

SG-Library 4.7 Documentation: Introduction to the functional scope

(Status of: 2019-10-22 (c) by Tim C. Lueth, 85386 Eching-Dietersheim, Germany, Professor at Technical University of Munich)

The Solid Geometry Library is a Matlab toolbox with which geometric bodies, mechanisms, kinematics, and robots can be designed, simulated and shape-optimized (FEM analysis) as a multibody system. STL files or medical image data can also be imported to link the design with machine elements or patient-specific information.

- IF YOU WANT TO USE THE LIBRARY FOR DESIGN, OPTIMIZATION AND DYNAMIC SIMULATION OF SG, THE BEST WAY TO GET STARTED IS WITH SOLID GEOMETRIES

- IF YOU WANT TO UNDERSTAND AND DEVELOP THE LIBRARY, START WITH THE DATA STRUCTURES.

In contrast to CSG modeling, the SG library is based on surface data.

The SG library has been developed since the end of 2010 with the goal of being able to design robots and mechanisms automatically so that the development time of individual robots for medicine and care in combination with additive production and laser cutting is massively accelerated and the number of necessary drives is minimized.

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The functions are separated into the following toolbox sections:

- **1 Data Structure and Manipulation:**
- **2 Analytical Geometry:** Basic functions for geometric calculations
- **3 Polygons and Contours:** Processing of lines, edges and circular contours in 2D and 3D
- **4 Surfaces:** Processing of open or closed tessellated surfaces in 2D and 3D
- **5 Solid Geometry Modeling:** Generation of surface models
- **6 Frames and Kinematics:** Generation of coordinate systems and kinematic chains
- **7 Automatic Design, Optimization, Simulation:** Solid Geometries, Joints, Mechanisms, Robotics
- **8 STL & 3D Printing & Voxel Models:** Handling of STL, DICOM, CVG for 3D printing and lasercutter
- **9 Testing and Test Generation:** Systematic testing of geometries and functions

New and not yet assigned:

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There are some functions and experiments that are not yet assigned to certain chapters of the SG-Lib. Until these functions are assigned, they are listed here:

NEW

1 Data Structure and Manipulation:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation)

The Solid Geomtry Toolbox has not been written object-oriented, but could easily be reworted if necessary. From the authors' point of view, the main reason is the automatic addition of function names using the tab key, which does not work properly with object-oriented programming methods, but extremely accelerates the search for suitable functions when using the Toolbox.

The Solid Geometry Toolbox uses few data structures.

They are

PL - 2D point lists

VL - 3D Point Lists

R - Rotary matrices[3x3 in 3D and[2x2] in 2D

HT - Homogeneous transformation matrices[4x4] in 3D or[3x3] in 2D

CPL - closed 2D point lists separated by NaN

CVL - closed 3D point lists separated by NaN

EL - sorted or unsorted edge lists that can be sorted and separated

FL - sorted or unsorted area lists that can be sorted and separated

TL - sorted or unsorted tetreder lists that can be sorted and separated

CEL/CIL/SEL/ - sorting index lists for EL, FL and TL

SG - struct from VL and FL or cell list of these structures

SGT - struct from VL and FL as well as transformation matrices for frames

The function names typically specify the result type of the function with the first 2 letters.

PL - 2D point lists

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The functions are separated into the following toolbox sections:

- **1.1 Point List Manipulation:**
- **1.2 Vertex List Manipulation:**
- **1.3 Transformation Matrices:**
- **1.4 CPL as NaN Separated List:**
- **1.5 Edge List Manipulation (PL/VL):**
- **1.6 Facet List Manipulation (PL/VL):**

- **1.7 Tetradron List Manipulation (VL):**

- **1.8 VLFL Manipulation:**

- **1.9 SG Manipulation:**

1.1 Point List Manipulation:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> Point List Manipulation)

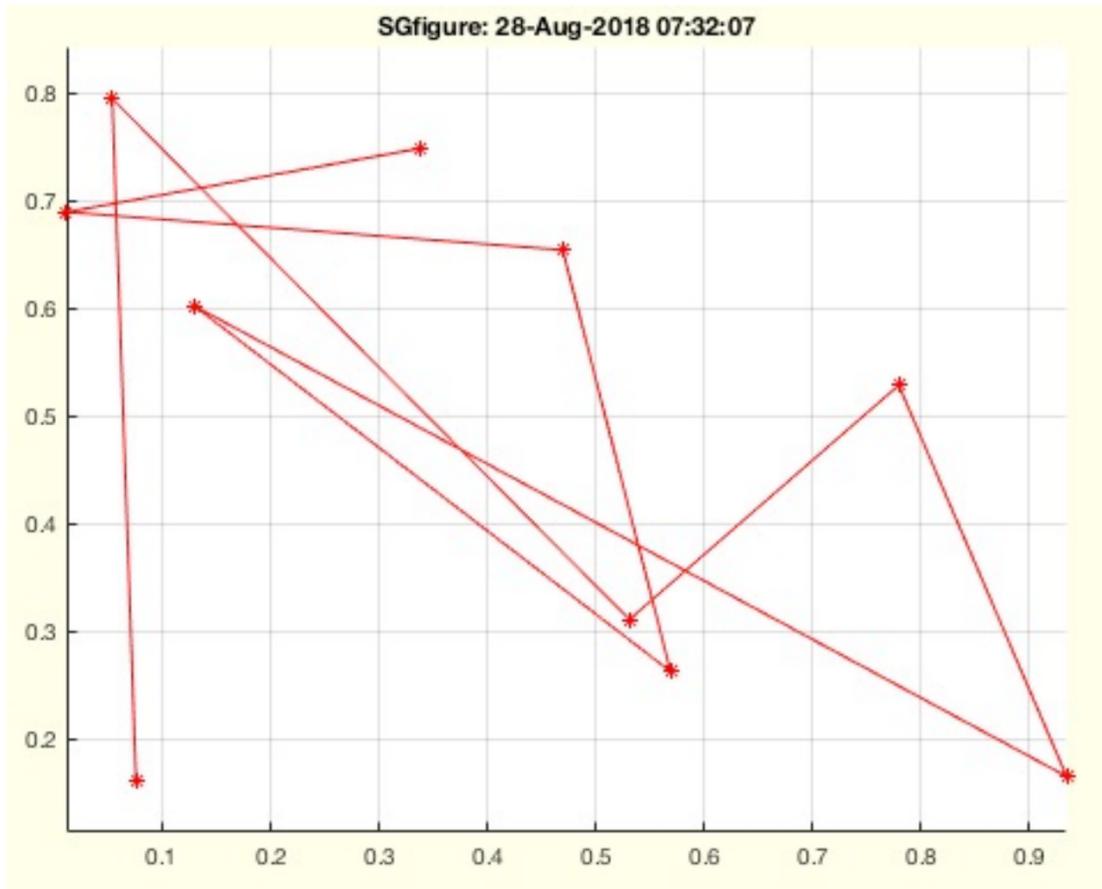
Point list are a single sequence of x and y values like:

PL=[x1 y1, x2 y2, x3 y3; x4 y4; x4 y4;

Example: PL=[0 0; 10 0; 10 10 10; 0 10]].

The first point and the last point are not the same (difference to CPL).

Example: PL=rand(10,2); PLplot(PL); view(0,90)



The following toolbox functions belong to this group:

- **PLofVL(VL)** - Converts a planer VL[nx3] into a PL [nx2]
- **PLofVLFL(VL,FL,fi)** - returns the 2D representation for a planar VLFL
- **PLofFloorPlan(FP)** - Returns a point list from a distance angle list
- **PLofVLprojection(VL,pc,pt,cup,sc,ysize)** - returns image point on a target screen
- **PLofimcontourc(I,cent,pixs)** - returns the centers of pixel coordinates in an image
- **PLtransform(PLA, PLB, sl,CL);** - transform one PL into another

1.2 Vertex List Manipulation:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> Vertex List Manipulation)

Vertex lists are a single sequence of X, Y and Z values such as:

VL=[x1 y1 z1, x2 y2 z2; x3 y3 z3; x4 y4 z4; x5 y5 z5;

Example: VL=[0 0 0 0; 10 0 0; 10 10 0; 0 10].

The first point and the last point are not the same (difference to CVL).

Example: SGfigure; VL=rand(10,2); VLplot(VL); view(-30,30)

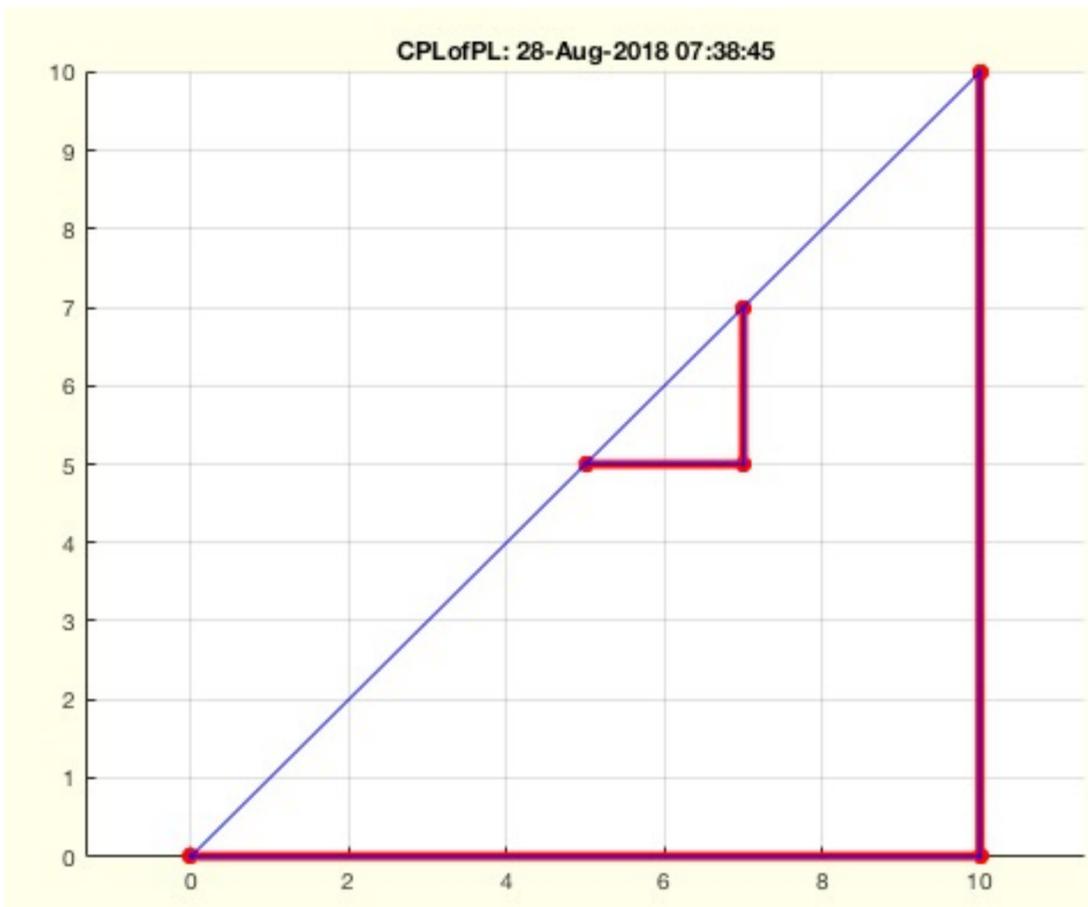
- **TofSG(SG,rel)** - sets a HT matrix relativ to nested solid
- **TofPEul(p,eul)** - return from euler angle and position an HT matrix
- **TofPez(p,ez)** - creates a T matrix from point and ez-Vector
- **TofP(p)** - returns a T matrix from a point in 2D or 3D
- **Tof2vec(p1,p2,q1,q2)** - returns transformation matrix based on the 2 point movements
- **TofVLprojection()** - returns the HT matrix of camera based on a VL and Projection image PL
- **Tofcam(pc,pt,cup)** - returns HT matrix of camera and target for a given camera point, target point, and camera up vector
- **TofFS(TR,Nr,fe,FS,Rz,dz)** - returns a HT matrix for a specified feature surface
- **TofT(T0,R,P)** - returns a T matrix defined relative to another T matrix

1.4 CPL as NaN Separated List:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> CPL as NaN Separated List)

Matlab uses several different concepts to display multiple contours in a list. So the `contourc` function uses a different representation than the closed polygon list of the mapping toolbox. The SG-Lib uses the CPL format of the mapping toolbox. Individual point lists are separated from each other by a `[nan nan]` line. Optionally, the last point of a contour is also the last point. This second rule is not always observed in the SG-Lib

Correspondingly there are then also functions for the conversion of the `contourc` format into the CPL format or PL into CP etc.



The following toolbox functions belong to this group:

- **CPLofPLEL(PL,EL)** - returns a polybool contour from PL and EL
- **CPLofPLFL(PL,FL,bound)** - returns a polybool contour from PL and each edge of FL
- **CPLplot(CPL,c,w,t,b,f)** - plots a 2D polybool contour polygon in a 3D figure
- **CPLuniteCPL(CPL)** - returns a correct directed closed polygon list from a undirected closed polygon list
- **CPLisccw(CPL)** - returns index list for CPL direction
- **CPLcircshift(PL,cl)** - shifts & closes a PL. First point is `[minx miny]`
- **CPLorder(CPL,smax)** - returns an xy ordered and shifted CPL
- **CPLremstraight(CPL)** - removes points from straight lines in all contours of CPL
- **CPLrecontour(CPL,frm)** - returns a contour list for a sliced/cutted object
- **CPLofPL(PL)** - appends the first point to a point list of required
- **CPLnonmanifold(CPL)** - true if a point is used twice in the CPL or PL
- **CPLcopypattern(CPL,number,delta)** - creates patterns by copying CPLs
- **CPLunite(CPL,ord)** - returns a CPL that has no crossing lines anymore
- **CPLedgeNormal(CPL)** - returns edge normals and point normals for a CPL
- **CPLinvert(CPL,add)** - Change the direction of all contours in a CPL
- **CPLofplateSG(SG)** - returns for a flat plate solid its contour
- **CPLfillPattern(CPL,CPLA,w,d,cut,pc)** - fills a contour with copies of a pattern
- **CPLinsideCPL(CPL,CPLs)** - returns the contours of a CPL that inside another CPL
- **CPLgrow(CPL,w,edge,unid)** - grows a contour line in a distance
- **CPLofVLFL(VL,FL,fi)** - creates a CPL and T of a planar VL,FL
- **CPLsortC(CPL,ctype,CA)** - returns a contour that start with angle -pi

- **CPLgrowEdge(CPL,w)** - grows a contour line in a distance
- **PLcrossCPLline(CPL,pa,pb,touch,full)** - return the crossing point of a CPL and a line
- **CPLcopypatternPL(CPL,PL,dw)** - copies a CPL at positions of a PL
- **CPLremnoise(CPL,r,maxw)** - returns a smoother CPL
- **iscrossingCPL(CPLA,CPLB,touch)** - checks crossing/touching of two CPLs
- **CPLofBB(BB,d)** - returns a CPL around a 2D Bounding Contour BB
- **CPLtextimage(text,dt,f,sx,sy,sz,ha)** - returns contour of text string
- **CPLfillHoneycomb(PLs,w,d,ww,n)** - fills a contour with honeycomb
- **CPLarea_2016(CPL,sep)** - returns the area of the surfaces (VL/PL)
- **SGofCPLCVLR(CPL,CVL,R,R1,R2)** - Returns a solid of a contour along a path
- **PLofCPL(CPL)** - converts a nested CPL into a nested PL
- **CPLfaceplot(PL,c,w,a)** - plots the faces of a CPL
- **CPLoutercontour(CPL,out)** - returns for a CPL the outer contour wrt cw/ccw-orientation
- **CPLsortinout(CPL,in1st)** - returns a inside outside sorted CPL
- **CPLofimage(l,n,f)** - returns a point list related to matlab's contour function
- **CPLofcontourc(C,rem)** - converts the contourc format into the CPL format
- **CPLoftext(str,siz,FW,FN)** - returns a CPL of one or more textlines separated by \n
- **CPLcontourc(Inputparameter)** - returns the CPL of matlab's contourc command
- **CPLaddauxpoints(CPL,d)** - add supporting points to embedded CPL to guarantee a specified points distance
- **CPLunitesorted(CPL)** - returns sorted and added closed polygons
- **CPLofmeshgrid(X,Y)** - returns two grid line templates
- **BBofCPL(CPL,zmax,d)** - returns the bounding box of a CPL
- **centerCPL(CPL)** - returns the center of all contours of a CPL
- **CPLisccwinout(CPL)** - returns which contour has the right orientation wrt shell and orientation
- **CPLisccwcorrected(CPL)** - returns a CPL with all CPLs in correct orientation cw/ccw
- **CPLconvexseg(CPL)** - returns the segments of convex and concave contours a CPL.
- **CPLcorrelate(CPLA,CPLB)** - correlates the contours from two CPLs
- **circshiftCPL(CPL,n)** - returns a circular shifted CPL
- **delaunayofCPL(CPLB)** - more sharp delaunay triangulation in 2D (planar case)
- **CPLdisttopoint(CPL,p);** - returns the minimal distance between a contour and a given point

1.5 Edge List Manipulation (PL/VL):

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> Edge List Manipulation (PL/VL))

The structures Edge List (EL), Facet List (FL) and Tetrahedron list (TL) are to be fixedly divided with the Delaunay triangulation or the method point sets by drawing boundary edges, boundary surfaces or boundary volumes.

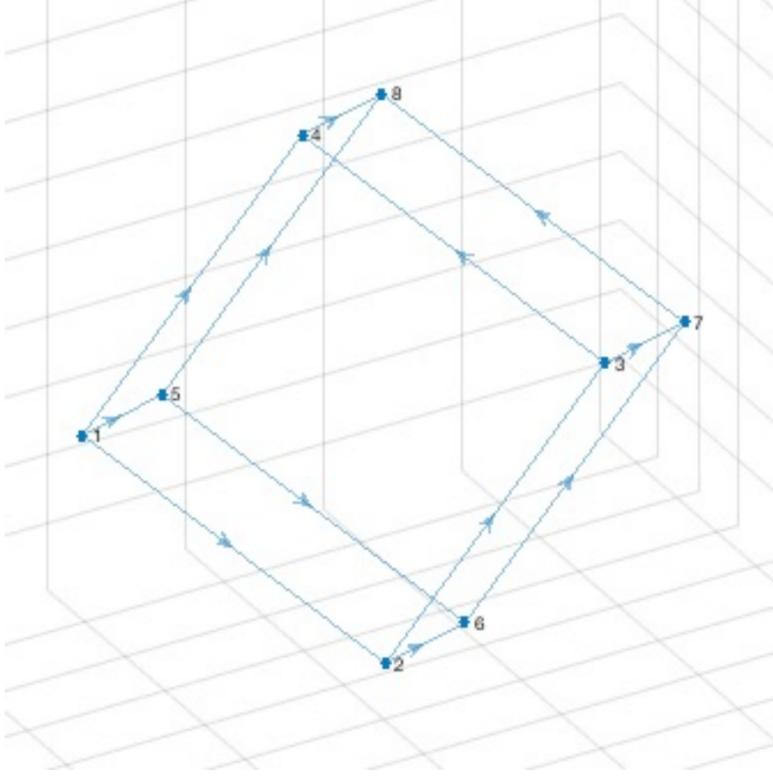
In PL planar point lists, edges and their direction of rotation are used to separate inside and outside surfaces. The delimited contours can be filled with triangular surfaces, whereby the boundary edges influence the surface formation. The boundary edges are therefore also called constraints.

In spatial vertex lists surfaces are used to separate inside and outside from volume. The delimited volumes can be filled with tetrahedra, whereby the interfaces influence the formation of tetrahedra. In volume decomposition, the interfaces are therefore also called constraints.

The SG-Lib offers functions to convert CPL or CVL contours into EL. EL, FL, TL to sort and separate, find open ends or open edges or open surfaces, etc.

Since EL can in principle be unsorted, they must occasionally be sorted and assigned to closed contours or nets. So-called index lists are generated which, after sorting or grouping, specify which consecutive points of an EL belong to a group.

Since SG-Lib 4.2 the graph classes are used for this.



The following toolbox functions belong to this group:

- **ELofCVL(VL,close)** - returns a simple edge list for a vertex list
- **ELofFL(FL)** - converts a facet list into an edge list (simple)
- **ELofn(n)** - returns an edge list for a contour of n points
- **ELofFLborder(FL)** - returns the border edges of an open 3D or closed 2D surface
- **ELofFLborder2(FL)** - returns the border edges of a surface
- **ELofjointFL(FL1,FL2)** - returns a list of joint edges of two facet list
- **ELofCIL(CIL,cl)** - Converts a Contour Index List into an Edge list
- **ELofELmesh(EL)** - returns a separated EL consisting of independent meshes and a rest of points and lines
- **ELseparate(EL,jv)** - reorders the edge list (triangle, tetrahedron) to individual polygons, surfaces, solids

1.6 Facet List Manipulation (PL/VL):

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> Facet List Manipulation (PL/VL))

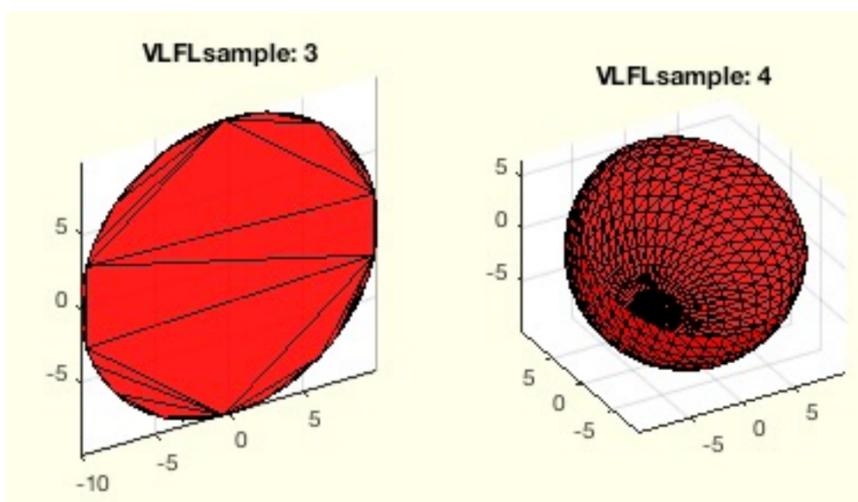
The rows of a facet list define triangular areas and the order of vertex indices within a vertex list of a triangle simultaneously defines the direction of the normal vector.

