information in a specification field is shown. The specification field gives a detailed description of the support structure type, the geometry as well as the connection to the part and the building platform. Also uncommon support types like lattice structures or CAD based support structures can be implemented. To ensure the usability the depiction is editable and extendable.

## Introduction

Layer-by-layer and tool-free additive manufacturing processes allow the production of almost all conceivable component geometries. Nevertheless process-specific restrictions must be considered. For example, thermal residual stresses occur in components during metal powder-based laser beam melting, which can result in component distortion and dimensional deviations [1,2]. This can lead to an abort of the build job. In addition, the production of overhanging component areas is only possible with support structures. The support structures ensure better heat dissipation and provide a physical, stable anchorage between the building platform and the component overhang. However, this results in disadvantages, as the support structures lead to increased material consumption and require cost-intensive removal. In addition, the support structures can have a negative impact on the component surface roughness. Consequently, it is important to use application-adapted support structures for a successful and efficient manufacturing process [3]. It is important to design the support structures in a way that the component requirements, such as costs, surface quality and dimensional accuracy, are met and, at the same time, stability and heat dissipation are ensured during additive manufacturing. Not all requirements can be implemented at the same time. For example, particularly stable support structures lead to robust production, but can only be removed with increased effort. In order to design the support structures to suit the application, there are a large number of different support structures, each of which can be varied via geometric parameters. This manufacturing-relevant support structure information has not yet been recorded in a uniform and generally applicable manner. Although it is possible to determine the support structure information from the job preparation program for additive manufacturing, these data takes up a large storage volume and requires expensive software programs to read out the required support structure parameters. Especially, if the used support structure has an influence on the post-processing of the part [4, 5], it is difficult to transfer this information. This is where technical drawings (both in written and digital form) have become established in recent decades. In addition to the component shape and dimensions, materials, manufacturing processes and permissible deviations are also specified in technical drawings. Thus, they provide a complete, unambiguous, and easily understandable description of components, which are used in different divisions and companies for communication and information transfer [6,7]. An unambiguous and generally understandable depiction is provided by binding rules during drawing creation. These rules are listed in internationally valid standards [ISO 128-2, ISO 128-3].

## Objective and procedure

In order to ensure uniform documentation of support structure information, a concept is presented in Figure 1 which enables a standardized form of depiction of support structures in technical drawings based on ISO 128-3. For this purpose, laser beam melting and basic support structure information are explained in the state of the art. Requirements for a uniform support structure depiction are defined and a procedure for drawing entry is presented. The drawing entry should contain all production-relevant support structure information. Not only thin-walled support structures, as used in common support preparation programs, are to be considered, but also special support structure shapes and future support structures should be integrable. The standardized documentation of support structure information in technical drawings should ensure the exchange of information between business units or different companies along the value chain. Integration into software tools (CAD, PDM programs) has to be taken into account by generation of a low data volume. The training effort of the drawing-creating employees should be kept low by applying well known principles of technical depiction.