FL=[vi1 vi2 vi3;vj1 vj2 vj3;vk1 vk2 vk3; etc].

FL can be tessellated planar with the delaunayTriangulation in 2D as PLFL

FL can be spatially tessellated with the delaunayTriangulation in 3D as VLFL.

Also in Matlab 2018b the delaunay triangulation fails if planar surfaces are decomposed in 3D. In this case the surface can be transformed into the plane with the help of TofVL. A planar tessellation takes place and this then also applies in 3D.



The following toolbox functions belong to this group:

- **FLselect(FL,vi)** - returns all neighbor facets of vi
- **FLseparate(FL,jv)** - reorders the edge list (triangle, tetrahedron) to individual polygons, surfaces, solids

1.7 Tetrahedron List Manipulation (VL):

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> Tetrahedron List Manipulation (VL))

The lines of a tetrahedron list[v1 v2 v3 v4] describe the vertex indices of the 4 surfaces. The 4 faces are: FL=[2 3 4;2 4 1;4 3 1;2 1 3];

Currently the DelaunayTriangulation, the AlphaShape function and the pde-Toolbox can generate the tetrahedron model from point clouds VL. However, only the pde Toolbox can link surface models to tetrahedral models.

```
>> TLoFfL ([1 2 3; 1 3 4],4)
```

```
ans =
```

```
5    1    3    2
7    5    3    2
7    6    5    2
5    1    4    3
8    5    4    3
8    7    5    3
```

The following toolbox functions belong to this group:

- **VLFLofTR(TR)** - returns the freeboundary surface of a tetrahedron or the surface of a triangulation
- **TLseparate(TL,jv)** - reorders the edge list (triangle, tetrahedron) to individual polygons, surfaces, solids

1.8 VLFL Manipulation:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> VLFL Manipulation)

Since the edge lists, facet lists and tetrahedron lists refer to indices of a vertex list, the corresponding EL/VL/TL must be adjusted if the vertex list changes. Accordingly, it must be possible to convert new created areas back into the old vertex lists and, if necessary, append new points to the original list.

The following toolbox functions belong to this group:

- **VLFLcat2(V1,F1,V2,F2)** - appends without any check a vertex list after another and also a facet list
- **VLFLcat(V1,F1,V2,F2)** - concatenates two solids and removes double vertexes
- **VLFLshort(VL,FL)** - shortens a vertex list to the vertices that are really used in the facet list
- **VLFLcat(VLA,FLA,VLB,FLB)** - returns combined solid geometries
- **VLFLshort2(VL,FL,thr)** - shortens a vertex list to the vertices that are really used in the facet list

1.9 SG Manipulation:

(SG-Library 4.7 Documentation -> Data Structure and Manipulation -> SG Manipulation)

The simplest version of an SG is a struct with the FElder VL and FL. SG can also have other formats. You can add further fields

SG.VL - Vertex list

SG.FL - Facet List

SG.col: - Facet Color

SG.Tname: - Cell list of frame names

T: - Cell List of[4x4] HT matrices

TFil - Cell list of facets that define the T Transformation matrix

TFoL: - Cell list of facets that are attached to TFil

SGs can also be defined as cell lists of several SGs

SG={SGA, SGB, SGC, ...}

Accordingly, some functions are designed recursively, others connect cell list to a frame

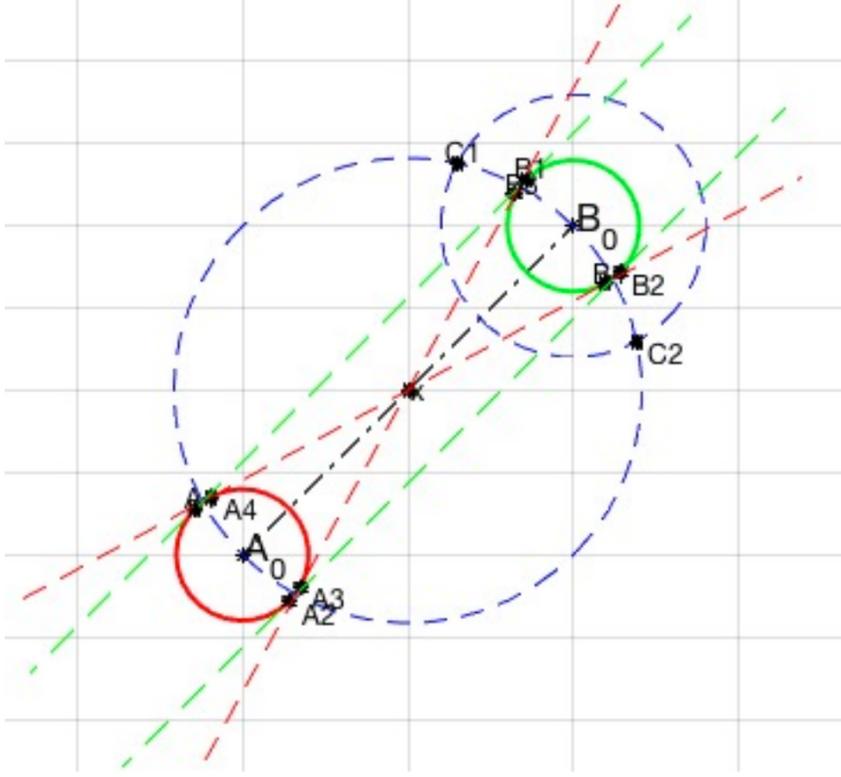
The following toolbox functions belong to this group:

- **SGmelting(SG)** - returns a surface model without intrusion of solids
- **SGsurfacemeltbool(SG,si,Amin,grw)** - returns a solid which surfaces were added using SGbool

2 Analytical Geometry: Basic functions for geometric calculations

(SG-Library 4.7 Documentation -> Analytical Geometry)

Analytical geometry is an important basis for the automatic construction of mechanisms. This also applies to the modeling of bodies and their intersection. For this reason, there are a number of functions that seemingly solve simple geometric tasks:



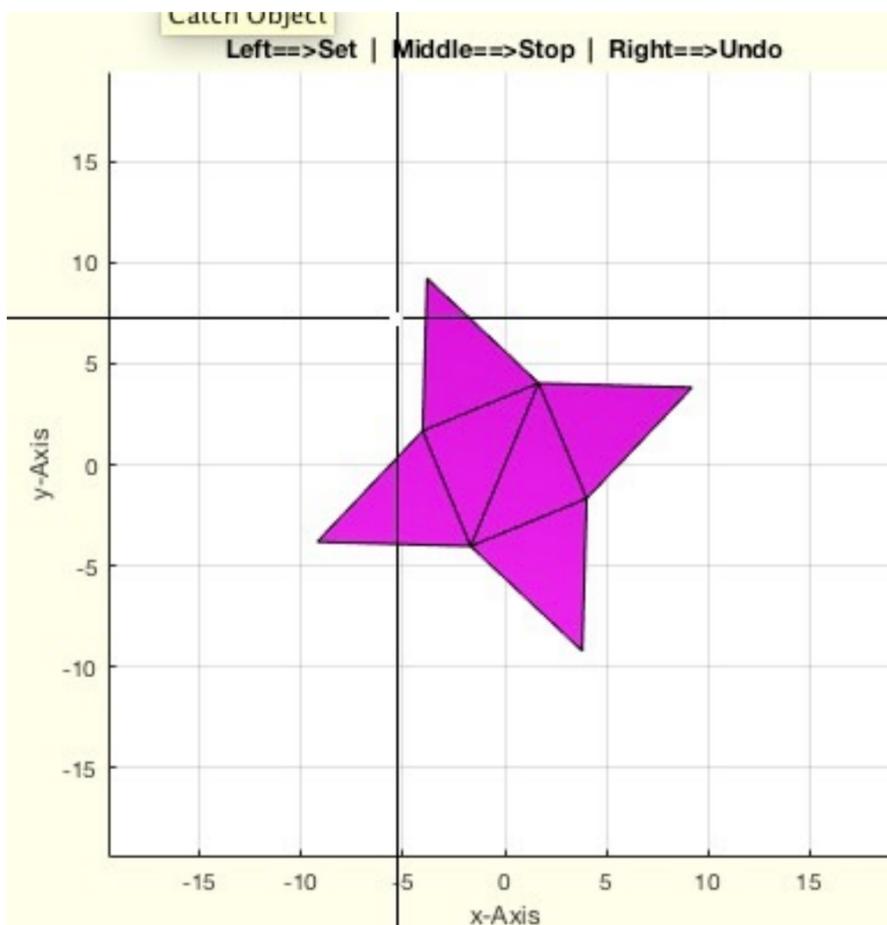
The functions are separated into the following toolbox sections:

- **2.1 Graphical User Interface:**
- **2.2 Geometry Drawings:** Geometric drawings
- **2.3 Plot Annotation:** Labeling of drawings
- **2.4 Crossing points and tangents:** Geometric calculations
- **2.5 Planar and Spatial Transformation:** Description of motion and rotation

2.1 Graphical User Interface:

(SG-Library 4.7 Documentation -> Analytical Geometry -> Graphical User Interface)

The SG-Lib provides a modified figure command which supports some important menu items as well as a possibility to touch 3D structures by mouse click. This makes it possible to build interactive user interfaces that can be converted as EXE or App to a Stand-alone function.



The following toolbox functions belong to this group:

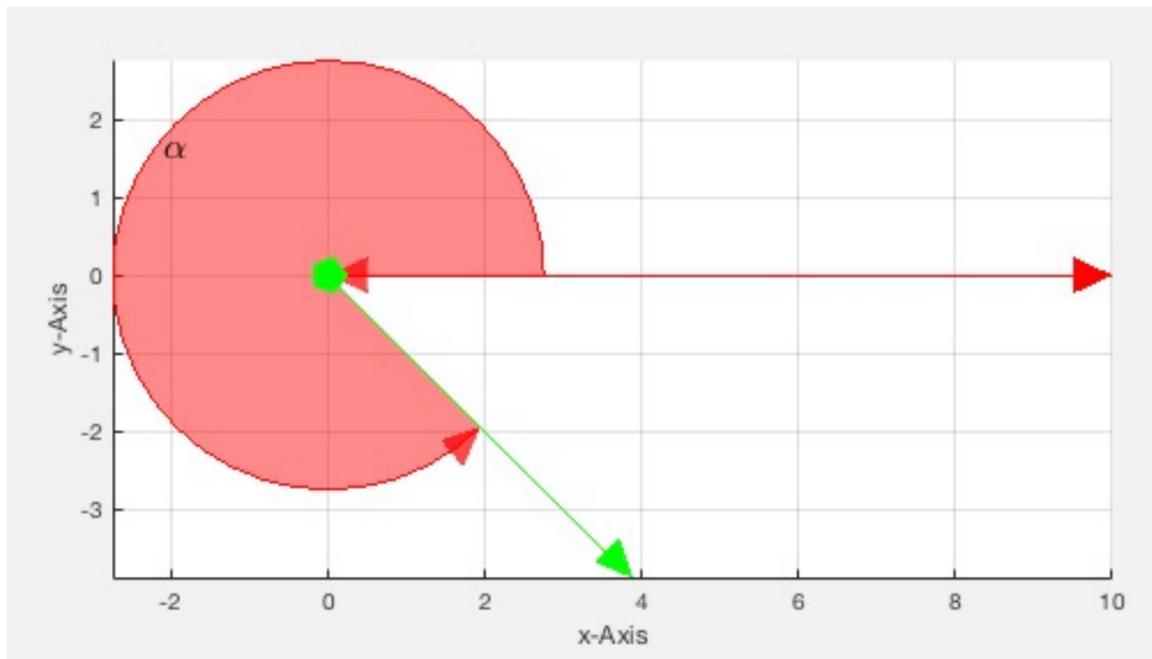
- **VLFLplotlight (mode,al,goh,c)** - switches the light and renderer on for VLFLplots and VLFLplots4
- **select3d(obj)** - Determines the selected point in 3-D data space.
- **VLui(m,res,axcol,cppline,psdraw,linw,opl)** - returns a vertex list drawn by the user in a plot window
- **VLofgca(allpoints)** - returns all vertices of the current figure patches
- **snapplot (pname)** - saves the current figure as JPG-File on the user desktop
- **VLFLofgca** - returns the vertex list and facet list of the current figure
- **imreadui(fname,clip)** - reads an image file and opens dialogs to clip and scale the image
- **immeasureui(imf)** - user interface to measure distances within an image using mouse clicks
- **appsavegcaSTL** - Application callback procedure for writing the current figure as STL
- **VLFLfigure()** - Application for opening and viewing STL Files

- **SGfigure()** - Application for opening and viewing STL Files
- **pixelofaxis** - returns the axis position of the current axis in the figure
- **SGtitle(n,w)** - draws the name of the calling fnct as figure title
- **setgcapixelsize(siz)** - sets the current gca to a default pixelsize
- **getgcapixelsize** - returns the position of the gca in the current figure
- **patchofgca(gh)** - returns all patches of the current graphics axis
- **Tofgca** - returns the HT matrix of the current camera position
- **setplotlight(hi,col,alpha)**; - changes the alpha value of a given graphics object handle
- **SGofgca(hgca)** - returns the solid of the current figure
- **SGfigureannotation(str,bc,sz,sl,hl)** - creates a simple help text annotation into the current figure
- **SGfiguremovie(fname,mtime,angle,ofs)** - creates a movie from a simple rotating view point in MP4 Format
- **gcahandleofSG** - returns the handle to all patches of gca

2.2 Geometry Drawings: Geometric drawings

(SG-Library 4.7 Documentation -> Analytical Geometry -> Geometry Drawings)

These functions are used to draw one or more points, vectors, angles, coordinate systems, planes in 2D and 3D in order to display the results of geometric procedures comprehensibly on the screen.



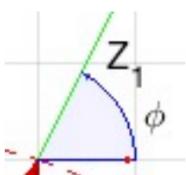
The following toolbox functions belong to this group:

- **lplot(p1,p2,c,w,ts,ss,str,fs)** - plots a straight line between 2 points
- **tfplot(T,f,a,c1,c2,c3)** - plots an HT matrix including the x/y plane
- **tplot (T,c,l)** - plots a line given as HT matrix using $t+k*ez$
- **splot (p,ez,c,w,l,d)** - straight line plot
- **T2plot(p,c,w,N,N)** - plots a HT matrix as straight line vector
- **plotTP (T,f,a,c1,c2,c3)** - plots the basic planes of a coordinate system
- **plotL(T,c,s,w,N)** - plots a HT-matrix as straight line
- **aplot(pc,la,lb,c,w,r,alpha)** - draws an angle relative to a center and two vectors
- **plotT(T,s,w,N,ts)** - plots a coordinate system given as HT matrix

2.3 Plot Annotation: Labeling of drawings

(SG-Library 4.7 Documentation -> Analytical Geometry -> Plot Annotation)

With this function point lists, edge lists, surface lists and vertex lists as well as coordinates and angles can be labeled.



The following toolbox functions belong to this group:

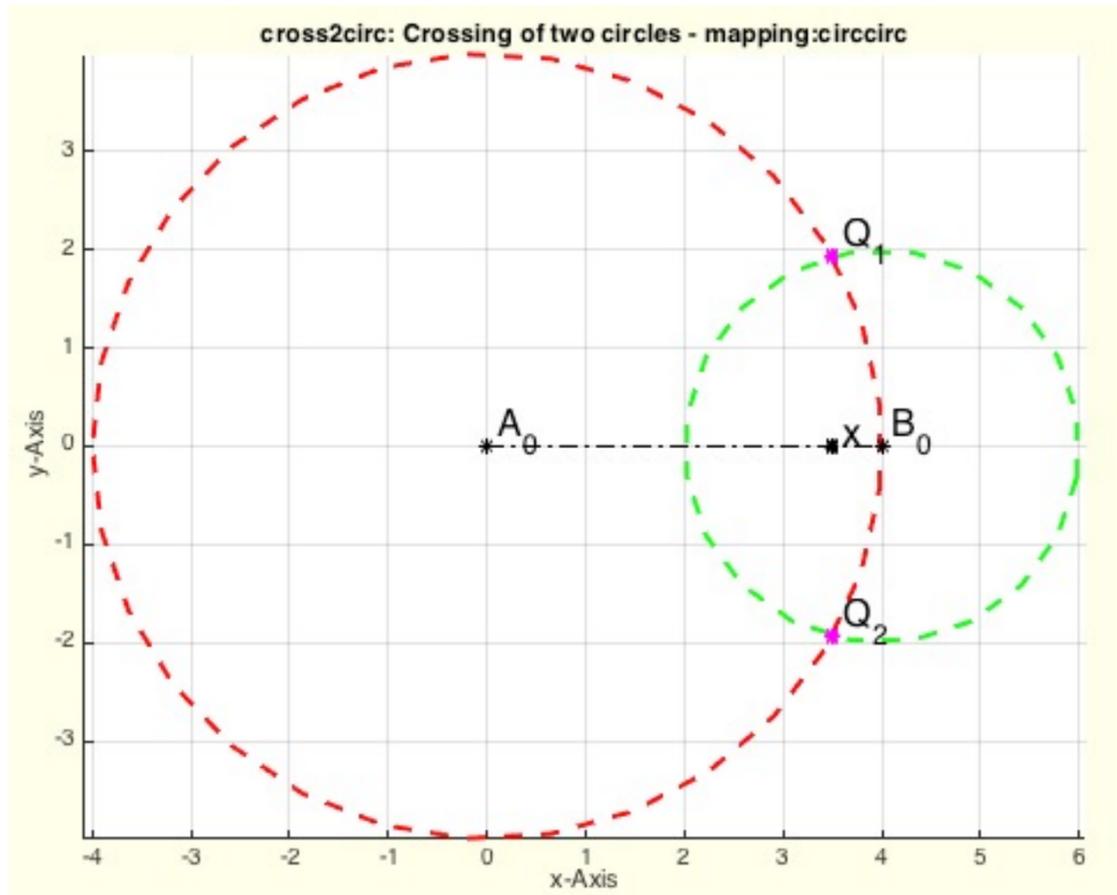
- **textVL(VL,c,s,nt,lb)** - plots descriptors for each vertex in the figure using the text command
- **textP(p,str,dely,dely,Fnts)** - draws a texlabel text at the position
- **textT (T,TStr,c,s)** - drawn a text at the position of a HT matrix
- **textCVL (CVL,c,s,nt,lb)** - plots descriptors for each contour into a figure using text command
- **textVLFL(VL,FL,c,s,nt,lb)** - plots descriptors for each facet in the figure using the text command

- **textVLFS(VL,FL,FSi,c,s,nt,lb)** - plots descriptors for each feature surface and the corresponding feature edges

2.4 Crossing points and tangents: Geometric calculations

(SG-Library 4.7 Documentation -> Analytical Geometry -> Crossing points and tangents)

These functions calculate intersections, tangents or circle segments between lines and circles in 2D



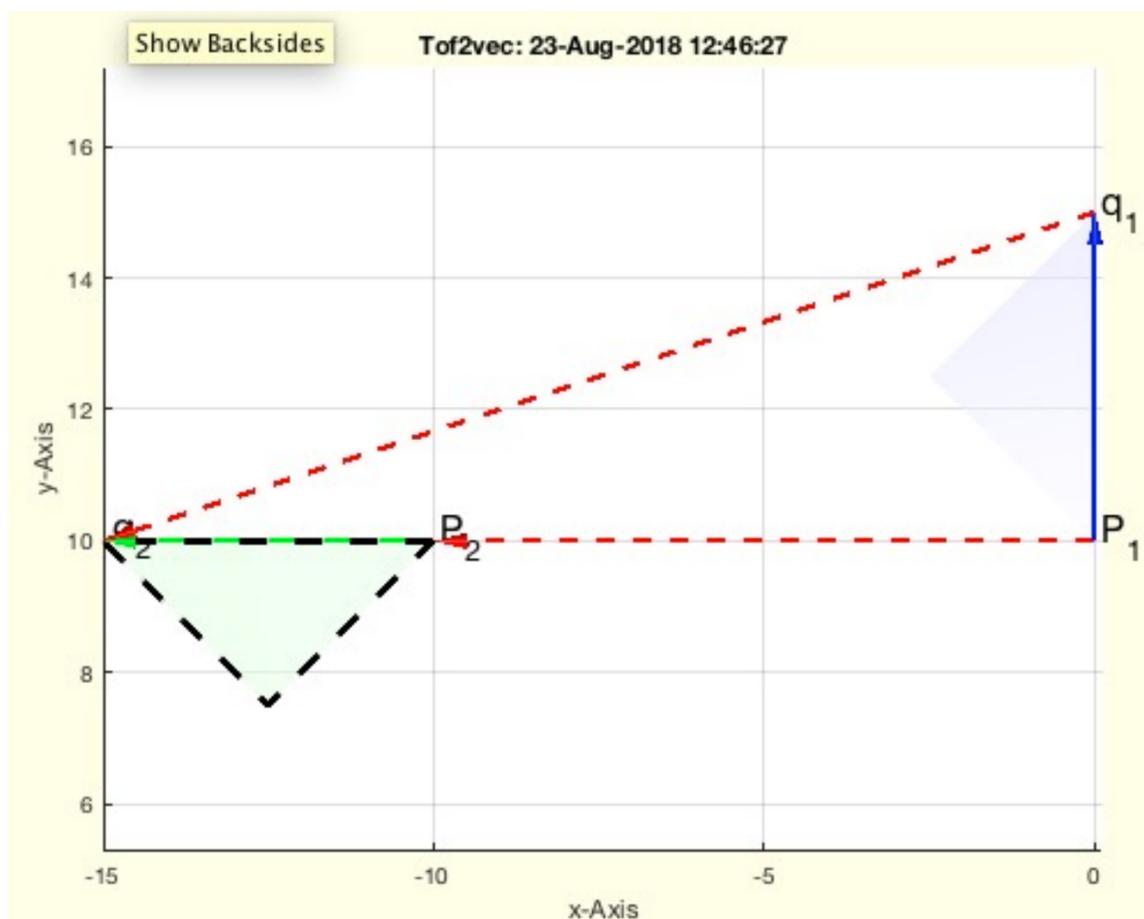
The following toolbox functions belong to this group:

- **crossz(pa,pb)** - calculates in 2D only the z-part of the cross product and handles values near zero
- **PLcross2Lines(A,B,C,D)** - returns the crossing point of 2 lines in [x y]
- **cross2circ(A0,B0,ra,rb)**; - returns the crossing points of two circles
- **PLof3dist(d1,d2,d3,srt)** - creates a 3P Tracker geometry using the given distances
- **tangent2circ(A0,B0,ra,rb)** - returns outer and inner tangents of 2 circles
- **PLchordof2PR(PL,R,rhand)** - returns a radial segment for a given chord and a radius
- **crosscircline(C,R,p,eZ)** - returns the cross points of a circle and a straight line

2.5 Planar and Spatial Transformation: Description of motion and rotation

(SG-Library 4.7 Documentation -> Analytical Geometry -> Planar and Spatial Transformation)

This group of functions creates and changes homogeneous transformation matrices in 2D ([3 x 3]) or 3D ([4 x 4])



The following toolbox functions belong to this group:

- **VLtransT(VL1,T)** - transforms all points of a vertex list using an HT matrix
- **VLtransP(VL,P)** - Moves all points of a vertex list using a translation vector p
- **VLtrans1(VL)** - moves an object into the first quadrant
- **VLtrans0(VL)** - moves an object into the origin of the coordinate system
- **VLtransR(VL,R)** - transforms all points of a vertex list using a rotation matrix
- **VLtransT(VL,T)** - returns a transformed Vertex list
- **PLtransP(PL,p)** - returns a translated point list
- **PLtransR(PL,R)** - rotates all point of a point list
- **PLtrans(PLin,T)** - multi transformation modes for a point list
- **PLtrans0(PL)** - returns an origin centered point list
- **PLtrans1(PL)** - returns a point list moved into the first quadrant
- **PLtransT(PL,T)** - rotates and moves a point list nx2
- **VLtrans(VLA,T)** - return similar to PLtrans or SGtrans a transformed VL
- **VLtransN(VLO,FLO,s,d)** - returns a relative to normal vectors transformed vertex list
- **PLtransC(PL,C,w)** - rotates a point list around a center

3 Polygons and Contours: Processing of lines, edges and circular contours in 2D and 3D

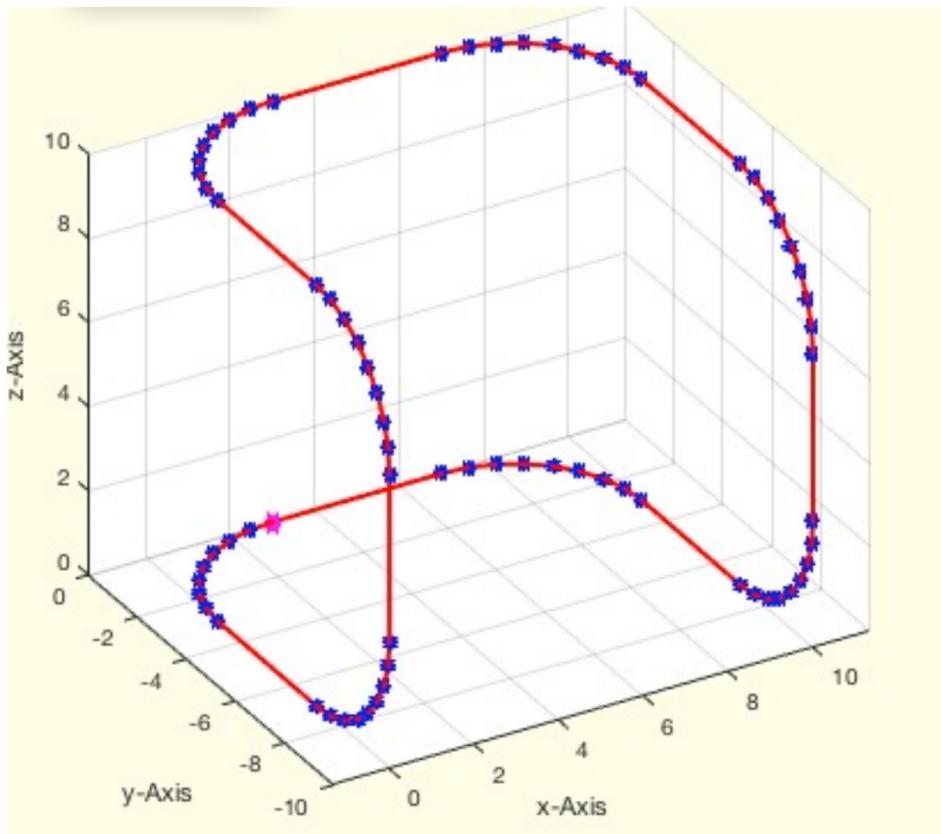
(SG-Library 4.7 Documentation -> Polygons and Contours)

Polygons (PL) are point lists in 2D or 3D space. In 3D they are called Vertex Lists (VL) in the SG-Lib.

Closed Point Lists (CPL) are point lists in which the last point is identical to the first point of the list.

Encapsulated point lists (CPL) can consist of several point lists that are separated from each other via[x1 y1; nan nan; x1 x1,...] in the same list.

With the Delaunay triangulation or other tessellation functions, closed point lists can be used as boundary edges of surfaces.



The functions are separated into the following toolbox sections:

- **3.1 Single 2D Polygons (PL):** Point lists in the 2D plane
- **3.2 Closed Nested 2D Polygons (CPL):** Encapsulated boundary contours in the 2D plane
- **3.3 Planar 3D Polygons (VL):** Planar contours in 3D space
- **3.4 Spatial 3D Polygons (CVL):** Point lists in 3D space
- **3.5 General PL functions:** Point list manipulation
- **3.6 CPL to Surfaces:** Surfaces from spatial contours
- **3.7 CVL to Solid Geometries:** Surfaces from spatial contours

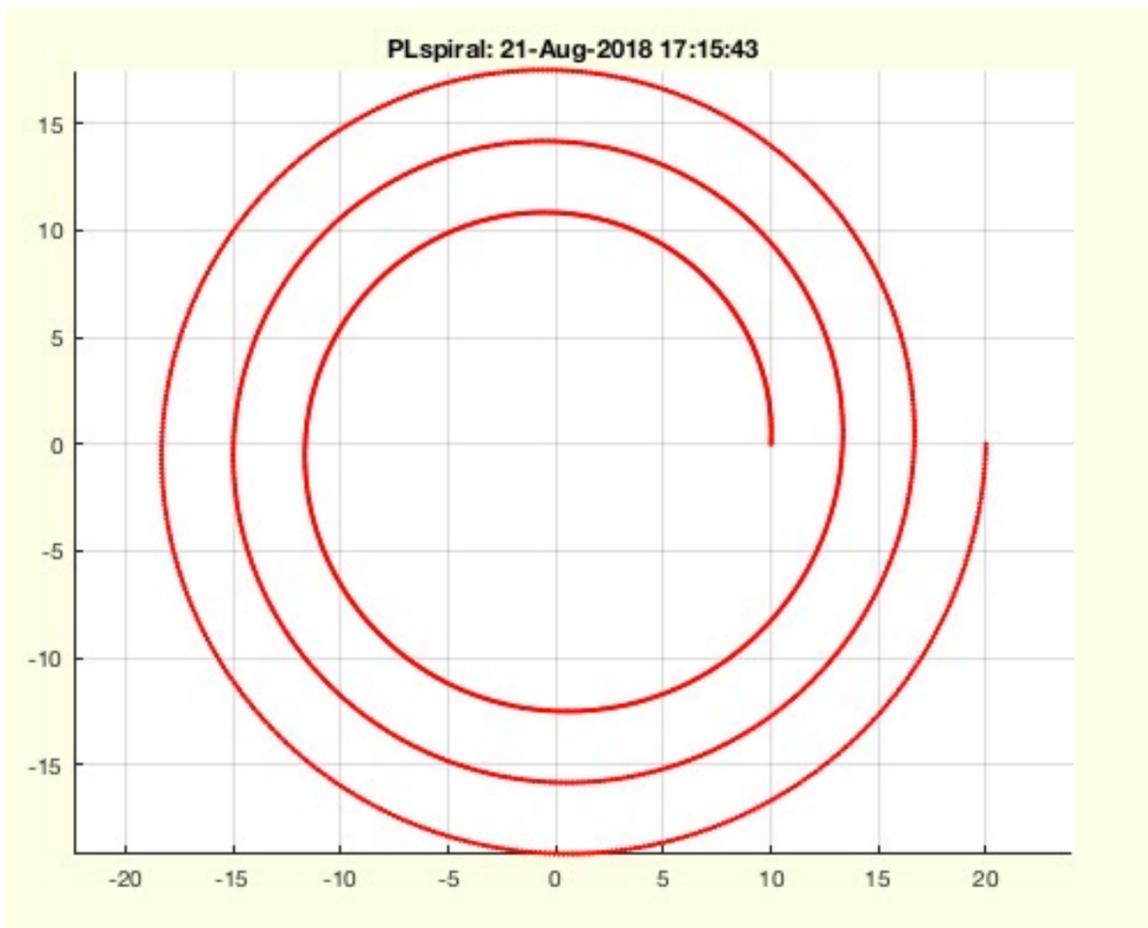
3.1 Single 2D Polygons (PL): Point lists in the 2D plane

(SG-Library 4.7 Documentation -> Polygons and Contours -> Single 2D Polygons (PL))

A simple polygon course is a list $PL=[x_1 y_1; x_2 y_2; x_3 y_3; \dots]$

The polygon course does not necessarily have to be closed. If the first point and the last point are identical, we speak of a CPL.

With this group of functions frequently used 2D point lists[n x 2] of the form[x1 y1; x2 y2...] can be generated. Examples are circles, ellipses, spirals, involutes,

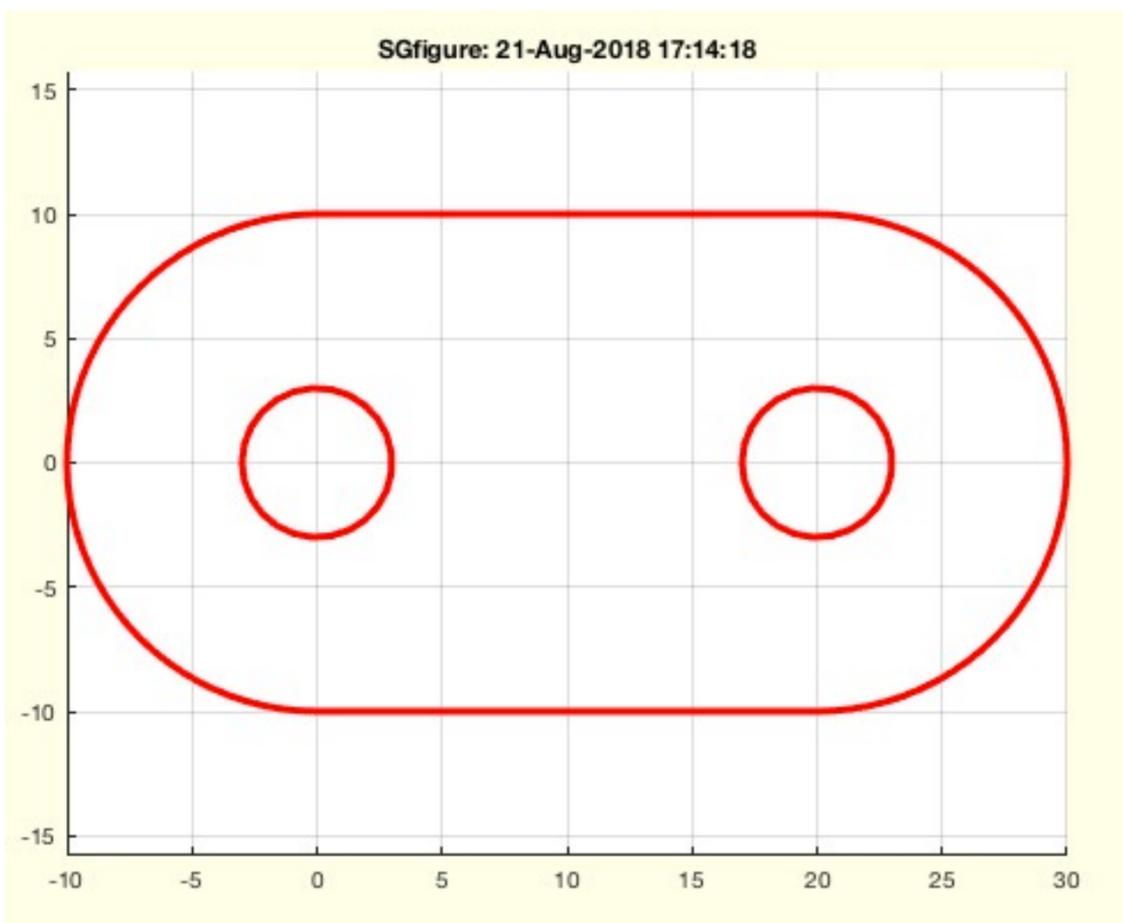


The following toolbox functions belong to this group:

- **PLhelix(R,d,w2,w1,err)** - generates a list of points for a specified helix/spiral
- **PLcircle(R,nf,dw,Ry,ow)** - returns a 2D point list of a circle or circle segment
- **PLEvolvente(r,w,n)** - returns the point list of an involute curve
- **PLgearDIN_2012(m,z,gap,tig,n,rsp,x)** - returns a gear contour wrt DIN from 9 to 48 teeth (ORIGINAL PLgearDIN frct OF 2012)
- **PLsquare(X,Y,dx)** - returns a 4 point list describing a rectangle or trapeze in 2D
- **PLcircseg(R,n,phiA,phiB,Ry)** - returns a PL for a circle segment
- **PLrand(n,r,c)** - returns a point list with random points
- **PLstar(R,nf,dw,Ry,ow,sk)** - returns a 2D point list of a star or star segment
- **PLkidney(RI,RO,w,n)** - returns a kidney shaped point list
- **PLspiral(RI,RO,wm,n)** - return the PL of a spiral
- **PLcircleoval(R,n,L,Ri)** - returns a circle-based-oval point-list

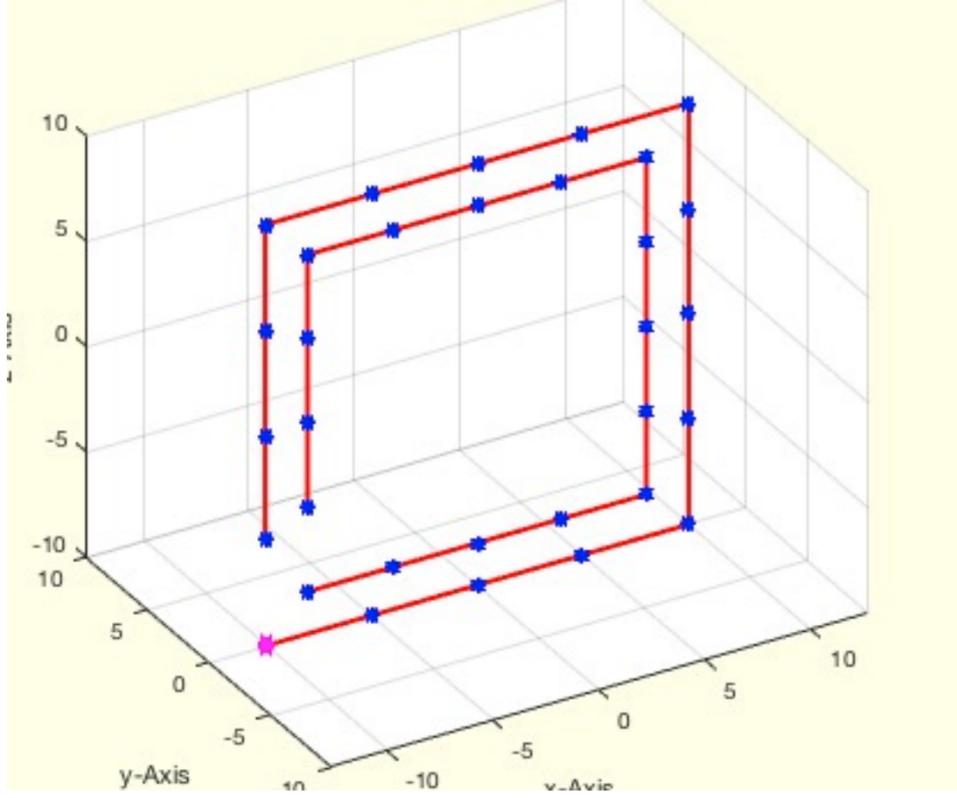
3.2 Closed Nested 2D Polygons (CPL): Encapsulated boundary contours in the 2D plane

(SG-Library 4.7 Documentation -> Polygons and Contours -> Closed Nested 2D Polygons (CPL))



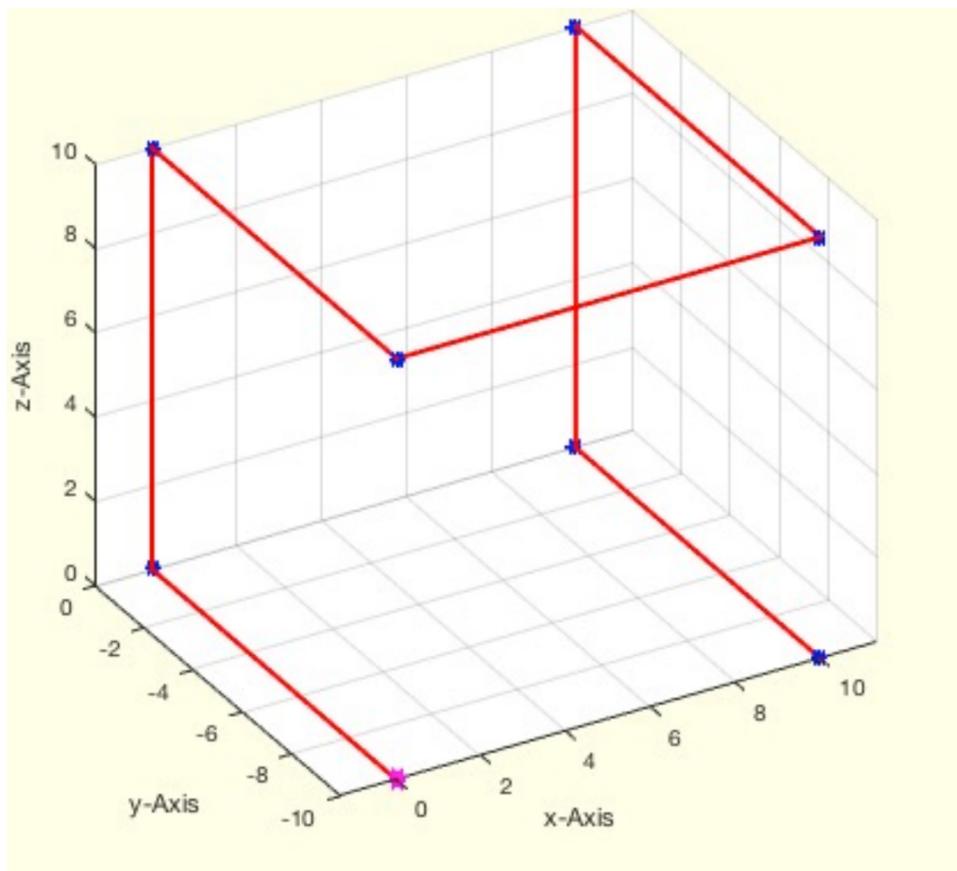
3.3 Planar 3D Polygons (VL): Planar contours in 3D space

(SG-Library 4.7 Documentation -> Polygons and Contours -> Planar 3D Polygons (VL))



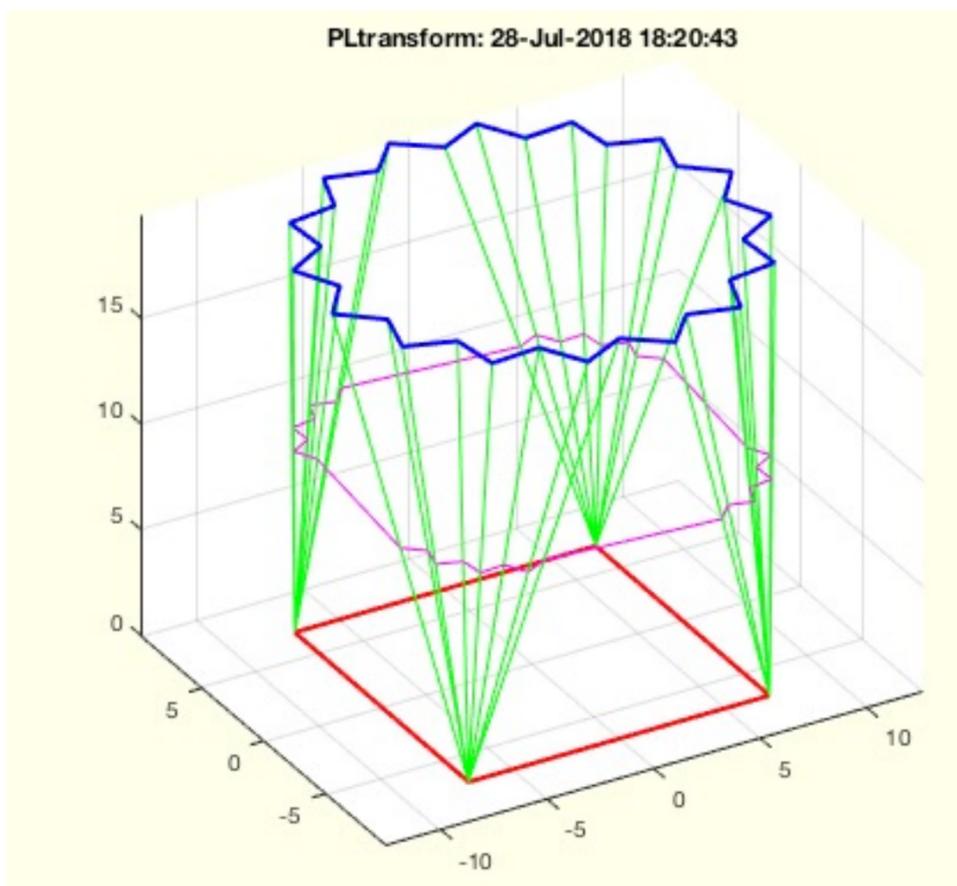
3.4 Spatial 3D Polygons (CVL): Point lists in 3D space