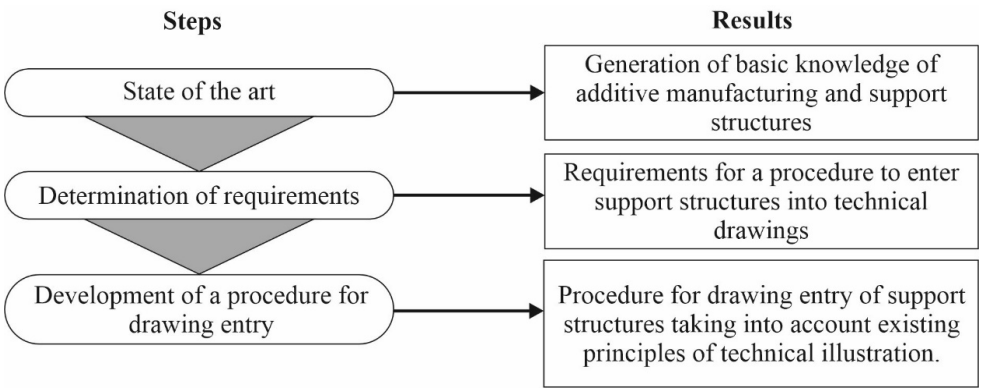



*Figure 1: Flow diagram of paper concept*

## State of the art: Procedure for additive manufacturing

For manufacturing by laser beam melting, a virtual 3D CAD model of the component has to be available. These 3D data can be generated using CAD software or by a 3D scan of an existing object. Likewise, numerical methods, such as topology optimization, enable the generation of a component structure that is suitable for the application loads [8,9,10,11]. During 3D data generation, design guidelines should already be taken into account for a manufacturing- or post-processing-oriented design of additively manufactured components in order to keep process-related, negative restrictions and the support structure or finishing effort low [4,9,10,12,13,14,15]. For further data preparation, the CAD model is converted into a data format that can be processed by the data processing software of the additive manufacturing system. In most cases, the STL format is used, which triangulates the CAD solid model and converts it into a surface model consisting of triangular facets. If necessary, surface defects caused by the conversion must be repaired in the STL file [14,16]. In addition to the STL format, there are other data formats, which, however, are hardly used in the field of laser beam melting. The AMF and 3MF formats should be mentioned here. These formats allow triangulation with curved triangles as well as the storage of additional component information, such as the color or the material [17,18]. The triangulated component model is then virtually oriented in the building chamber of the manufacturing machine. The orientation has a serious effect on the part quality [15,17]. Thus, with a suitable component orientation, the surface quality of the component or the support structure requirements can be optimized. After the part orientation, the support structures are usually generated. This is done with the data preparation software. For this purpose, overhanging areas are automatically supported with support structures. Often, support structures are applied to surfaces with an angle of 45° to the build platform. Recent investigations and optimized support parameters [1,18] show that smaller angles are also possible. Ultimately, the limit value for the angle to be supported depends on the material, the machine and the manufacturing parameters used. For example, to improve the detachability of the support structures or to minimize their material costs, various settings can be made to adapt the support structure geometry

to the part or process requirements. Additional solid support structures to improve heat dissipation and warpage can be added if they have not been added in the CAD program during component design. After the support structures have been generated, the part can be placed on the virtual building platform with other parts and the final data preparation step of slicing can be performed. During slicing, the virtually created build job is converted into individual layers in which the manufacturing parameters, such as the layer thickness, the component layer contour or the exposure strategy are specified [15,18]. After that, the data can be transferred to the manufacturing system and manufacturing can be initiated. In laser beam melting, a metal powder is applied layer by layer, melted and bonded to the previous layer. A laser scanner unit ensures that powder is melted only locally where the desired components have been placed in the virtual build space. The surrounding, unmelted powder can be reused after a sieving process. The process takes place under an inert gas atmosphere. After all layers have been generated, the components generated in this way can be freed from powder, detached from the build platform and transferred for further post-processing, such as support structure removal or surface treatment.

## State of the Art: Support structure design parameters

There are many different types of support structures. In the following, the widely used block support and the associated adjustment parameters are shown (Figure 2). It can be seen that there are already a large number of adjustable parameters for this type of support, which have an effect on the process stability, the component quality and the post-processing effort and thus also on the costs. Figure 2 lists only the most important support structure parameters. Depending on the software used, additional settings can be made. The parameters can either be defined globally for the entire build job or an individual support structure can be provided locally for specific component areas. This way, the tooth geometry, perforation or fragmentation can be set, and material consumption and removability can be simplified by a more filigree support structure with plenty of free space between the melted areas.