(SG-Library 4.7 Documentation -> Polygons and Contours -> Spatial 3D Polygons (CVL))



3.5 General PL functions: Point list manipulation

(SG-Library 4.7 Documentation -> Polygons and Contours -> General PL functions)

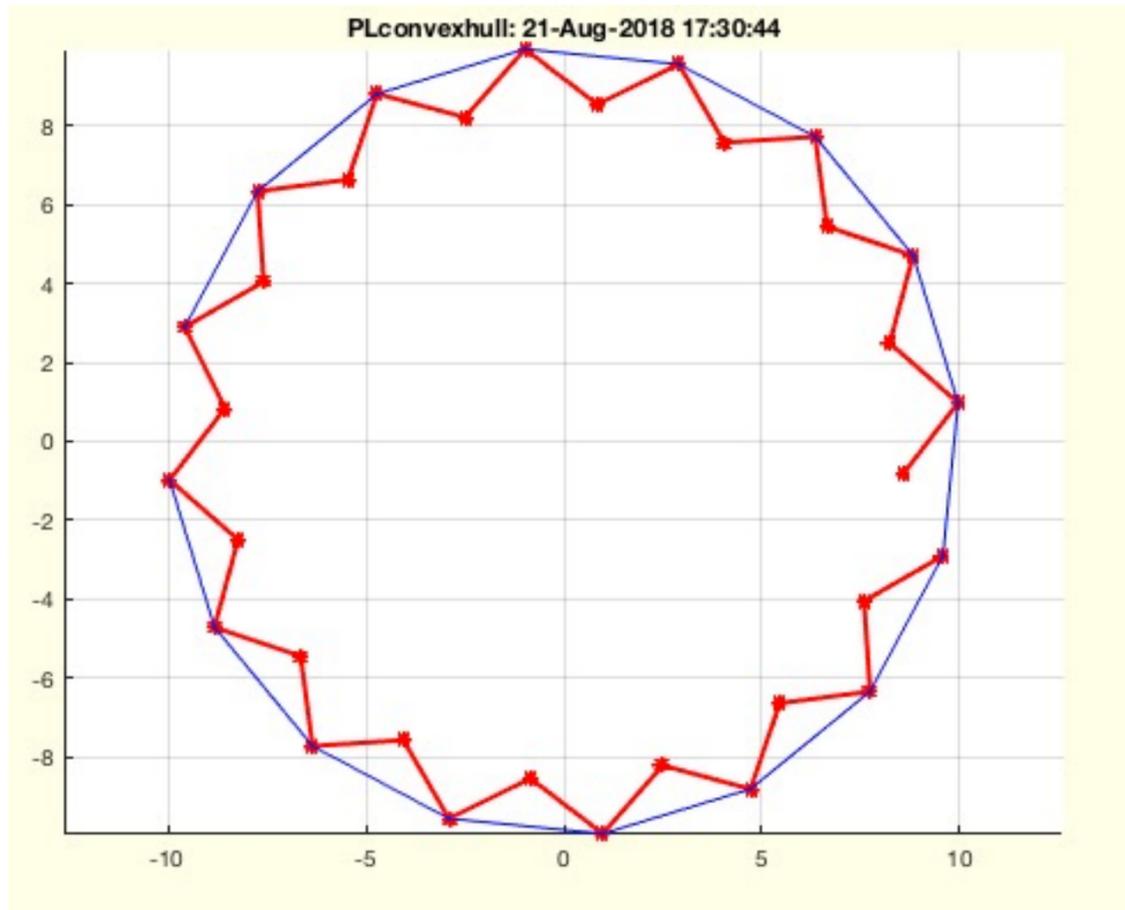


The functions are separated into the following toolbox sections:

- **3.5.5 PL modification: Forming of point lists**
- **3.5.6 Crossing Points: Crossing Points of PL**
- **3.5.7 Boolean Operation: Boolean Operations for PL**
- **3.5.8 PL comparison: Comparison, assignment and transfer of PL**

3.5.5 PL modification: Forming of point lists

(SG-Library 4.7 Documentation -> Polygons and Contours -> General PL functions -> PL modification)



The following toolbox functions belong to this group:

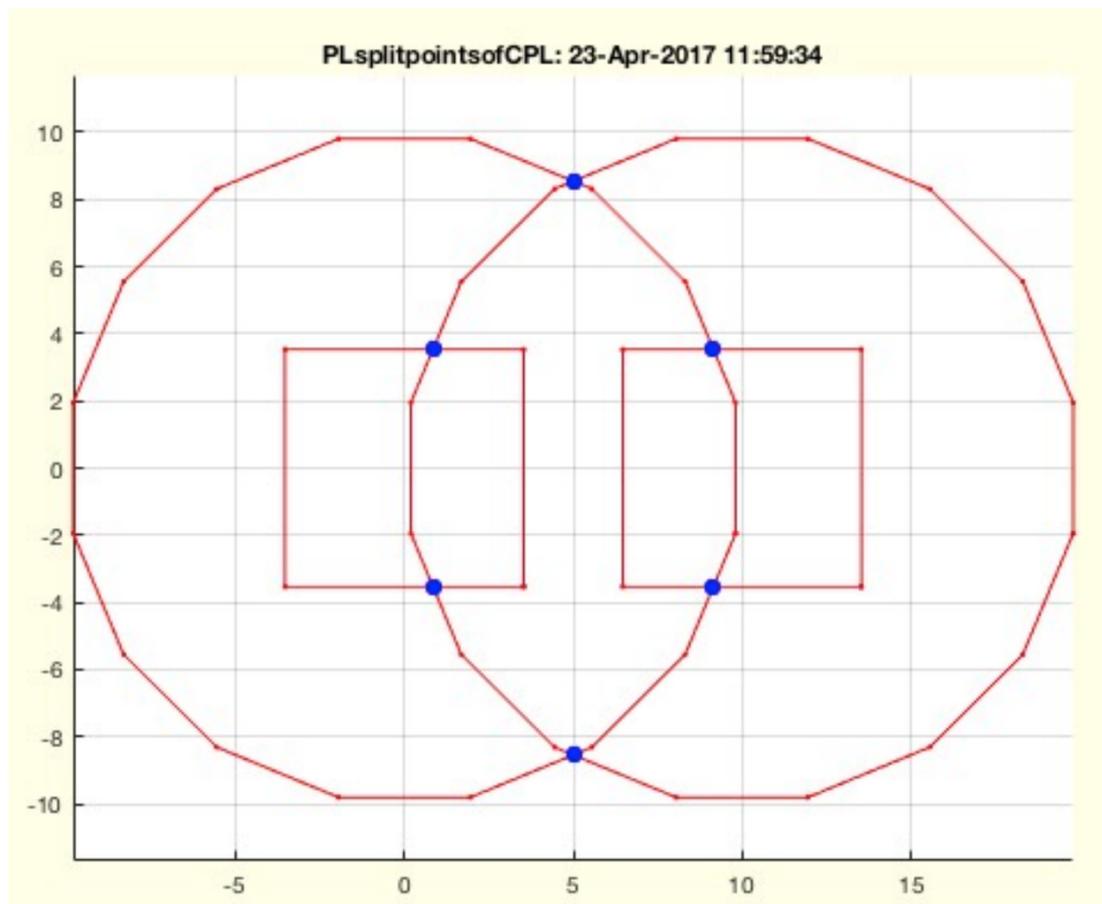
- **isconvexPL(PL)** - return $S > 0$ if PL ($n \times 2$) is convex.
- **PLconvexhull(PL)** - returns the convex hull of a 2D point [$n \times 2$] list

3.5.6 Crossing Points: Crossing Points of PL

(SG-Library 4.7 Documentation -> Polygons and Contours -> General PL functions -> Crossing Points)

While the function of analytical geometry has the task of calculating intersections of ideal circles or lines, the function of this group has the task of processing polygon courses as they are also used in the mapping toolbox, for example.

For the intersection point calculation the Delaunay triangulation is almost always used.



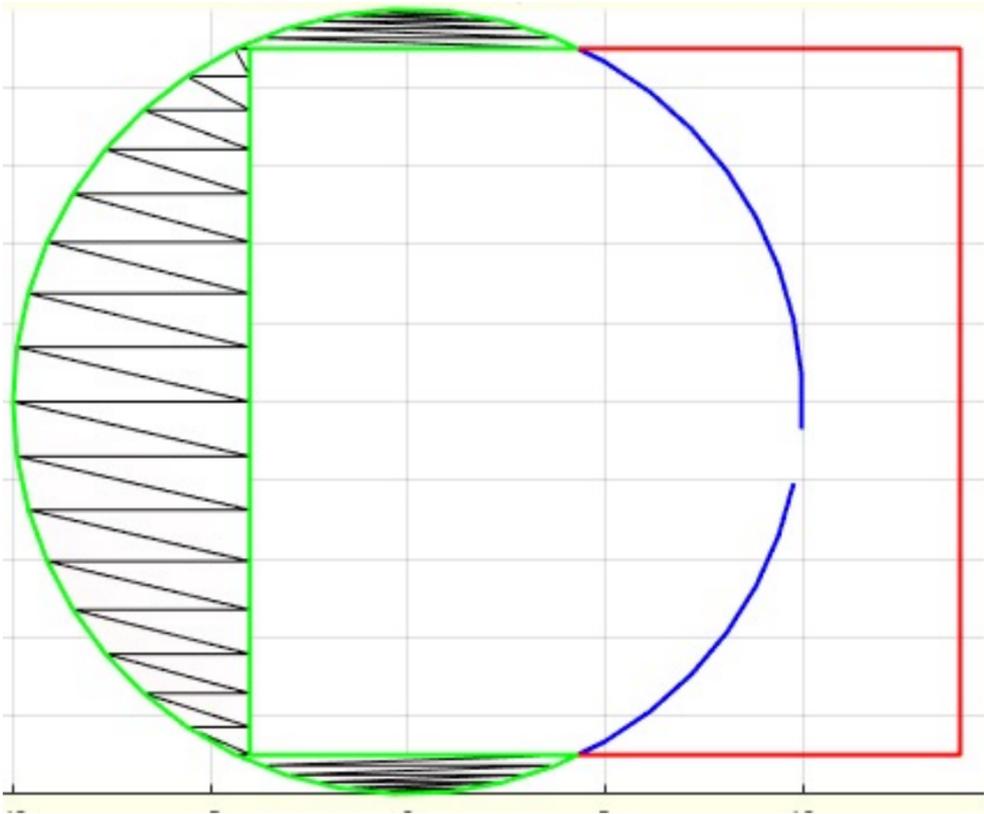
The following toolbox functions belong to this group:

- **CPLsplitpoints(CPL)** - Splits non manifold points in a CPL

- **PLsplitpointsofCPL(CPL)** - returns splitpoints created by delaunaytriangulation

3.5.7 Boolean Operation: Boolean Operations for PL

(SG-Library 4.7 Documentation -> Polygons and Contours -> General PL functions -> Boolean Operation)

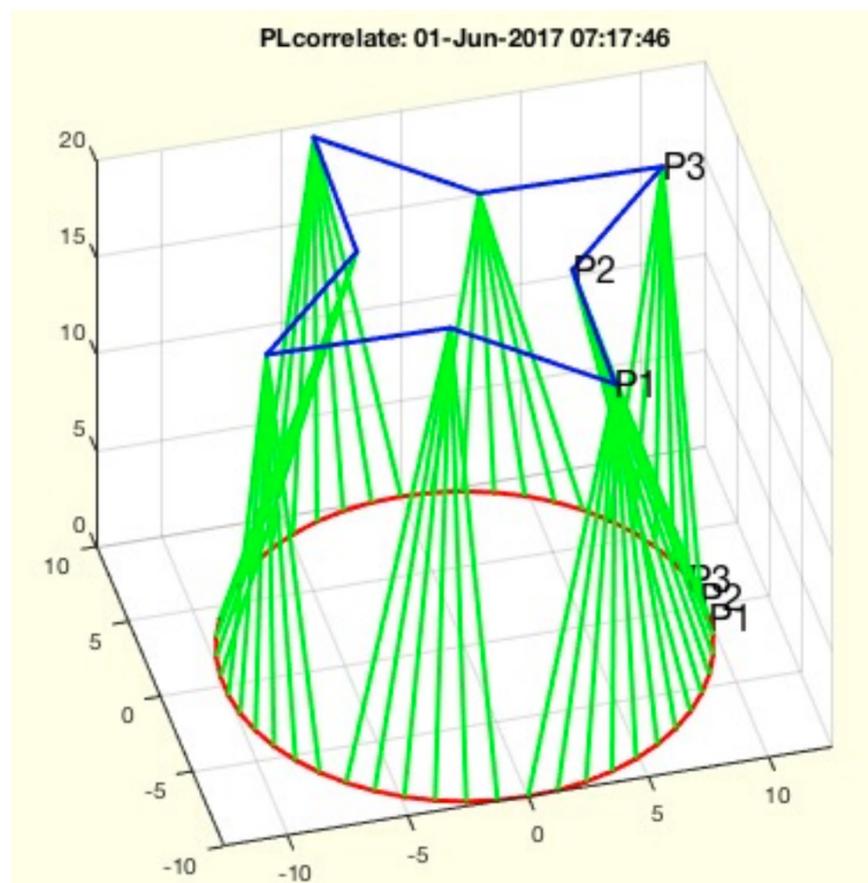


The following toolbox functions belong to this group:

- **PLELboolAuB(PLA,ELA,PLB,ELB)** - returns union set of two 2D Point closed contours
- **PLELboolAmB(PLA,ELA,PLB,ELB)** - returns A minus B: Subtraction set of two 2D Point closed contours
- **PLELboolAiB(PLA,ELA,PLB,ELB)** - returns A intersects B: Intersection set of two 2D Point closed contours
- **PLELboolABcheck (PLA,ELA,PLB,ELB)** - checks the spatial relationship of two contour planes
- **PLELboolAiBx(PLAorg,ELA,PLBorg,ELB)** - returns A intersects B: Intersection set of two 2D Point closed contours
- **PLELboolAxBx(PLAorg,ELA,PLBorg,ELB)** - returns union set of two 2D Point closed contours
- **PLELboolAmBx(PLAorg,ELA,PLBorg,ELB)** - returns A minus B: Subtraction set of two 2D Point closed contours
- **CPLpolybool(flag,CPLA,CPLB,s)** - Utilizes the polybool fnct for VLFL-LIb

3.5.8 PL comparison: Comparison, assignment and transfer of PL

(SG-Library 4.7 Documentation -> Polygons and Contours -> General PL functions -> PL comparison)

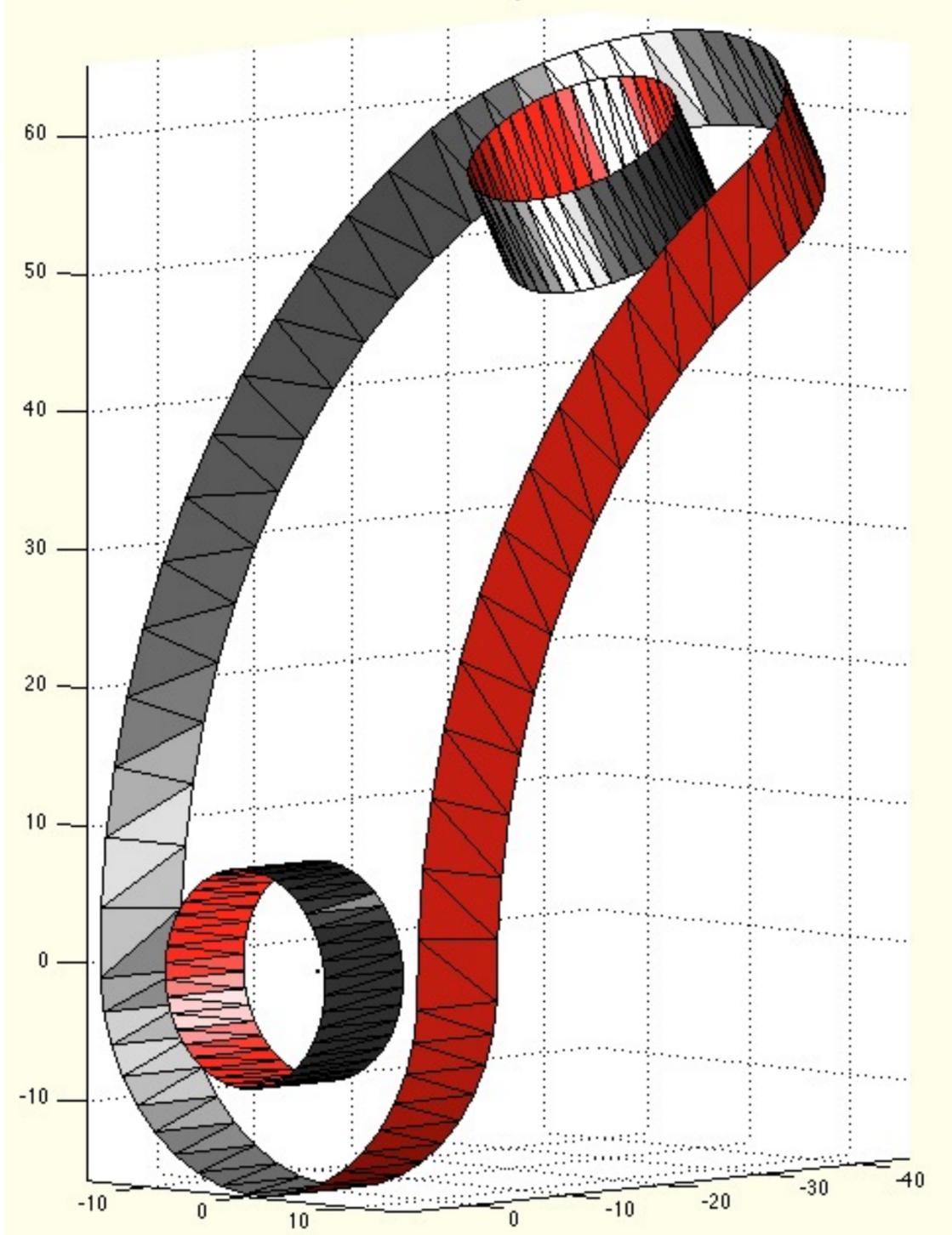


The following toolbox functions belong to this group:

- **PLcorrelate(PLA,PLB,stype,ctype,mtyp)** - returns the correlation of two single point lists

3.6 CPL to Surfaces: Surfaces from spatial contours

(SG-Library 4.7 Documentation -> Polygons and Contours -> CPL to Surfaces)



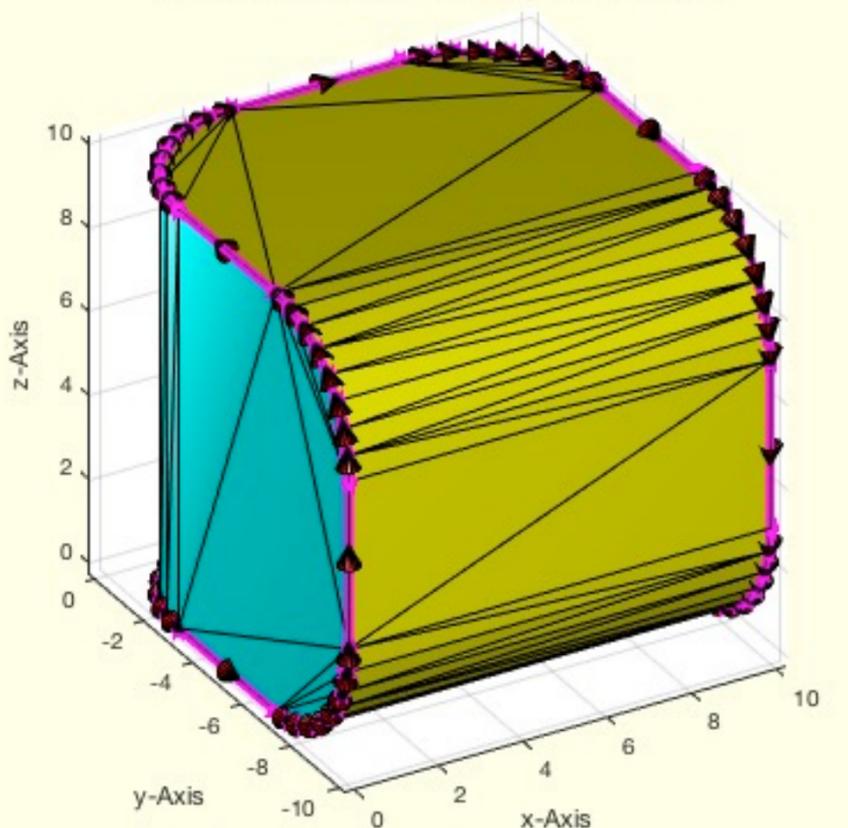
The following toolbox functions belong to this group:

- **FLcontourwallELn(EL,n)** - returns the wall facets between 2 contours given by an edge list

3.7 CVL to Solid Geometries: Surfaces from spatial contours

(SG-Library 4.7 Documentation -> Polygons and Contours -> CVL to Solid Geometries)

VLFLoFCVLdelaunay3D: 22-Aug-2018 17:13:43



The following toolbox functions belong to this group:

- **VLFLoFCVLdelaunay2D(CVL)**; - returns a triangulation for an almost planar CVL
- **VLFLoVLELdelaunay3D(OVL,EL)** - returns the top and below tessellation for ONE closed vertex list which cuts a convex solid into two parts

- **VLFLofCVLdelaunay3D(CVL)** - returns the top and below tessellation for ONE closed vertex list which cuts a convex solid into two parts

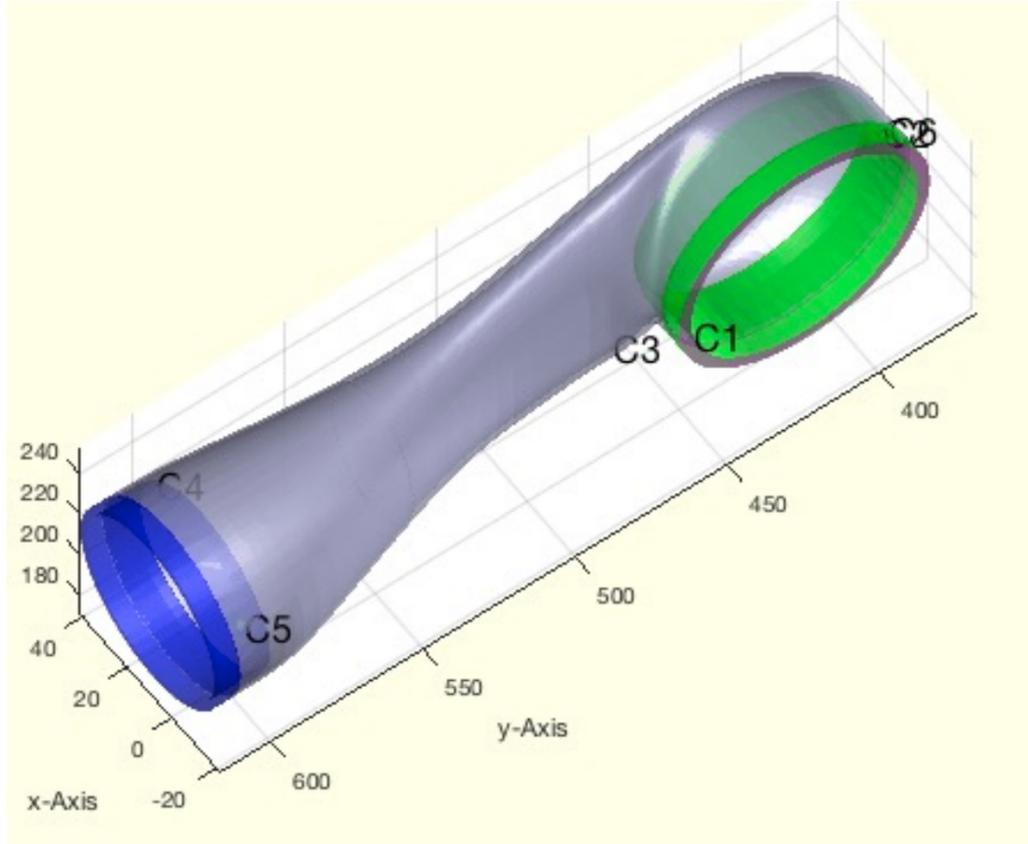
4 Surfaces: Processing of open or closed tessellated surfaces in 2D and 3D

(SG-Library 4.7 Documentation -> Surfaces)

Facets, Surfaces or Surfaces can only be viewed together. Many surfaces from CAD programs are not "waterproof", so they have open edges. Feature Surface, the surfaces between edges with a transition angle above an alpha threshold value, are always defined by the feature edges and are always open. The triangular surfaces are tessellated from circular edges, whereby matlab has two approaches.

Mapping Toolbox: Fill Polygon

Matlab: Delaunay triangulation



The functions are separated into the following toolbox sections:

- **4.1 2D Surfaces:** Surfaces in the 2D plane
- **4.2 3D Surfaces:** Open and closed surfaces in 3D space
- **4.3 Feature Surfaces:** Feature Edges and Feature Surfaces
- **4.4 Surfaces to Solid Geometries:** Solid bodies from open surfaces

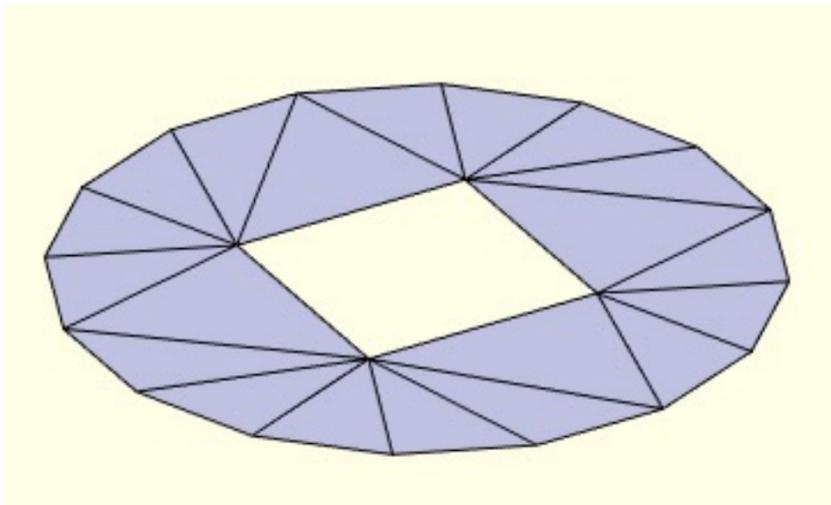
4.1 2D Surfaces: Surfaces in the 2D plane

(SG-Library 4.7 Documentation -> Surfaces -> 2D Surfaces)

Planar surfaces in 2D always consist of a 2D point list and a surface list. They always have edge contours, which are described via an edge list.

The creation of the polygons is possible via the

Delaunay Triangulation (Matlab) or via the function poly2fv (Mapping Toolbox).



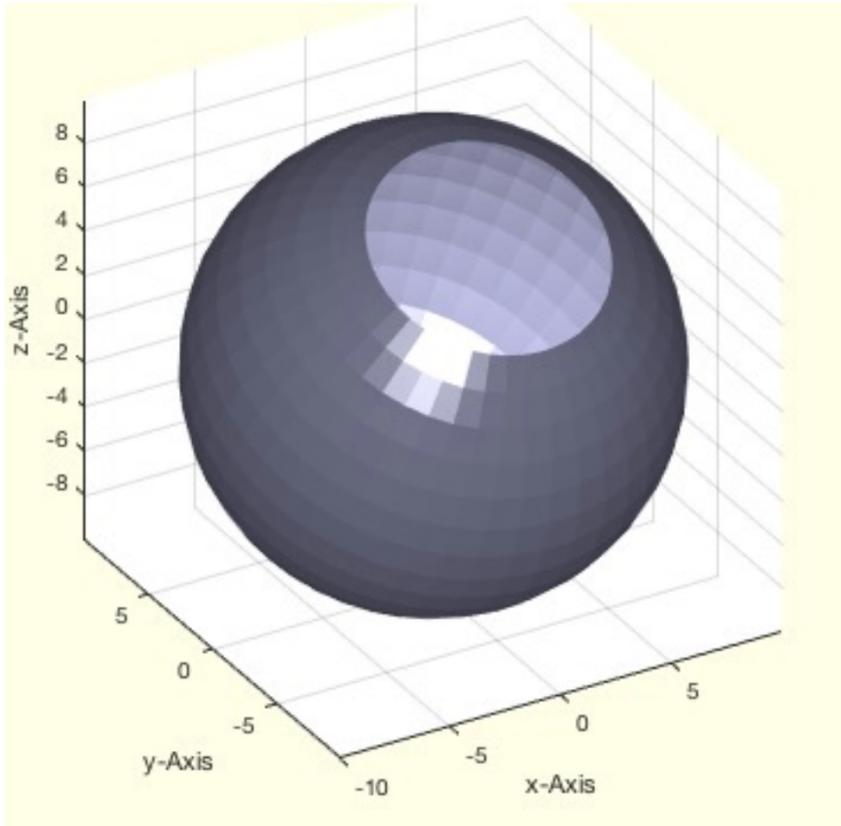
The following toolbox functions belong to this group:

- **FLofPLEL(PL,EL)** - returns tessellation of a 2D points list and contour edge list
- **GPLauxgridpointsPLEL(PL,EL,dx,dy)** - returns for a given 2D contour point list auxiliary points to define a plane surface
- **VLFLspherecurvedPLEL(PL,CEL,R,d)** - returns VL and FL for a sphere-curved surface given by a point list and contour edge list
- **PLELDelaunay(PL,EL)** - return the Delaunay Triangulation

- **PLFLselect(PL,FLG)** - returns only the required points for a given edge list. The edge list is reindexed
- **PLFLofCPLdelaunay(CPL,ADDVL)** - Returns 2D point list and facet list of a triangulated contour
- **CPLunitePLFL(PL,AFL)** - returns the enclosing contour point list for a 2D triangulated surface
- **PLFLfaceNormal(PL,FL,fi)** - returns the rounded (1e-5) length of the area size/length of normal vector
- **PLFLofVLELdelaunay(VL,EL)** - closes a planar surface of VLEL by delaunay
- **PLFLofCPLdelaunayGrid(CPL,ds,dx,dy)** - returns a point list and facet list for a grid filled contour list

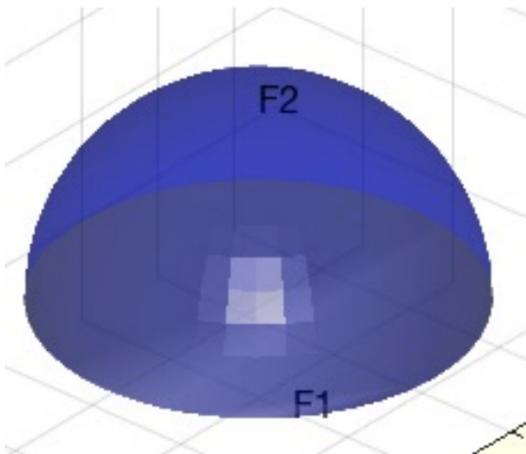
4.2 3D Surfaces: Open and closed surfaces in 3D space

(SG-Library 4.7 Documentation -> Surfaces -> 3D Surfaces)



4.3 Feature Surfaces: Feature Edges and Feature Surfaces

(SG-Library 4.7 Documentation -> Surfaces -> Feature Surfaces)



4.4 Surfaces to Solid Geometries: Solid bodies from open surfaces

(SG-Library 4.7 Documentation -> Surfaces -> Surfaces to Solid Geometries)

There are a whole series of problems in which one or more surfaces open at the edge are obtained, which one would like to transform from a two-dimensional surface into a three-dimensional body.

Typical applications are the processing of surfaces of scanned objects such as people or clothing etc.



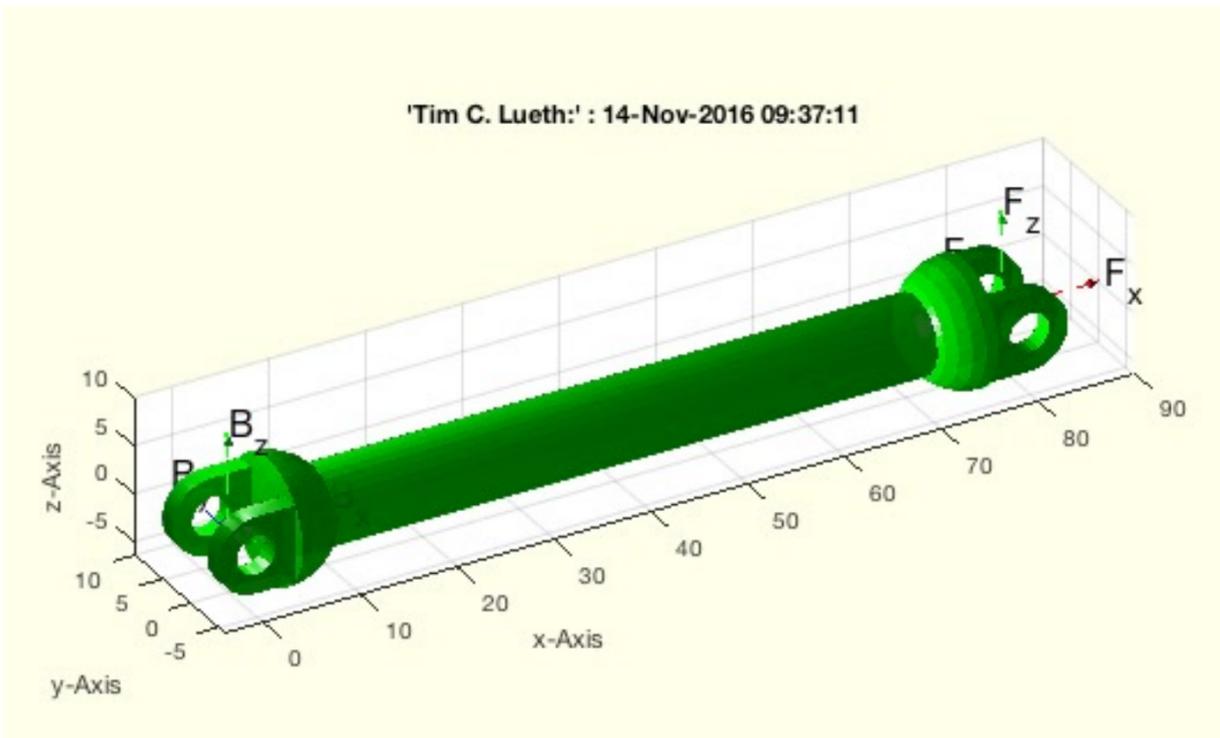
The following toolbox functions belong to this group:

- **SGofSurface(OVL,OFL,t,d,s,cn)** - returns a fitting solid relativ to a surface

5 Solid Geometry Modeling: Generation of surface models

(SG-Library 4.7 Documentation -> Solid Geometry Modeling)

This function group can be used to design solid bodies.



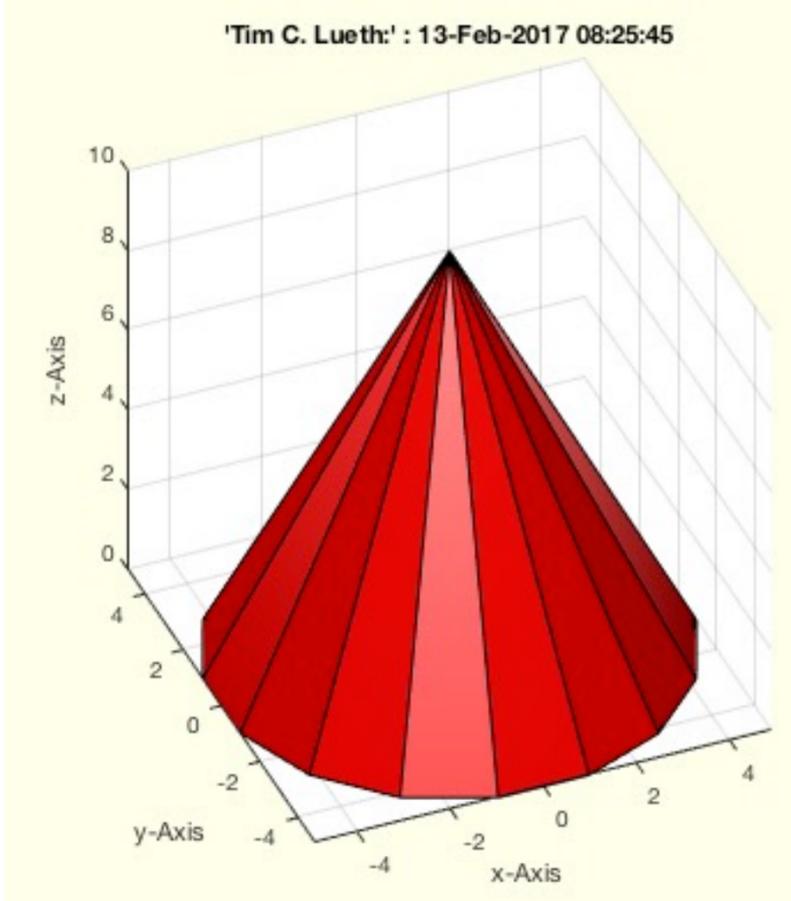
The functions are separated into the following toolbox sections:

- **5.0 SG basic shapes:** Generation of elementary solid bodies
- **5.1 Spatial Transformation:** Spatial rotation and movement of SG
- **5.2 SG of CPL Extrusion:** Extrusion of boundary contours
- **5.3 SG of CPL Connections:** Connecting boundary contours
- **5.4 SG of Meshes:** Creates SG from lines, edges, meshes
- **5.5 SG Cutting:** Cutting SG into several parts
- **5.6 SG Boolean Operations:** Boolean operations with surface models
- **5.8 SG Slicing:** Layer separation of SG

5.0 SG basic shapes: Generation of elementary solid bodies

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG basic shapes)

These functions directly create a solid. These are simply basic shapes that are used more frequently, for example when marking coordinate systems or converting text into 3D letters.



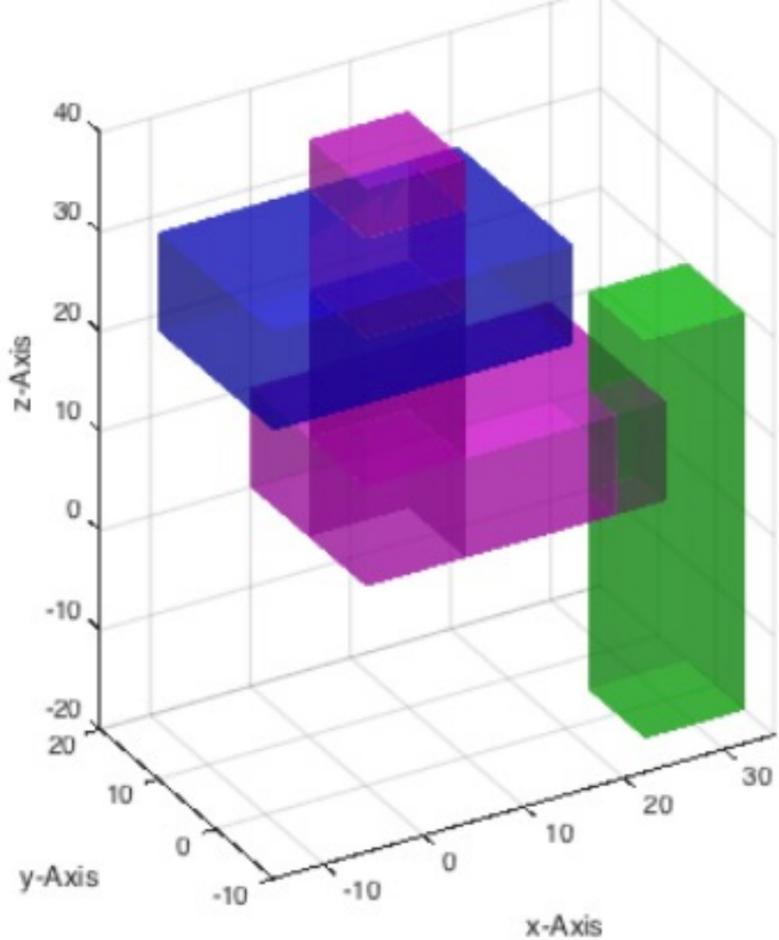
The following toolbox functions belong to this group:

- **VLFLweave(x,y,n,m,h,b,s,f)** - returns the vertex list XVL and facet list XFL of a weaved rectangle
- **VLFLyarn(l,n,ld,b,h,s,u)** - calculates vertex list and facet list for a wire-yarn
- **VLFLcylinder(Z,R,f,o)** - calculates vertex list and facet list for a cylinder
- **VLFLellipse1(Z,Rx,Ry,dx,f)** - returns a vertex list and a facet list for a defined tube geometry
- **VLFLtext(text,dt,t,sx,sy,sz)** - returns vertex/facet list for a text string
- **VLFLexpboard(text,dx,dy,dz,nx,ny)** - returns vertex/facet list of a test board with textural description
- **VLFLellipse2(H,Rx,Ry,dx,f,sn,h,sb)** - returns a vertex list and a facet list for a defined light weight tube geometry
- **VLFLellipse3(rx,ry,rz,dr,nc,na,nb)** - returns light weight structure of a closed sphere or ellipsoid
- **VLFLcreateframe(X,Y,H,b)** - returns a solid frame model in the x/y plane
- **VLFLcreateblock(X,Y,H)** - returns a solid block model in the x/y plane
- **VLFLdome(RZ,RX,RY,wall,nfo,nfi)** - return VL and FL of a dome
- **VLFLhemisphere(CL,RZ,wmin,wmax)** - returns a surface of a hemisphere
- **VLFLpost(h,RX,RY,wall,nfo,nfi)** - returns VL and FL of a hollow post
- **VLFLcap(ZP,ZD,RX,RY,wall,nfo,nfi)** - returns a tube covered with a cap
- **VLFLcone(H,R,nf)** - returns vertex list and facet list for a cone solid
- **SGtext(SG,stext,ez,sx,sy,ha)** - returns a SG that does fit on the surface on another SG
- **SGlinkage(R,D,H,RA,D2)** - returns the solid geometry of a linkage
- **SGbox(S,n)** - returns solid geometry of a origin centered box
- **SGsphere(R,nr,wt,wb,Ry,Rz)** - returns a spherical SG with minimal nr of points
- **SGcone(H,R,nf)** - returns a solid geometry of a cone
- **SGspherelink(Lz,R1,R2,olap)** - returns a spherical link

5.1 Spatial Transformation: Spatial rotation and movement of SG

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> Spatial Transformation)

This group of functions has the task to move the bodies in space absolutely or relative to each other or relative to frames or feature surfaces.