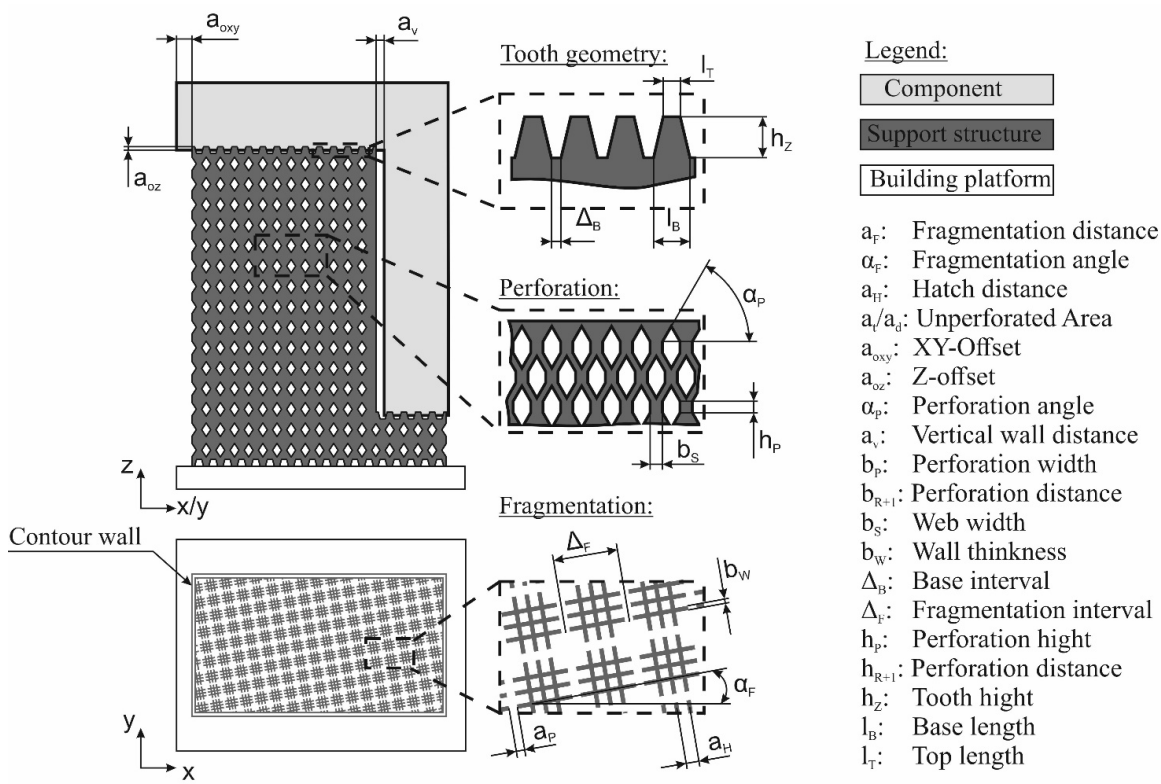



*Figure 2: Block support parameters [LLZ21a]*

In return, however, thermal conductivity can be impaired, possibly jeopardizing robust production. Here it is necessary to investigate the different support settings in a structured way and to quantify their advantages and disadvantages and make them comparable, which has only been done in some scientific studies [1,19]

## Requirements for support structure depiction

As can be seen from the previous section, there are many parameters which can be varied regarding the support structures, and which must be documented for an information transfer. In order to determine the requirements for a suitable support structure depiction, surveys were carried out in scientific and industrial environments. Primarily users of laser beam melting were interviewed, but also participants in the field of standardized, technical representation. During the survey, the following properties were defined as elementary. The support structure representation should be as intuitively understandable, simple, unambiguous, and generally applicable. It should be easy to integrate into the existing standardized drawings and must not contradict existing standards or encourage confusion with other drawing entries. At the same time, it should be possible to represent different types of support structures and to record the support structure parameters that have been set. The representation should be integrable into existing software tools for technical drawing and thus, if necessary, can be added subsequently to already existing technical drawings. Support structures often have a much more filigree and complex structure than solid components. This complex, often lattice-shaped structure requires an enormous data volume in the CAD model. Therefore, a simplified representation of the support structures is useful. This simplified representation is not intended to show the exact shapes and dimensions of the support structures, but to highlight those areas where support structures are found. An exact definition of the support structures can be done by symbols and indication of the parameters and dimensions in supplementary text fields. In this way, the memory and storage requirement can be reduced, and the relevant geometric data can be read directly.