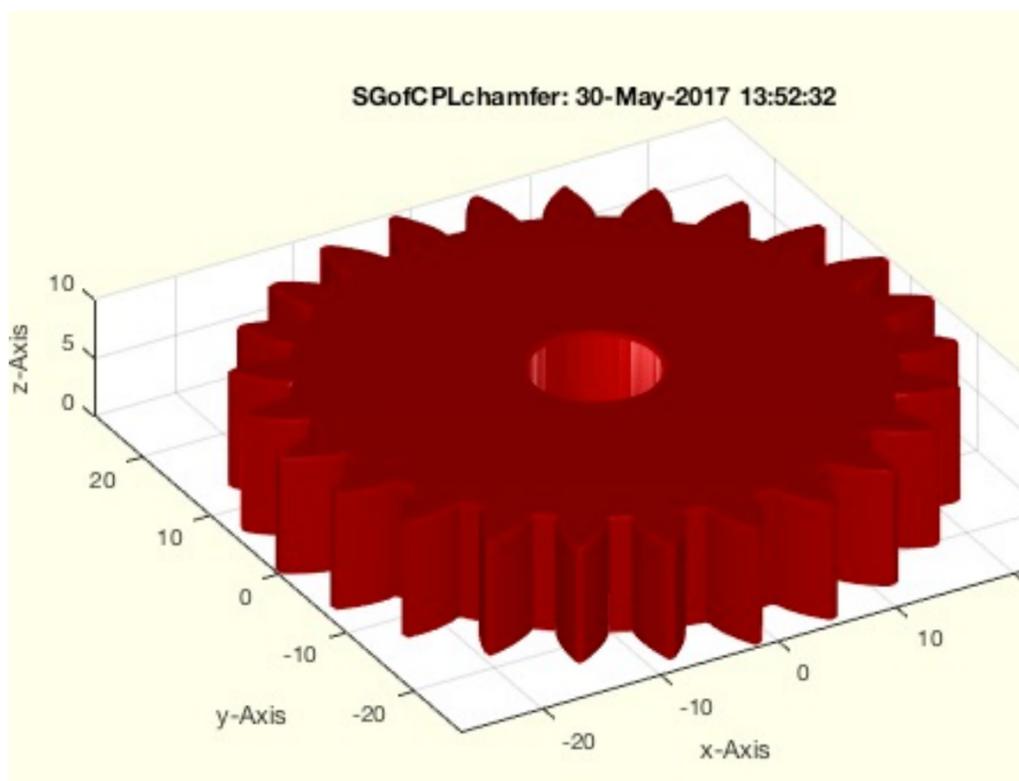
The following toolbox functions belong to this group:

- **SGtransP(SG,p)** - moves a solid geometry (or a list) relative using a translation vector
- **SGtrans0(SG)** - moves a solid geometry (or a list) into the origin of the coordinate system
- **SGtrans1(SG)** - moves a solid geometry (or a list) into quadrant 1 of the coordinate system
- **SGtransR(SG,R)** - rotates a solid geometry (or a list) relative using a rotation matrix
- **SGtransT(SG,T)** - transformats a solid geometry or list using a homogenous transformation matrix
- **SGtrans(SG,T)** - multi transformation modes for a solid geometry
- **SGtransrelSG(SGA,SGB,rel,gap)** - changes position of a solid relative to another solid
- **SGtransrelT(SG,T0,T)** - tranforms a solid relative to known one

5.2 SG of CPL Extrusion: Extrusion of boundary contours

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG of CPL Extrusion)

With the help of these functions planar polygons can be extruded by translation or rotation or along a path and the consideration of coordinate systems to bodies.



The following toolbox functions belong to this group:

- **SGofCPLz(CPL,z)** - returns a 2½D extruded Solid volume from a contour polygon list (CPL)
- **SGofCPLrot(CPL,n,rcorr)** - returns a solid geometry from of a z-axis rotated closed polygon list
- **SGofCPLsphere(CPL,Ri,d,ns)** - returns solid geometry of a wrapped shell
- **SGofCPLT(CPL,T)** - returns a extruded SG from a CPL and a final T matrix
- **SGofCPLzdeLaunayGrid(CPL,z,ds,dx,dy)** - returns a solid from a contour polygon list and grid resolution
- **SGofCPLzchamfer(CPL,z,ph,ed)**; - returns a solid with chamfered edges
- **SGofCPLrota(CPL,alp,mov,amin,h)** - returns a solid geometry by rotateing a closed x z contour around z axis

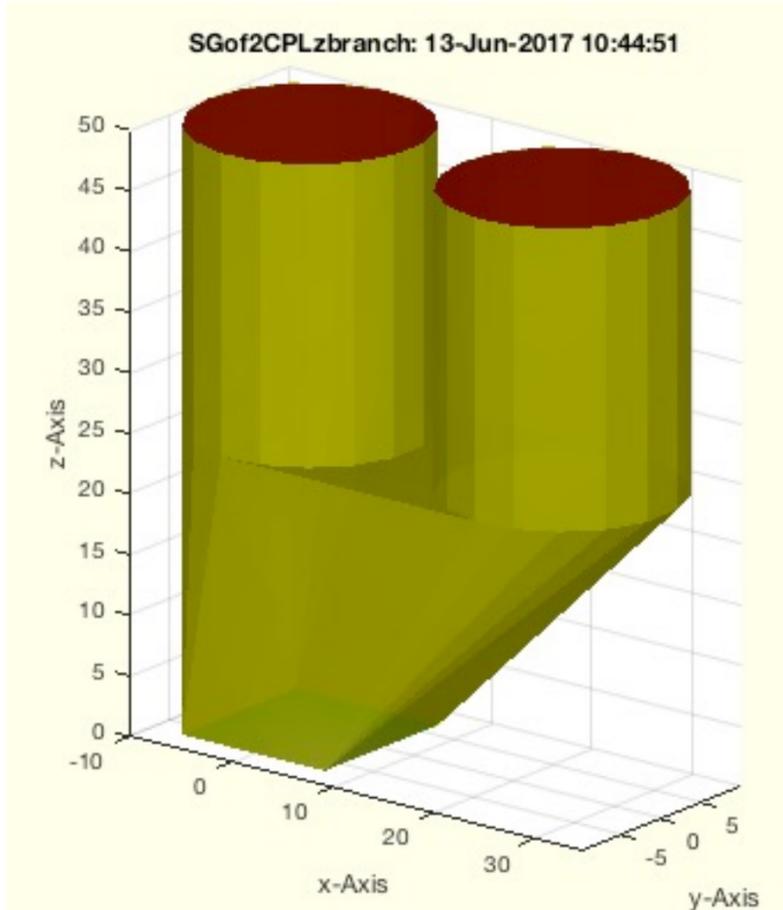
- **SGofCPLtransT(CPL,T1,T2)** - returns a solid from a 2D contour and a list of frames

5.3 SG of CPL Connections: Connecting boundary contours

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG of CPL Connections)

In contrast to extrusion, there are also tasks in which two, potentially nested, contours are to be connected via an outer surface. The task here is to

- to transfer different forms into each other
- Assign inner and outer contours
- map several contours to another or one to several contours



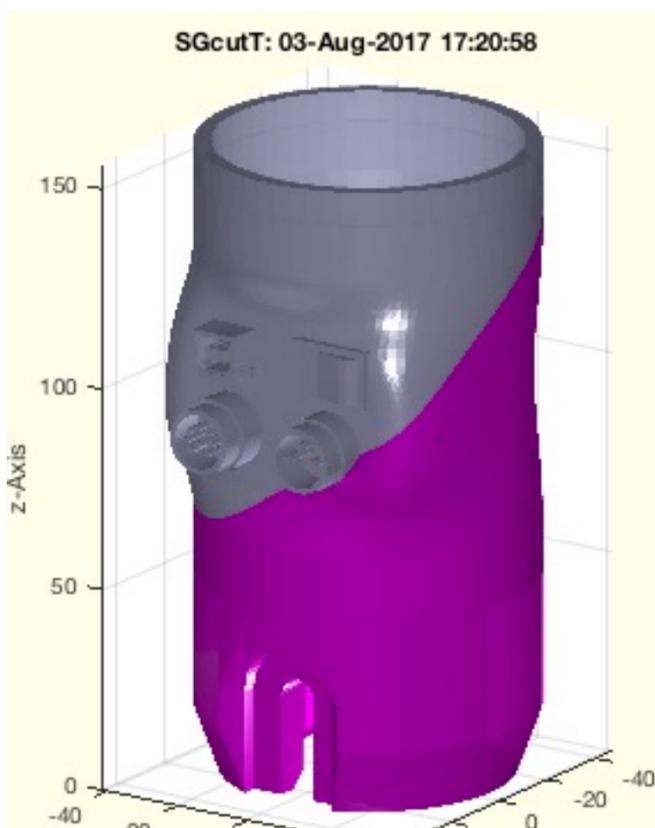
5.4 SG of Meshes: Creates SG from lines, edges, meshes

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG of Meshes)

5.5 SG Cutting: Cutting SG into several parts

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG Cutting)

This group of functions has the task to move the bodies in space absolutely or relative to each other or relative to frames or feature surfaces.



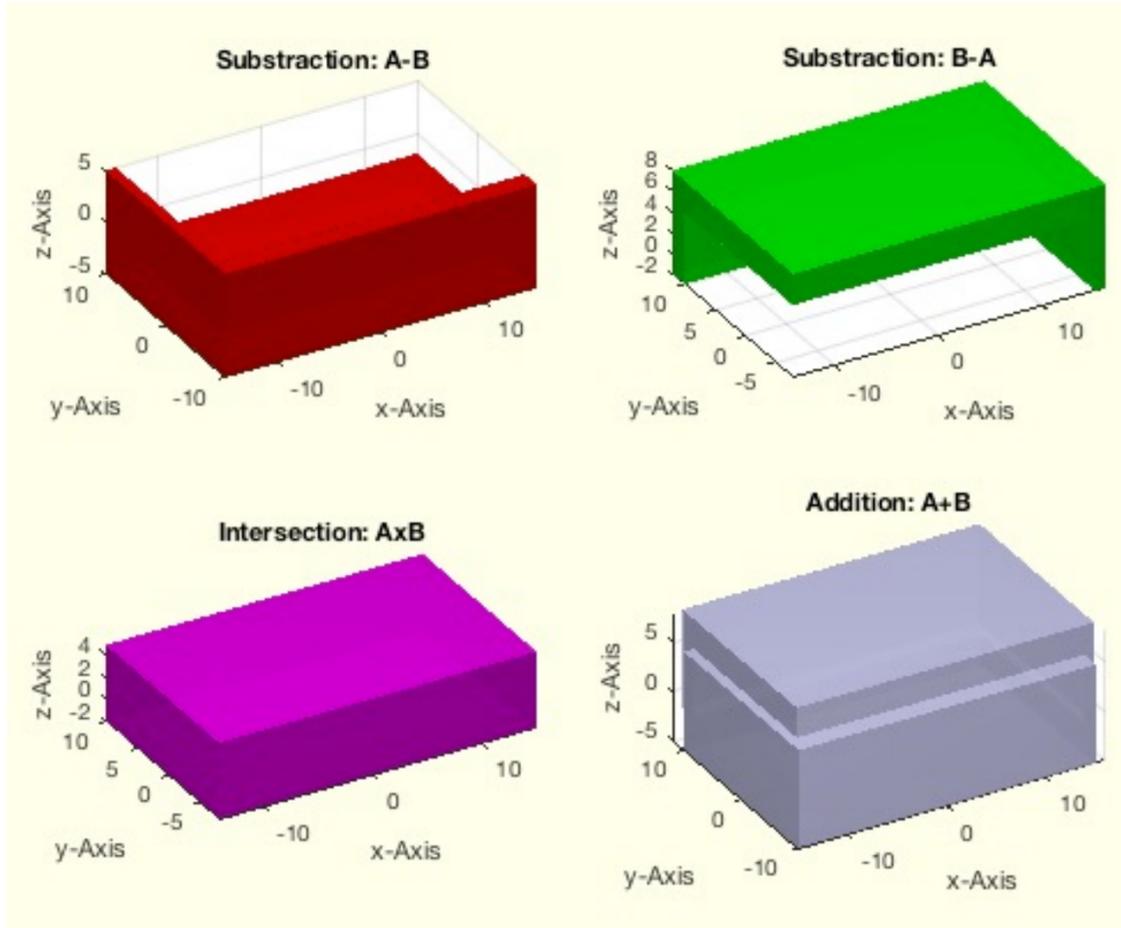
The following toolbox functions belong to this group:

- **SGcut(SG,z)** - Cuts a solid geometry into 2 parts at a defined z-plane
- **SGcut2(SG,z)** - Cuts a solid geometry by inserting vertices and facets
- **SGcutBB(SG,ax,de)** - cuts out a bounding box from a solid

- **SGpuzzlecut3D(SG,bsiz)** - creates from a large solid geometry smaller printable parts
- **SGcutT(SG,Ts,centxy,expl,ct)** - cuts an object below a arbitrary plane using SGcut relative to the center of floor of bb

5.6 SG Boolean Operations: Boolean operations with surface models

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG Boolean Operations)



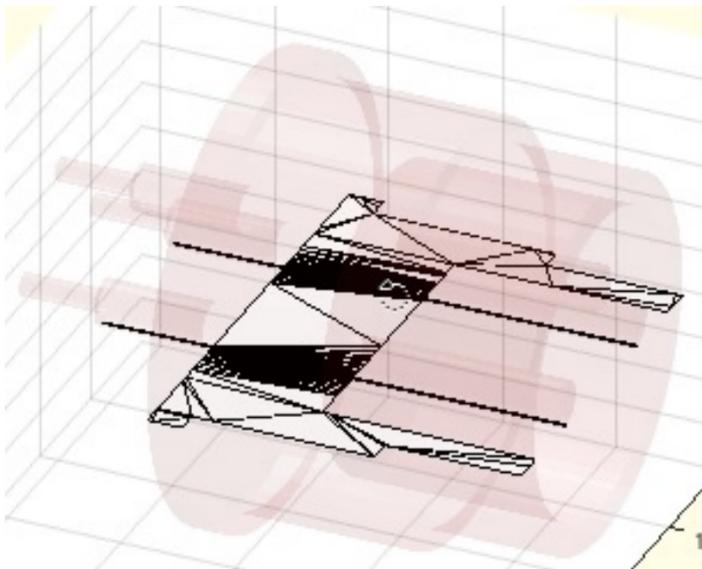
The following toolbox functions belong to this group:

- **SGbool3(flag,A,B,thr,tho)** - Boolean operators for solid geometries
- **SGbool3(flag,A,B)** - returns the result of a boolean operation on two solids
- **SGbool4(flag,A,B,thr)** - returns the result of a boolean operation on two closed elementary solids
- **SGbool5(flag,A,B,thr)** - returns the correct result of a boolean operation on two closed elementary solids
- **SGbooltest(tests)** - Procedure to test different cases using SGbool and CSGsample
- **SGboolanalyze(A,B,thr)** - plots the two separated surfaces of A and B when crossed
- **SGboolTL(A,op,B,Amin)** - returns a Boolean operation including re T esse L ation

5.8 SG Slicing: Layer separation of SG

(SG-Library 4.7 Documentation -> Solid Geometry Modeling -> SG Slicing)

This function group creates cross-sectional contours of solid bodies, as they are necessary for dimensions or technical drawings, cutting patterns or the construction of bodies over layered plats.



The following toolbox functions belong to this group:

- **VLELslicer(VL,FL,z)** - returns the crossing vertices and lines of a sliced object
- **VLFLofrangez(VL,FL,z1,z2,sname)** - returns a reduced facet list and resorted vertex list for all facets of a specified plane
- **PLELcheckerr(PL,EL,sllicence)** - checks whether a point list and edge list are correct
- **SGslicer(SG,z)** - returns the delaunayTriangulation of the sliced plane
- **FILofrangez(VL,FL,z1,z2)** - returns an facet index list for facets crossing a plane
- **SGslicer(SG,z)** - returns the delaunayTriangulation of the sliced plane

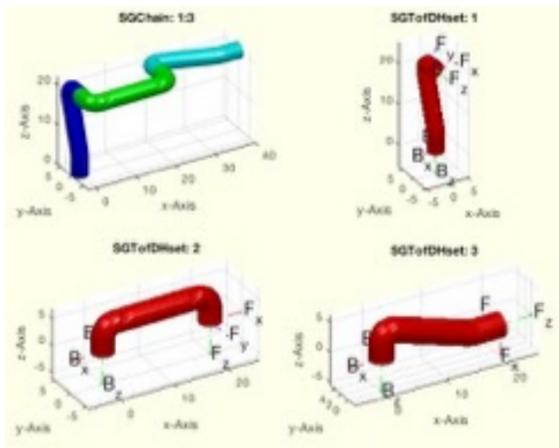
- **CPLsingleSolidSlicer(VL,FL,slz)** - Sliced CPL of a single closed surface
- **CPLofSGslice(SG,z)** - returns the CPL of a sliced SG
- **CPLofSGslice2(SG,z)** - return slices of a separated SG
- **CPLofSGslice3(SG,z)** - returns CPL and CVL for different sliced heights and directions
- **VLELslicer2(VL,FL,z)** - returns the crossing vertices and lines of a sliced object
- **CVLofSGslices(SG,n,l,thre)** - returns slices as CVL (CPL including z) of a SG

6 Frames and Kinematics: Generation of coordinate systems and kinematic chains

(SG-Library 4.7 Documentation -> Frames and Kinematics)

With these functions coordinate systems (frames) can be created to design kinematic chains of moving mechanisms, but also to be able to arrange bodies spatially to each other. Since frames are often relative to surfaces with certain properties, the concept of feature surfaces is explained here.

The real-time simulation of movements is implemented with multi-body simulation functions.

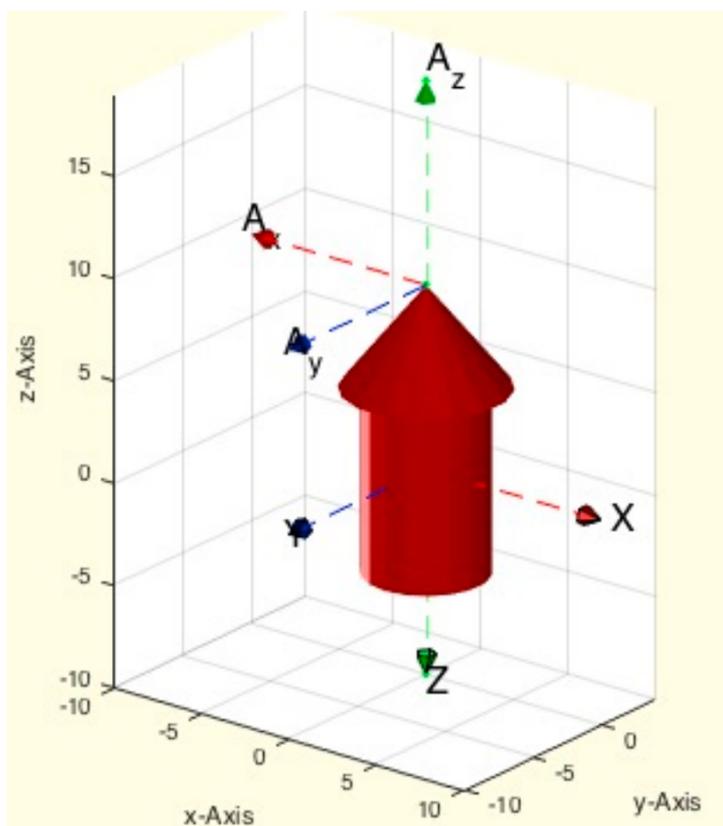


The functions are separated into the following toolbox sections:

- **6.1 Frame Definition** : Attaching Frames to a Solid Geometry
- **6.2 Kinematics Chains**: Creating Numerical Kinematic Chains
- **6.3 Forward and Inverse Kinematic**: Robotics
- **6.4 Symbolic Definitions**: Creating Symbolic Kinematic Chains
- **6.5 Fourbar Linkage**: Mechanism Design

6.1 Frame Definition : Attaching Frames to a Solid Geometry

(SG-Library 4.7 Documentation -> Frames and Kinematics -> Frame Definition)



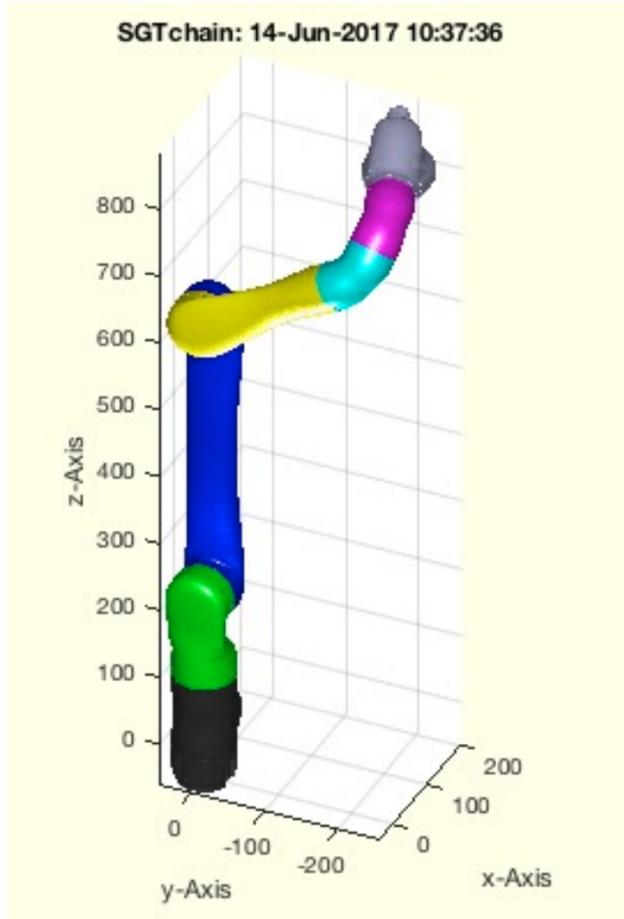
The following toolbox functions belong to this group:

- **SGTui(SG,N,fe,FS,Rz)** - returns a HT matrix for a manuel selected union space
- **SGTremove(SG,N)** - removes a transformation frame from a solid geometry
- **SGT(SGN,N,SN)** - returns a called HT-Frame from a solid's struct
- **SGTget(SGN,N)** - returns a named frame of a solid geometry
- **SGTset(SGN,N,T,TFiL)** - sets or replaces a named frame of a solid geometry
- **SGTplot(SGN,N,SN)** - simply plots solid including frames
- **SGTframeplot(SGN,N)** - plots one ore more frame of a solid

- **SGTsetorigin(SG,Nam)** - moves the solid into a position that the base frame become the origin
- **SGTBB(SG)** - replaces the complex surface geometry by a simplified bounding box

6.2 Kinematics Chains: Creating Numerical Kinematic Chains

(SG-Library 4.7 Documentation -> Frames and Kinematics -> Kinematics Chains)