## Depiction of support structures in technical drawings

Areas of different materials or special component areas are symbolized in technical drawings by different types of lines and area hatching [ISO 128-2, ISO 128-3]. This approach is also applicable to support structure areas. Thus, support structure areas in technical drawings can be delimited by different contour and filling of component areas.

## Depiction form of the contours

Simple, wide solid lines were selected for the boundary of the support structure areas. This type of line is also used to represent visible edges and outlines of components and enables a recognizable boundary of the support structure areas as well as clear dimensioning. Dotted lines or zigzag lines, on the other hand, are less clearly dimensionable and are used for the technical representation of other areas, so that there would be a risk of confusion. A combination of several line types should be avoided to enable simple and fast contouring. The contour color is black, which allows integration into existing technical drawings. A color accentuation in a CAD environment is also conceivable.

## Depiction form of the area filling

The filling of the support structure areas ensures differentiation from the actual component. For this purpose, a hatching is used which allows differentiation from existing hatchings in technical drawings [ISO 128-3] and at the same time symbolizes a simplified depiction of the support structures. After testing various fillings for support structure areas, a cross-hatching was identified as suitable. Although this has some similarity to the standardized hatching used to represent plastics, the use of a significantly larger 65° angle of the cross-hatching allows a clear distinction to be made. In addition, cross-hatching resembles a stylized, perforated support structure and thus increases the recognition value. The hatching lines are black with a clear white area between the lines to allow easy integration into existing drawings also by hand. An exemplary drawing entry is shown in Figure 3 a.

## Alternative simplified depiction

A simplified depiction can be used if support structure areas run directly from the building platform to the component surface. For this purpose, the entire support structure areas are not displayed. Only the supported surface is marked using a zigzag line delimited by dimension arrows. The angle of the zigzags is 65° (see Figure 3 b.

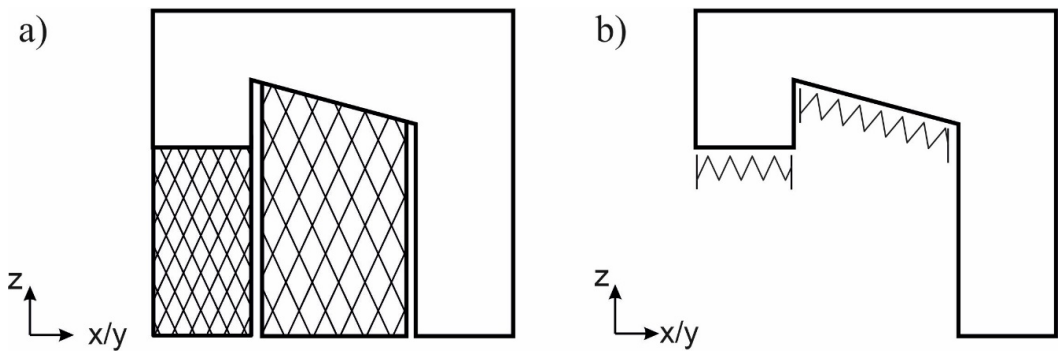



*Figure 3: a) Depiction form of the support area filling b) simplified depiction of the support area filling*

## Specification of support structure properties

To document the exact design form of the support structures and to specify the support structure parameters used, a representation scheme is presented below. Similar to the tolerance specification, a reference symbol is used to mark the corresponding area. The tangible support structure parameters are listed in a specification field. The reference symbol is a rhombus (see Figure 4 a)). The assignment of a support structure area bounded by its contour line is done by connecting the rhombus with a thin reference arrow. The arrow points perpendicularly to the edge of the area to be described, as is usual for other technical drawing entries. Alternatively, the hint arrow can end in the middle of the support structure area. For this purpose, a point should be provided at the end of the line instead of an arrowhead. The arrow is again connected to the rhombus symbol vertically at the left or right tip of the rhombus. (see Figure 4 b) and c))