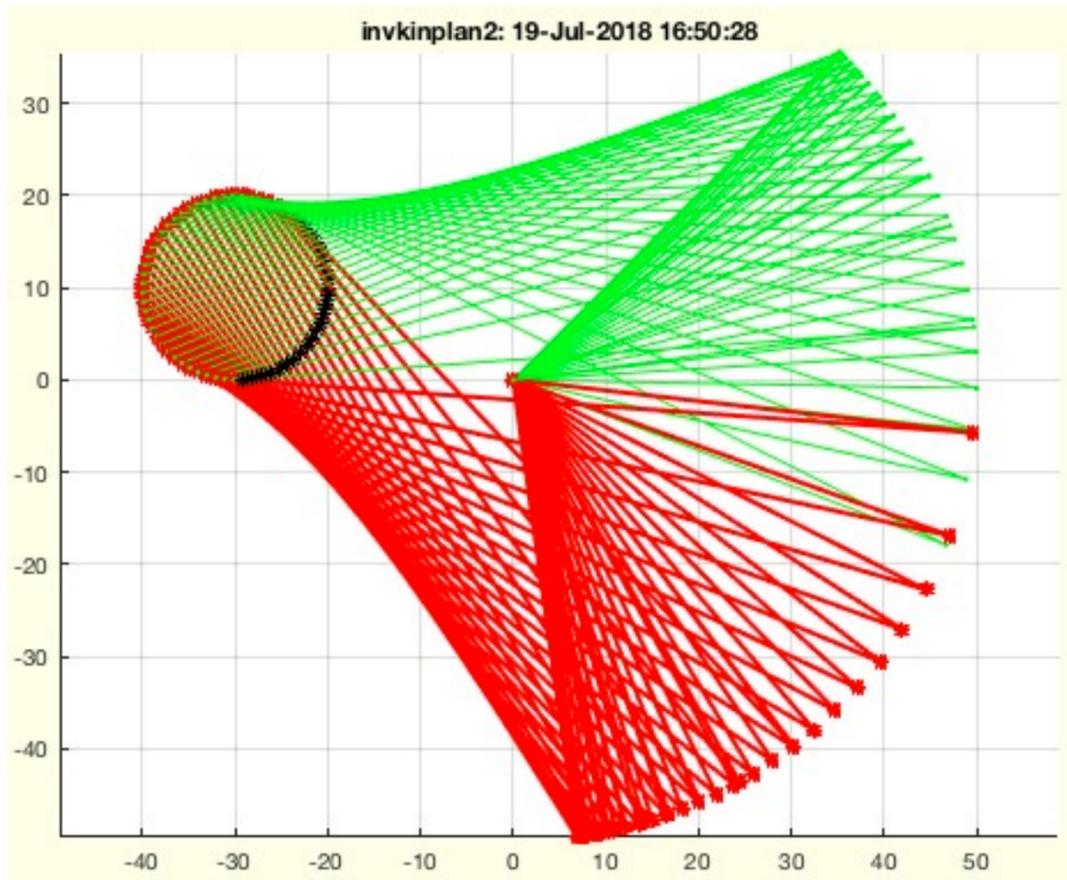


The following toolbox functions belong to this group:

- **SGTchain(SGs,phi,z,num,extr,B,F)** - returns the spatial transformed solids of a kinematic chain
- **SGTcalibchain(SGs,phi,Fram)** - changes the base frames of a set of solid geometries
- **SGTframeChain_39(num,extr,B,F)** - returns a list of frame connections for a cell list of solids

6.3 Forward and Inverse Kinematic: Robotics

(SG-Library 4.7 Documentation -> Frames and Kinematics -> Forward and Inverse Kinematic)

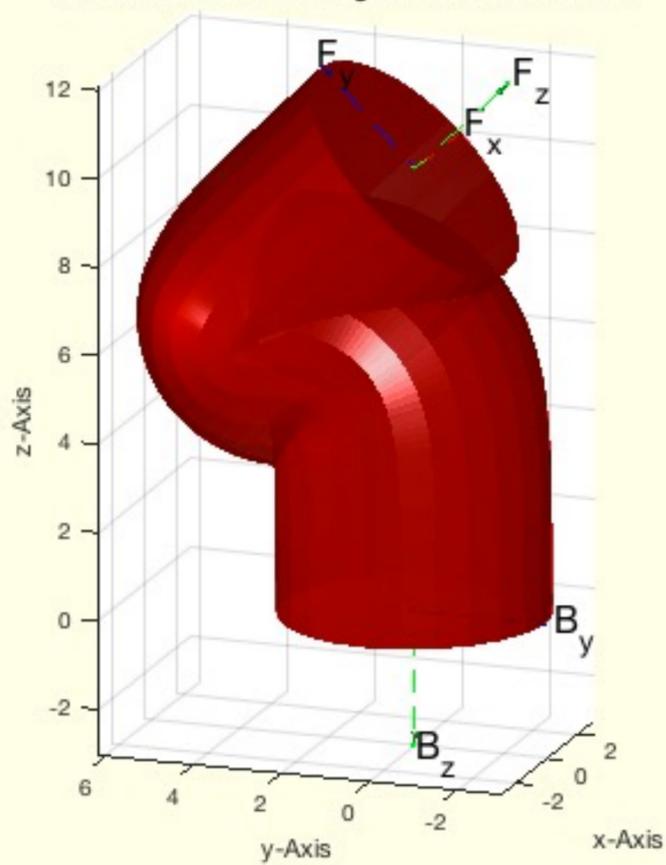


The following toolbox functions belong to this group:

- **invkinplan2(l1,l2,PL)** - returns the inverse kinematic for a planar 2 arm robot
- **invkinrplan3(d1,a2,a3,VL)** - returns the angles for a rotating planar two arm kinematic
- **forwkinrplan3(d1,a2,a3,WL)** - forward kinematic of a planar rz 2 arm rotating around an arm z axis

6.4 Symbolic Definitions: Creating Symbolic Kinematic Chains

(SG-Library 4.7 Documentation -> Frames and Kinematics -> Symbolic Definitions)

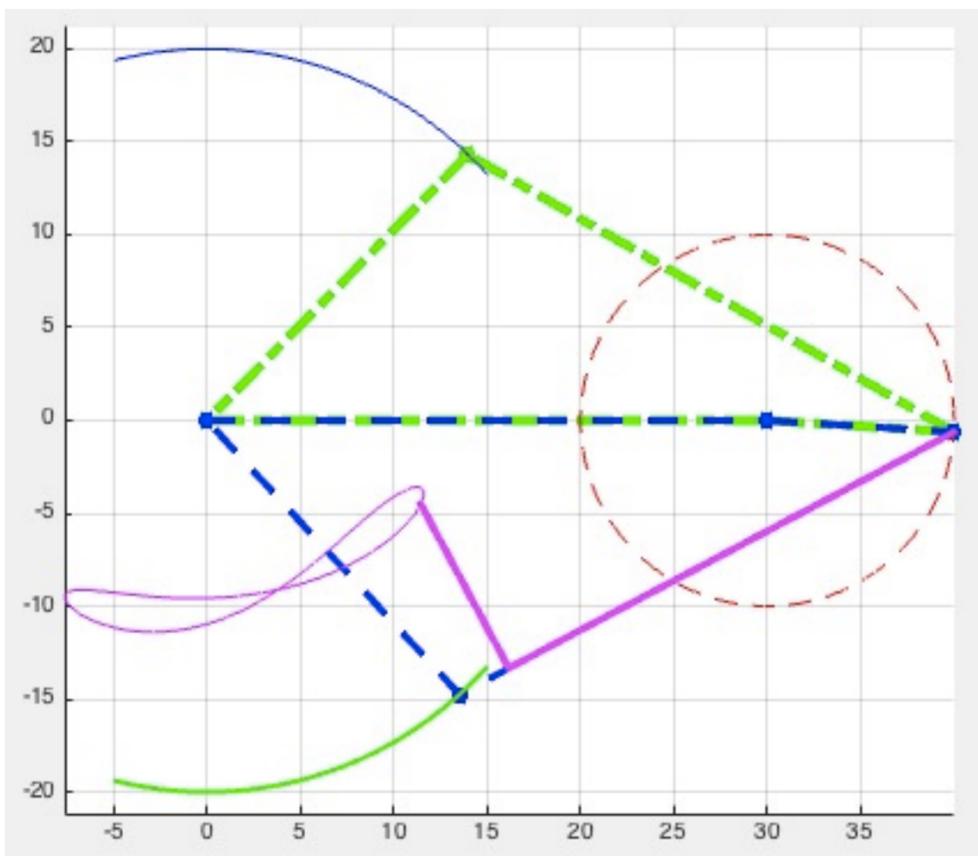


The following toolbox functions belong to this group:

- **SGTofDenavitHartenberg(D,A,be,r,g)** - returns from Denavit-Hartenberg values, a solid, frames and a symbolic description for DH
- **SGTofDHset(DHS,r,g)** - returns the solids for a kinematic chain defined by DH parameter

6.5 Fourbar Linkage: Mechanism Design

(SG-Library 4.7 Documentation -> Frames and Kinematics -> Fourbar Linkage)



The following toolbox functions belong to this group:

- **fourBarLinkage(a,b,c,d,wb,k1,k2)** - multi purpose function for a 4-Bar-Linkage
- **SGfourBarLinkageKit(task,2,3)** - Creation kit for Four-Bar-Linkages
- **synth4Bar2Pose(C1,D1,C2,D2,d,la,lb)** - returns 4 points for a 4 Bar linkage
- **calc4BarAngle(A0,B0,A1,lb,lc)** - returns 4-Bar-Linkage points for link B
- **plot4Bar(A0,B0,A1,B1,wl,cc)** - plots a 4-Bar-linkage
- **synth4Bar3Pose(C1,D1,C2,D2,C3,D3,d)** - returns 4 points for a 4 Bar linkage

7 Automatic Design, Optimization, Simulation: Solid Geometries, Joints, Mechanisms, Robotics

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation)

The SG library was originally written for this function group. The goal is to move from a manual or geometrically parameterized design to a criteria-based automatic design or an automatic optimization for criteria. Not only geometries but also kinematics and mechanisms should be designed automatically and optimized.

Manual interactive design steps are always necessary when there is no concept for the efficient formulation of the task.

The functions are separated into the following toolbox sections:

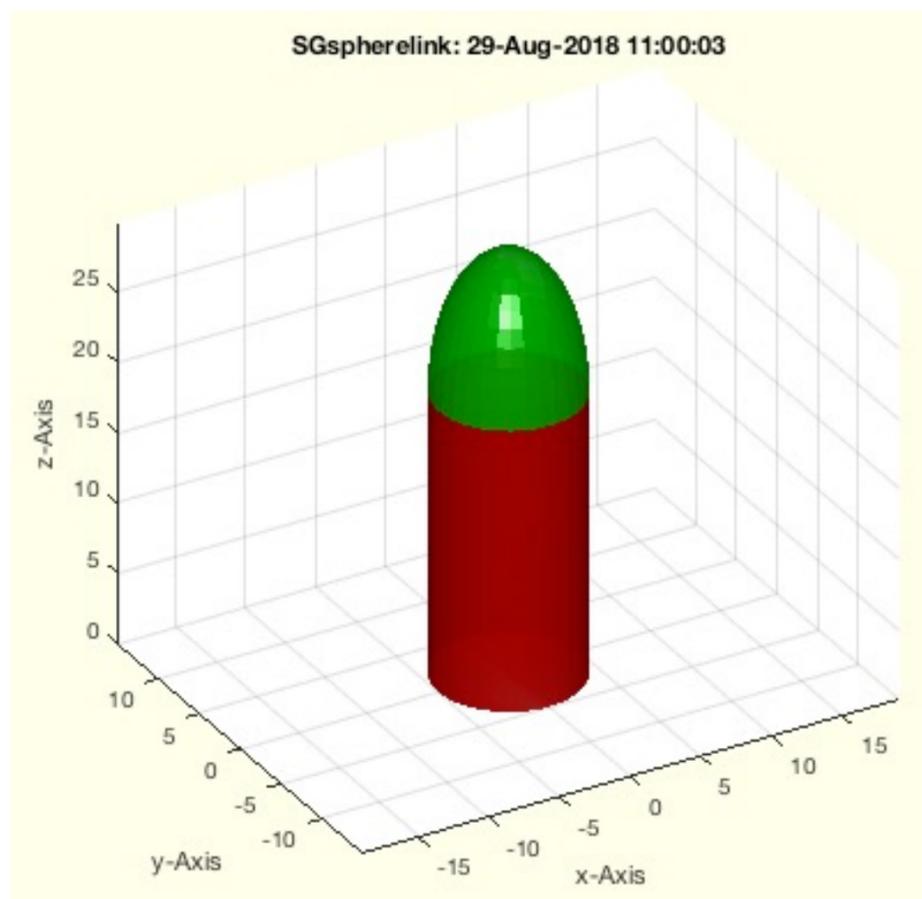
- **7.1 Parameterized Shape Generation:**
- **7.2 Parameterized Links and Joints:** SG for mechanisms
- **7.3 Automatic Shape Generation:**
- **7.4 FEM and Shape Optimization:** Analysis and shape optimization of SG with the PDE toolbox
- **7.5 Multi-Body Simulation:** Dynamic multibody simulation with Simulink/Simscape/Multibody

7.1 Parameterized Shape Generation:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> Parameterized Shape Generation)

The automatic design was based on the use of parameterized constructable solid bodies. It can be simply imagined that a screw diameter is determined according to the necessary tensile force acting on the screw. Instead of specifying the diameter, the force is specified and the diameter is calculated automatically. Nevertheless, the screw must also be designed according to DIN/ISO if the diameter is known. Instead of M6.234, M8 is selected, since M7 does not exist and it must always be greater than M6. Then the screw geometry must be calculated from the specification. The parameterisable design functions serve this purpose.

The aim of the automatic design is also to reduce the number of necessary parameterized designable basic elements.



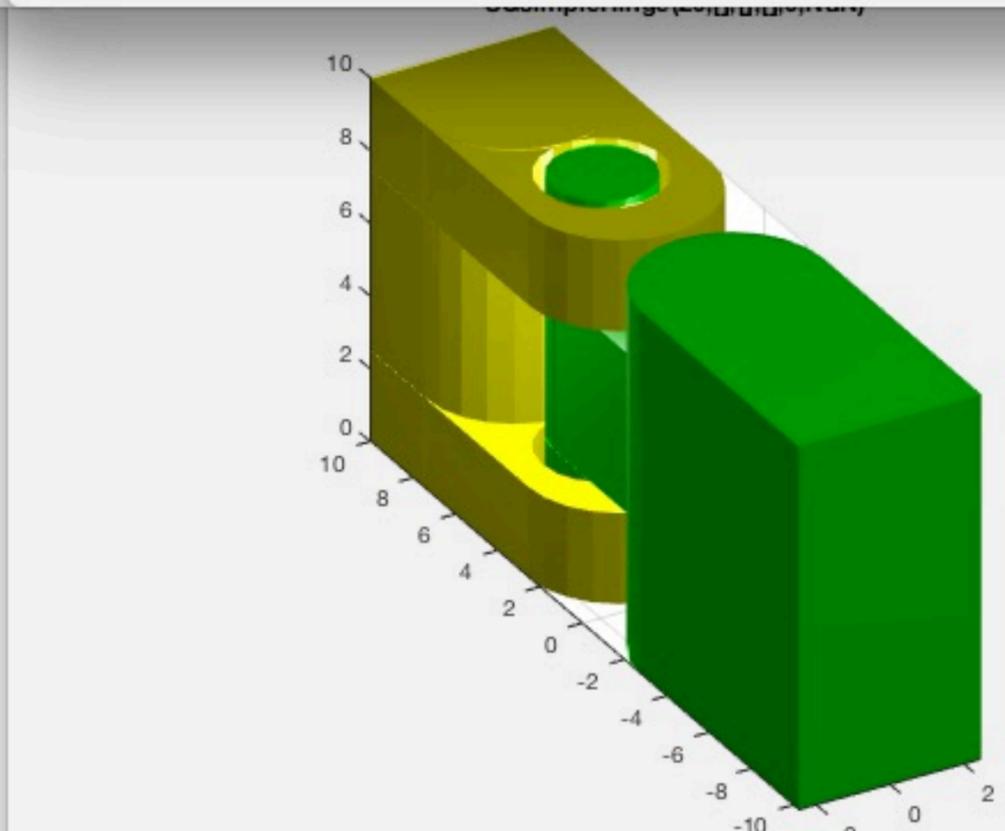
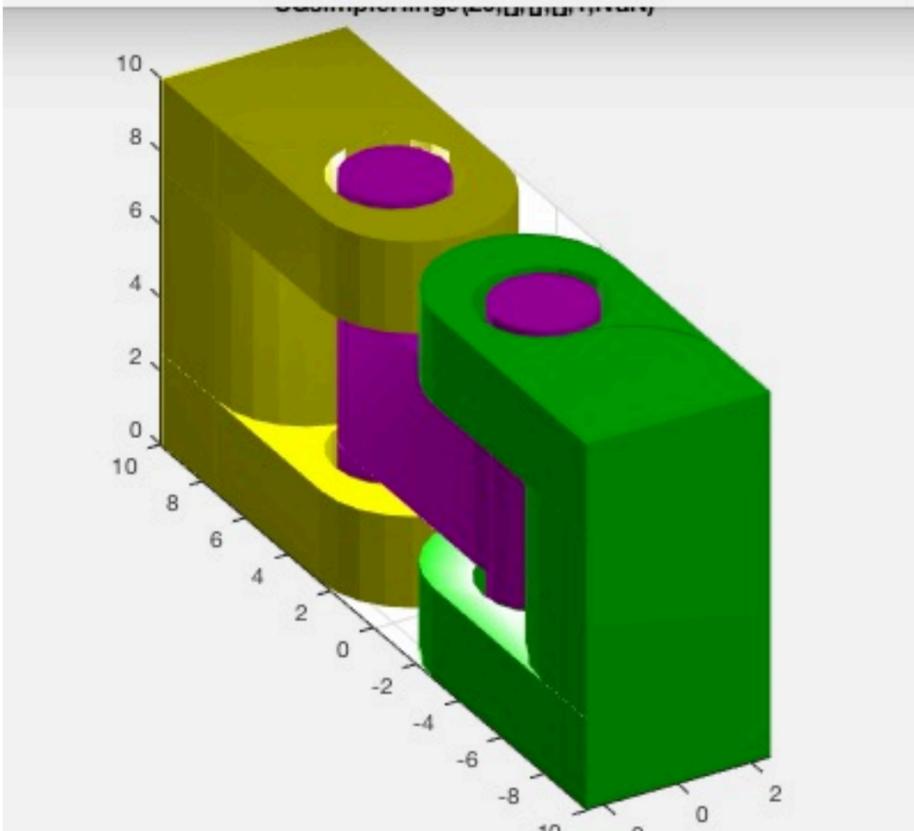
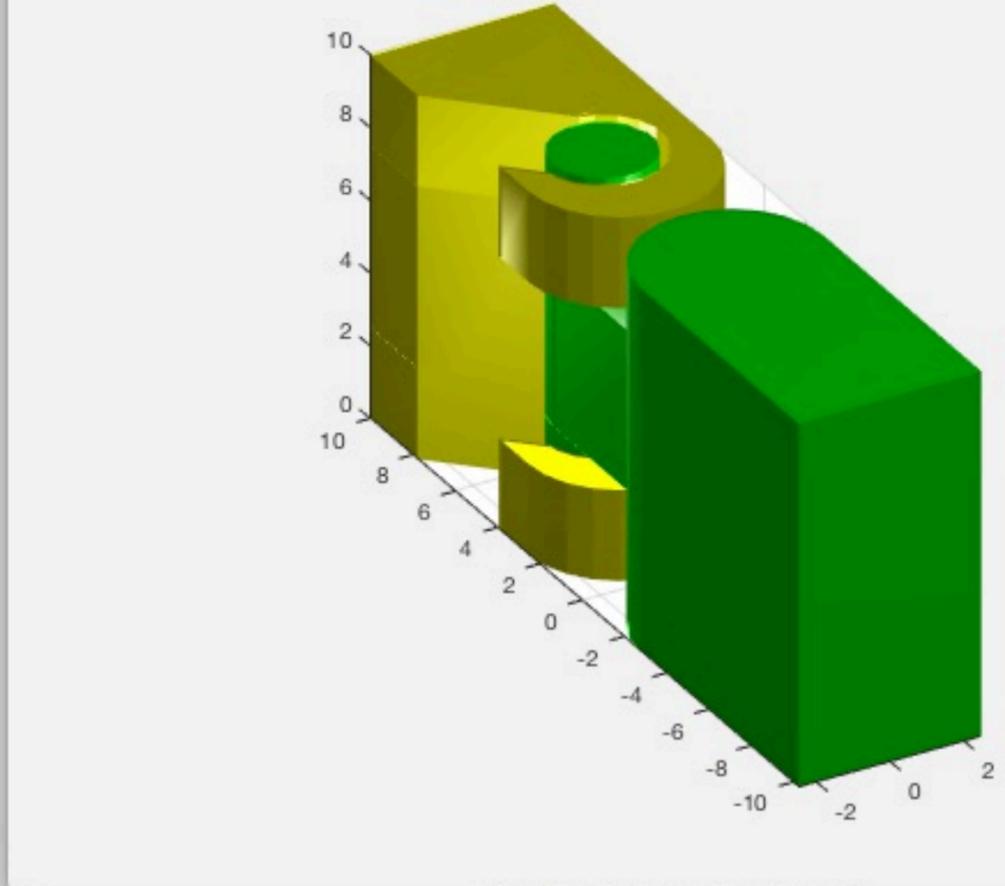
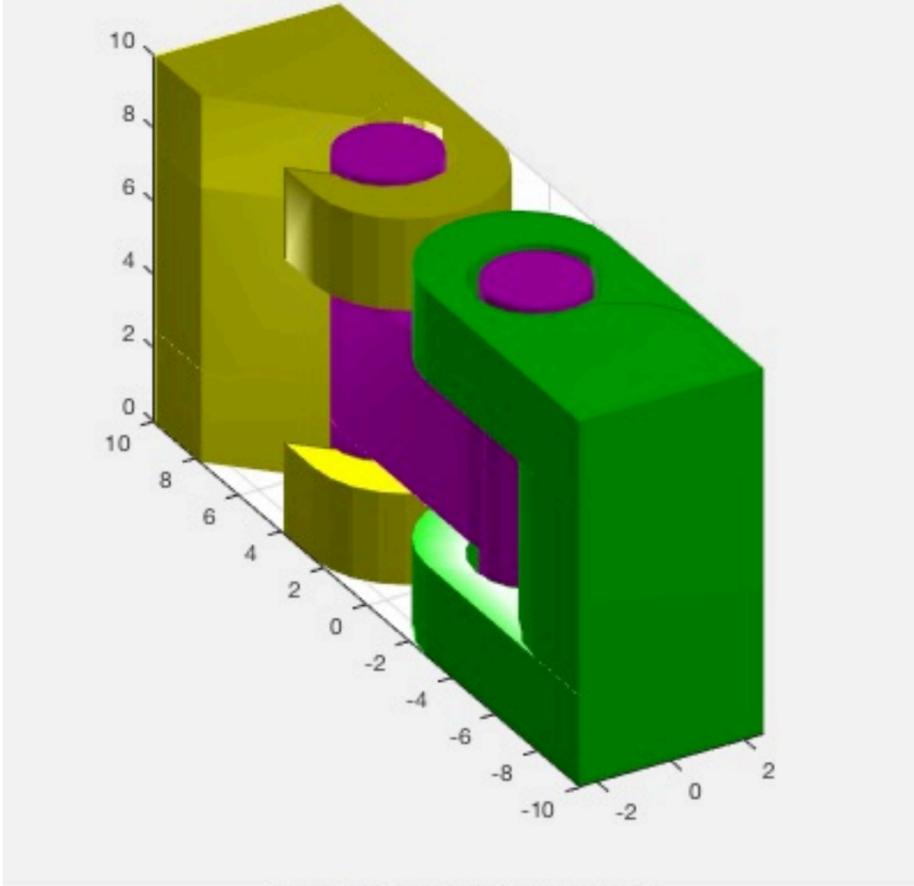
The following toolbox functions belong to this group:

- **DIN336(d)** - returns the parameter of the DIN 336 table
- **DIN13(M)** - returns the DIN-13 table for a metric threads
- **lofbendinggirder(h,b,s,F,E,Slim)** - returns the length of a bended girder
- **sofbendinggirder(l,h,b,F,E,Slim)** - returns the expected bending of a girder/cantilever
- **VLFLsnapfit(RI,RA,D,Hf,H,sh,Hh)** - returns VL and FL of a snapping hollow axle
- **DINhelp** - open different urls for DIN and ISO Standard Machine Elements
- **DIN913(M)** - returns the DIN913/ISO4026 table for a metric threads
- **SGiso4026(M,L,imb)** - SG of Hexagon socket set screw with flat point
- **DIN912(M)** - returns the DIN912/ISO4762 table for a metric threads
- **SGiso4762(M,L)** - SG of Hexagon socket set screw with cylindric head

7.2 Parameterized Links and Joints: SG for mechanisms

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> Parameterized Links and Joints)

With these functions, parameterized joints and structures can be designed to transform solid bodies into moving bodies. The functions are used for shaping and can already have frames to model kinetic chains.