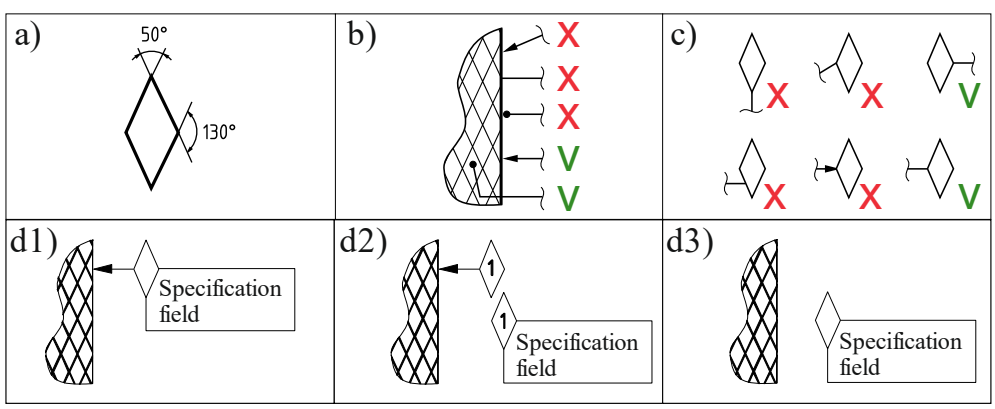
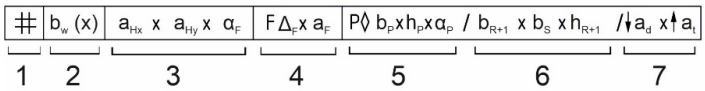



*Figure 4: a) Rhombus reference symbol b) Connection to support area c) Connection to Rhombus symbol d) Possible positioning of specification field (v allowed, x not allowed)*

The support structure parameters are specified in a rectangular specification field. This field can directly follow the rhombus symbol associated with the support structure (see Figure 4 d1). If there is not enough space, similar to the roughness specification, the rhombus symbol associated with the support structure can be given a number and the specification field can be placed in a free area of the drawing sheet, referencing the number (see Figure 4 d2). If all support structures have the same properties, it is sufficient to specify a single specification

field. This field does not need to be connected to a support structure area and can be specified above the title block. (see Figure 4 d3). The specification field is outlined with a narrow solid line. Depending on the support structure, it can be divided into several lines with additional information. Figure 5 shows as an example the specification field for a block support.




1: Support structure type according table 1
2: Dimension field 1
3: Dimension field 2 (optional, depends on support structure type)
4: Fragmentation (optional)
5: Perforation – hole geometry (optional)
6: Perforation – hole layout (optional)
7: Perforation – unperforated areas bottom and top (optional)

*Figure 5: Specification field for block support*

By using the symbols shown in Table 1, information on the support structure type or geometric features such as the tooth geometry can be symbolized. By adding dimensional information, support structure properties can be characterized. These dimensions must be given in millimeters. If several properties are dimensioned, the dimensions are usually separated by a small "x". If they form a group, as shown in Figure 5, areas 5, 6 and 7, the dimensions are separated by a slash. The first line of the specification field starts with a symbol according to Table 1 a) and b), which identifies the support structure type used. The further structure of the specification field depends on the support structure type.

## Wall-based support structures

The support structure symbol in the left column of Table 1 a) indicates that the support structure area does not have a contour wall or the contour wall has different attributes than the hatch area. If the contour wall has the same properties as the support structure in the hatch area, then the symbol version shown in the second column of Table 1 a) should be used. If the contour wall of a support structure area differs in its nature from the hatch walls. This can be indicated by an additional line in the specification field. For this purpose, an unfilled square is entered as a symbol for the specified contour geometry. The specification is done equivalent to the hatch walls. Also for the contour further fields for the thickness of the walls, the fragmentation, the perforation or the tooth geometry can be provided. An example of this is given in Figure 7. The symbol for the support structure type is followed by the specification of the support structure dimension. For wall based block support the relevant dimension is the wall thickness (see Figure 2, Table 1).

*Table 1: Symbols for support structure types*

| a) Wall-based support structures | | | |
|---|---|---|---|
| # | ▦ | Block | Used symbol depends on the existence of contour walls. Left column without contour. Right column with contour. |
| ✳ | ⬡ | Web | |
| ▣ | ▣ | Contour | |
| — | ⊟ | Line | |
| · | ⊡ | Point | |
| ◸ | | Angle | |

| b) Volume-based support structures | |
|---|---|
| ■ | Massive |
| \|\|\| | Pillar |
| △ | Cone |
| ⚲ | Tree |
| ⊠ | Lattice |
| CAD | Others, CAD based |

This is indicated by a preceding small "bw" followed by the dimension in mm. By using the symbols listed in Table 1 further support types can be documented and quantified by implementing dimension information. The sequence must be observed. To describe the tooth geometry of the wall-based support structures, the required

information is added in a new line within the specification field. This line is shown in Figure 6a. The double triangles point up and down symbolize the connection to the component and the connection to the building platform. The teeth thus have the same dimensions. If only one pair of triangles is shown, only the tooth geometry to the build plate (downwards) or to the component (upwards) is specified. If no explicit information on tooth geometry is given, the support structure walls extend unchanged to the component or building platform. The double triangle symbol is followed by the indication of the wall thickness of the teeth. This is indicated by a preceding "bw" and can differ from the main support attributes. The dimensions of the tooth geometry follows in the next section. The base length of the teeth lb, the top length of the teeth lt, the tooth height hz and the interval distance Δb between two teeth are displayed (see also Figure 2).

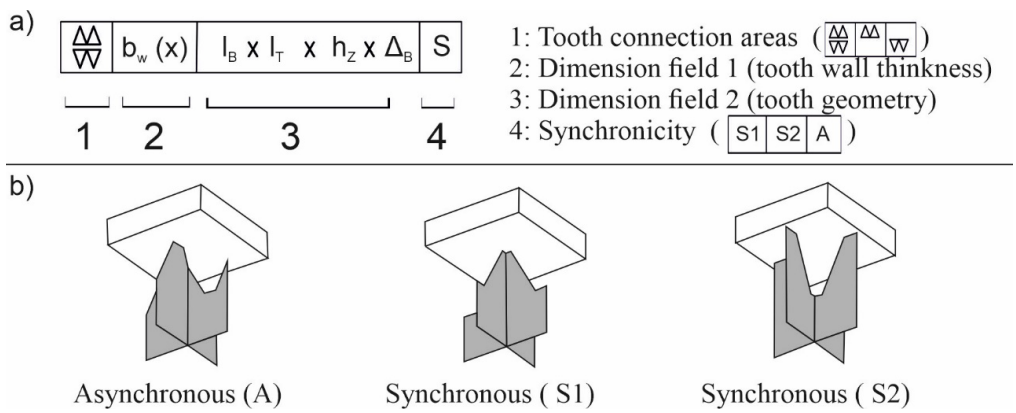


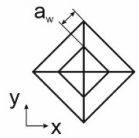
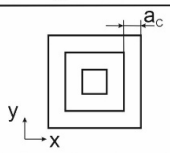
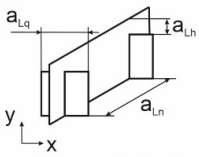
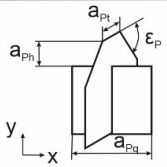
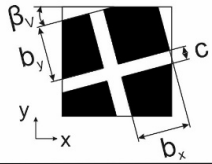
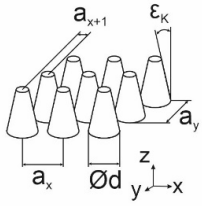
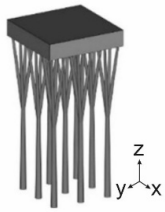

*Figure 6: a) Tooth geometry specification field b) Possible tooth synchronicities*

The support structure synchronicity can be recorded in the specification field. “A” means Asynchronous and that the teeth are cutting each other in a random way. Synchronicity is marked by an “S”. There are two different synchronicity variants “S1” means that they cut each other in the center of the tooth top and “S2” means that they cut each other in the middle of two adjacent tooth tops. The three variants are shown in Figure 6 b).

## Structure of specification fields

Some examples for a depiction in drawings of other wall-based support structures and volume-based support structures are given in Table 2. The general structure of the specification field is the same but there are different attributes that are added into the specification field. Moreover, the introducing symbol from Table 1 varies. The symbol for volume support structures is a black filled square. If the volume is fragmented for better removability, this can be supplemented by the dimensions shown in Table 2 in the specification field. Column or cone support structures are specified by usage of the corresponding symbol in Table 1. In the following field, the column diameter or the cone diameter at the building platform is listed. In the case of cone support structures, the taper angle $\varepsilon_K$ is also specified. The last field contains dimensions for the arrangement of the individual columns or cones. An example for the specification field is given in Table 2. Tree support structures or complex lattice structures are less relevant to the application of supporting parts, but should still be mentioned here. In principle, they can be described using a specification field, which is why the corresponding symbols are provided (Table 1). However, since many parameters can be varied in the case of tree support structures, the specification field can quickly take on large dimensions. Here, not only parameters describing the shape of the individual "trunks" and "branches" and their branching geometry are to be reproduced, but the arrangement pattern of the various individual trees. It is conceivable that each individual support structure tree is different from the others. At most, labels such as "Y-tree" or "IY-tree" could be used for a general characterization, as described by GAN et al [20]. In most cases it will be more appropriate to link the support structures to the engineering drawing as a CAD or STL file.

*Table 2: Specifications field for different support types.*

| Type | Sketch | Specification field | | | Parameters | |
|---|---|---|---|---|---|---|
| **Wall based** | | | | | | |
| **Web** |   | | $b_W$ (x) | $n \times a_W$ | n: $a_W$: | Amount net rays Distance of walls |
| **Contour** |   | | $b_W$ (x) | $a_C$ | $a_C$: | Distance of walls |
| **Line/Angle** |   | | $b_W$ (x) | $a_{Lq} \times a_{Ln} \times a_{Lh}$ | $a_{Lq}$: $a_{Ln}$: $a_{Lh}$: $\varepsilon_a$: | Fin length Fin distance Fin-part distance Angle |
| | | | $b_W$ (x) | $a_{Lq} \times a_{Ln} \times a_{Lh} \times \varepsilon_a$ | | |
| **Point** |   | | $b_W$ (x) | $a_{Pt} \times \varepsilon_P \times a_{Pq} \times a_{Ph}$ | $a_{Pt}$: $a_{Pq}$: $a_{Ph}$: $\varepsilon_p$: | Contact length Fin length Fin-part distance Angle |
| **Volume based** | | | | | | |
| **Massive** |   | | $b_x \times b_y \times c$ / $\beta_V$ | | $b_x$: $b_y$: c: $\beta_V$: | Thickness x Thickness y Distance Angle to x axis |
| **Pillar/Cone** |   | | Ød | $a_x \times a_y$ / $a_{x+1}$ | d : $a_x$: $a_y$: $a_{x+1}$: $\varepsilon_K$: | Base diameter Distance x Distance y Offset Angle |
| | | | Ød / $\varepsilon_K$ | $a_x \times a_y$ / $a_{x+1}$ | | |
| **Lattice/Tree** |   | | data name / direction | | - : | - |
| | | | lattice type (Vol-%) | | | |
| | | | CAD | data name / direction | | |

*x,y,z coordinate system of SLM Machine*

Lattice support structures can also rarely be described with the help of a few parameters. Lattice structures of the type "Schwartz Diamond" or "Schoen Gyroid", for example, are relatively easy to describe using the volume fraction in the specification field (Table 2). For more complex lattice structures, however, a reference to a CAD file containing the unit cell is more useful. High complex support structures can also be referenced to a CAD file, this must be indicated in the specification field with the abbreviation "CAD" in the first position of the specification field. In the subsequent field, the CAD file is named by a unique identifier. On a drawing, this can be a file name and the associated path. In a digital environment, a direct link to a database with the reference CAD file is also conceivable.

## Wall-based support structures: Example drawing entry

Figure 7 shows an example component with two different support structure areas. Both areas are connected by a reference line with a rhombus symbol. The rhombus symbol is followed by a specification field. For the right support structure area, the first line of the specification field indicates that the support structure has a net shape, and a wall thickness of 1.2 mm. The fact that the mesh has four mesh rays and the concentrically running walls have a distance of 3.5 mm can be seen in the third field of the top line. Finally, dimensions for fragmentation are added. The second and third lines of the specification field describe the connection of the support structures with different tooth geometries. Line four of the specification field indicates that the support structure area has a contour wall with a greater wall thickness of 2.2mm and a perforation. The last line describes the component connection of the contour wall. The support structures in the left area are contour support structures with a wall thickness of 0.8 mm. The walls are spaced 2.6 mm apart. The support structures are connected to the component and the building platform with teeth of the same geometry. Moreover there is no difference between hatch and contour walls.

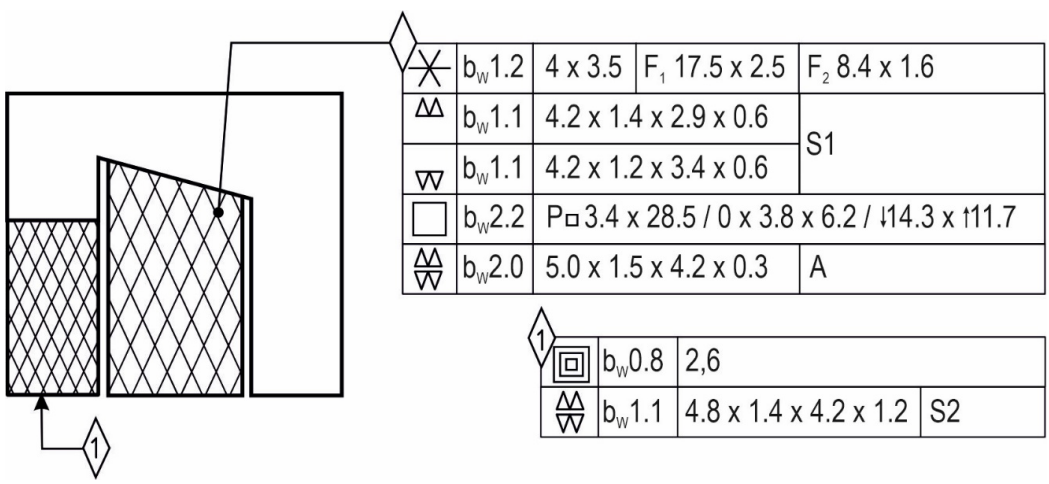



*Figure 7: Example drawing entry according to Figure 5 and Table 2.*

## Conclusion and outlook

In the present study a method to depict support structures of laser beam melted parts in technical drawings was presented. Therefore, the state of the art was determined, requirements for a useful depiction of supports were identified and a recommondation to depict the support structures in technical drawings was presented. The depiction of support structure areas was set by using cross-hatching in the drawing. To distinguish between different support structure types, a standardised depiction of geometrical information in a specification field was developed. The specification field gives a detailed description of the support structure type, the geometry as well as the connection to the part and the building platform. Also uncommon support types like lattice structures or CAD based support structures can be implemented. The forms of depiction developed in this study can serve as a basis for different future support structures. Moreover, additional geometrical information of the support structures can be implemented. An implementation in standardization or other AM processes is also conceivable.

## Literature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