The following toolbox functions belong to this group:

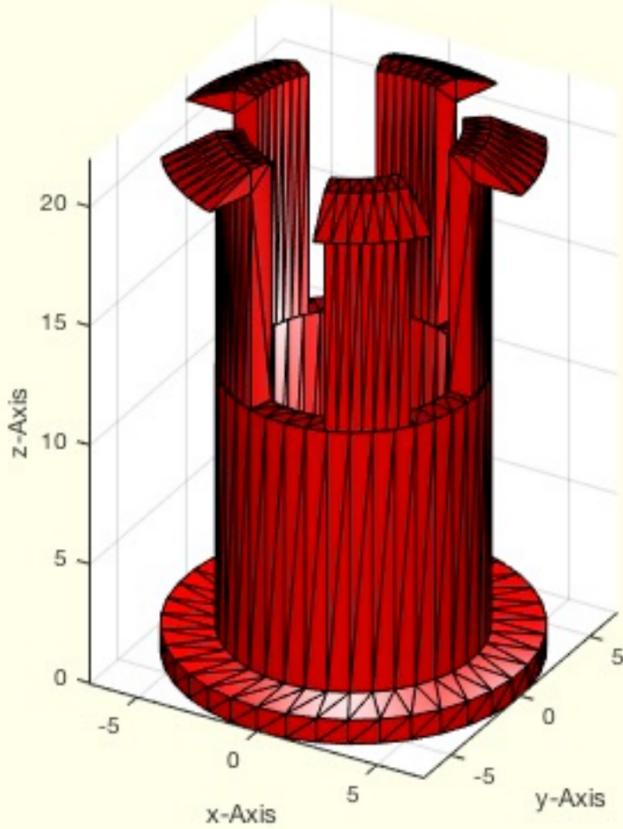
- **SGmodelJoint(Ty,pos,SL,EL)** - returns 3 separated Solids for automated design of joints
- **SGmodelNode(D,L,R,CPL,ez)** - returns a solid geometry of a post as fixed node
- **SGmodelLink3(L,lb,lf)** - returns solid geometries for R linkages
- **SGmodelKeyhole(RA,RO,rw,LA,LO,HO,slot)** - Creates a SG including a key and a keyhole
- **SGmodelLink1(L,D,SL,EL,DH,DL)** - SG of a cylindric rod
- **SGmodelLink2(L,L1,L2,K,H)** - Creates Solid for a Link im Style "Link2"
- **SGsimpleHinge(H,D,X,sl,ch,oa,ba,Ri)**; - returns a simple swivel hinge

7.3 Automatic Shape Generation:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> Automatic Shape Generation)

In contrast to parameterized form generation, automated or function-based form generation makes geometry generation dependent on the achievement of certain criteria.

For example, the force for compressing snap hooks is defined and the shape of these catches is calculated so that the force is reached.



The following toolbox functions belong to this group:

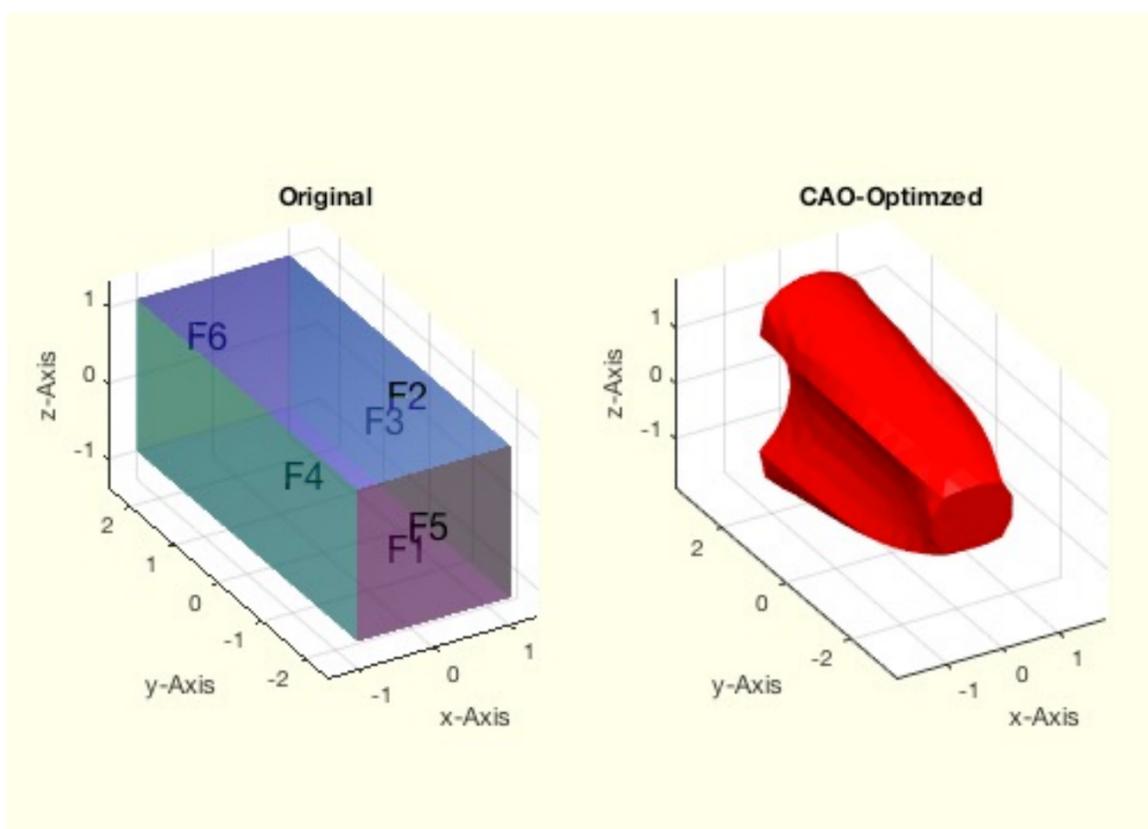
- `VLFLsnaprivet(Hb,Rb,Dw,Rf,Hf,m,F)` - returns the solid geometry (VL,FL) of a male snap rivet push pin with a specified opening force

7.4 FEM and Shape Optimization: Analysis and shape optimization of SG with the PDE toolbox

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> FEM and Shape Optimization)

FEM analysis and stress-based shape and topology optimization is based on the automated generation and modification of tetrahedron models for the Matlab PDE toolbox from SG library surface models.

The procedures for shape and topology optimization according to Sigeki Hirai and Claus Mattheck were implemented by Yilun Sun.

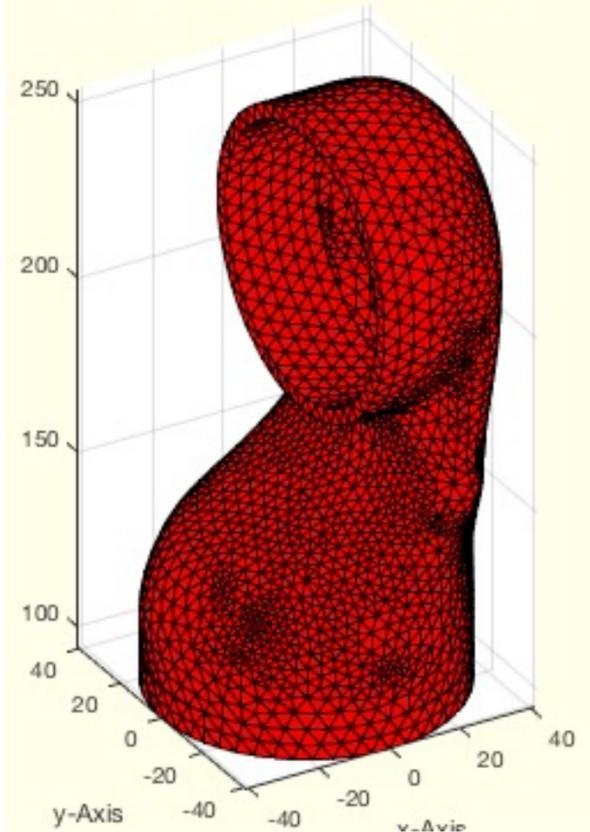


The functions are separated into the following toolbox sections:

- **7.4.1 Mesh and Model Creation:**
- **7.4.2 Load Definition and FS:**
- **7.4.3 Stress and Displacement:**
- **7.4.4 Shape Optimization:**

7.4.1 Mesh and Model Creation:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> FEM and Shape Optimization -> Mesh and Model Creation)

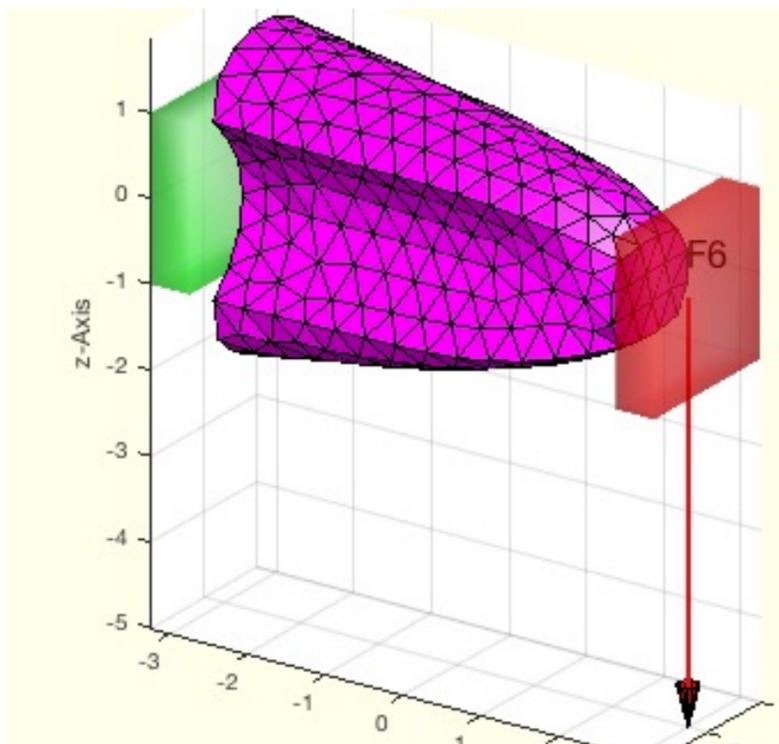


The following toolbox functions belong to this group:

- **SGtetramesh(SG,h)** - creates a tetramesh of a Solid Geometry
- **pdemodelofSG(SG,h,e)** - creates a pde model from a solid geometry

7.4.2 Load Definition and FS:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> FEM and Shape Optimization -> Load Definition and FS)

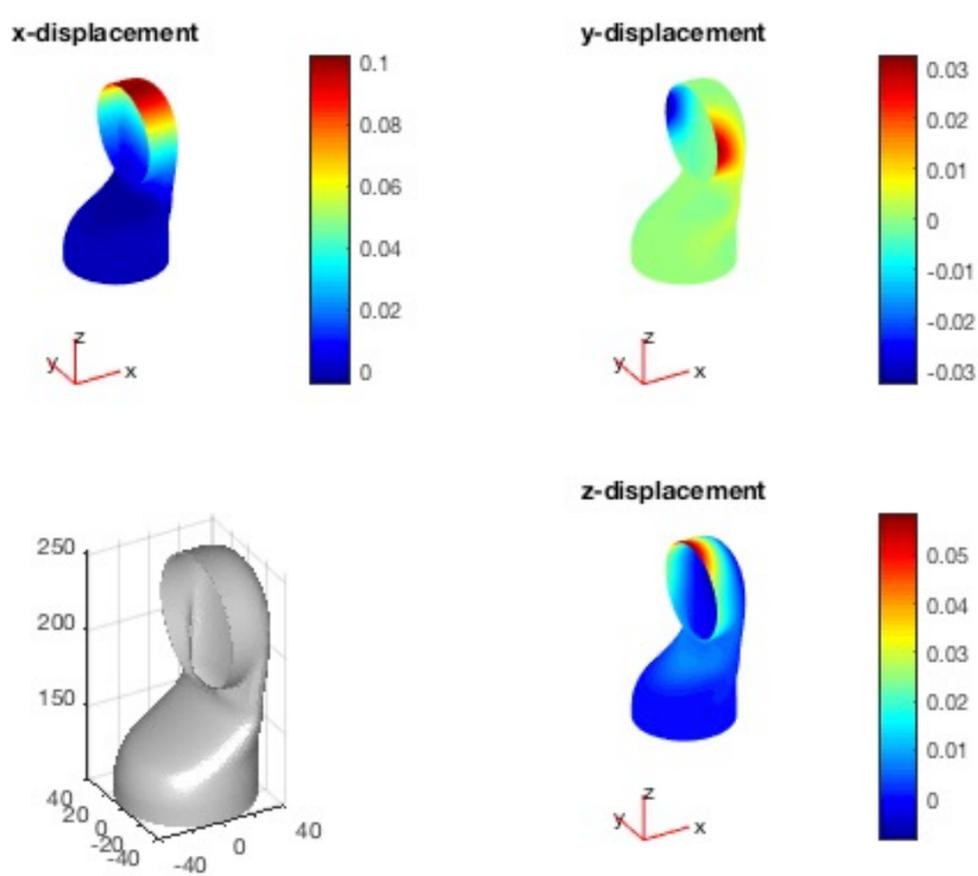


The following toolbox functions belong to this group:

- **pdeplotfaces(model)** - simply plots the surfaces to select
- **SGplotsurfaceload(SG,fixfacet,loadfacet,loadvec)** - plots the surface load of a solid geometry

7.4.3 Stress and Displacement:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> FEM and Shape Optimization -> Stress and Displacement)

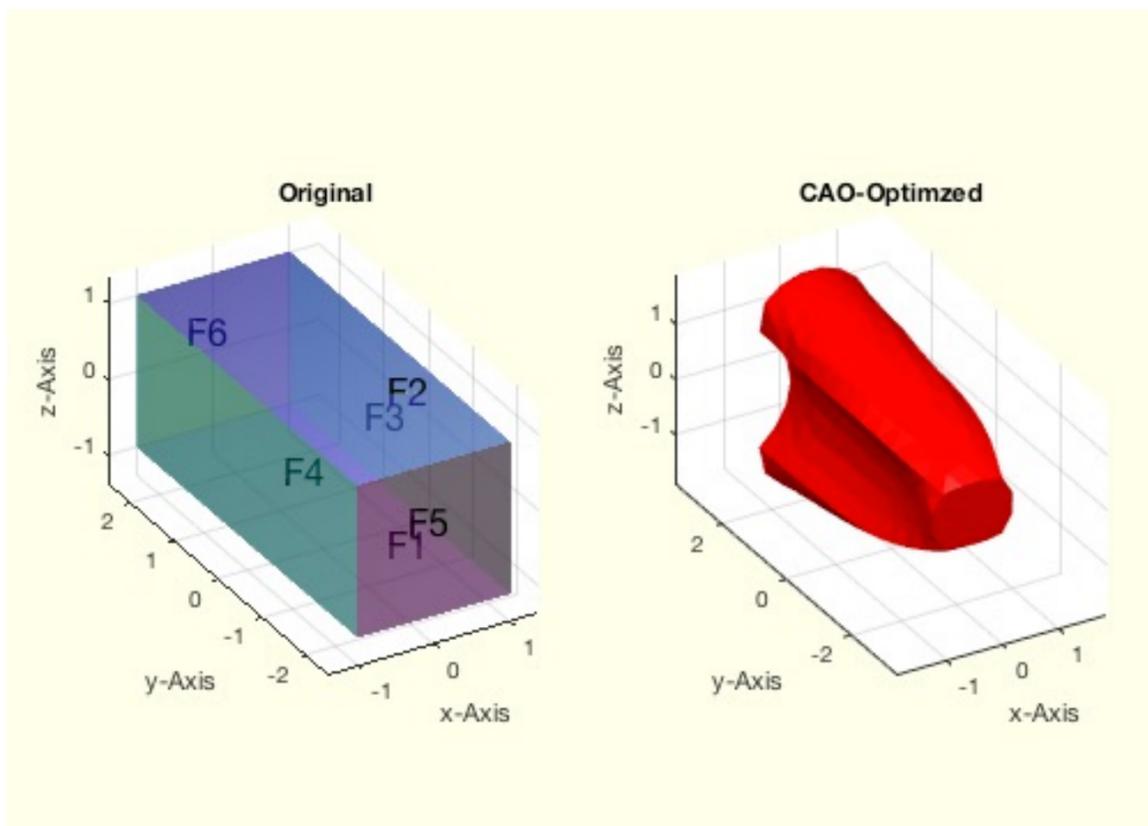


The following toolbox functions belong to this group:

- `pdesolvesurfaceload(model,fixfacet,loadfacet,loadvec)` - calculates the FEM analysis using pde for a pde mesh model
- `pdeplotresult(model,result)` - plots the displacement in 3 quadrants
- `pdestressstatic(model,result,inputParser)` - returns the calculated static stress inside a SG based on a pde model

7.4.4 Shape Optimization:

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> FEM and Shape Optimization -> Shape Optimization)



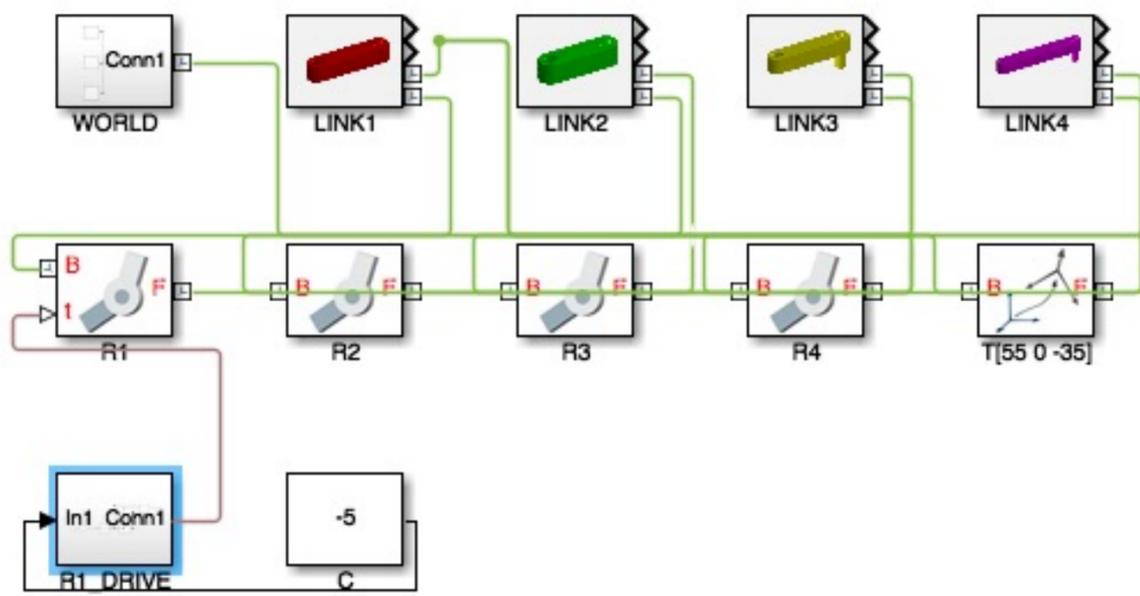
The following toolbox functions belong to this group:

- `SGshapeOptiCAO(SG,)` - returns the optimized shape of a given structure based on biological growth

7.5 Multi-Body Simulation: Dynamic multibody simulation with Simulink/Simscape/Multibody

(SG-Library 4.7 Documentation -> Automatic Design, Optimization, Simulation -> Multi-Body Simulation)

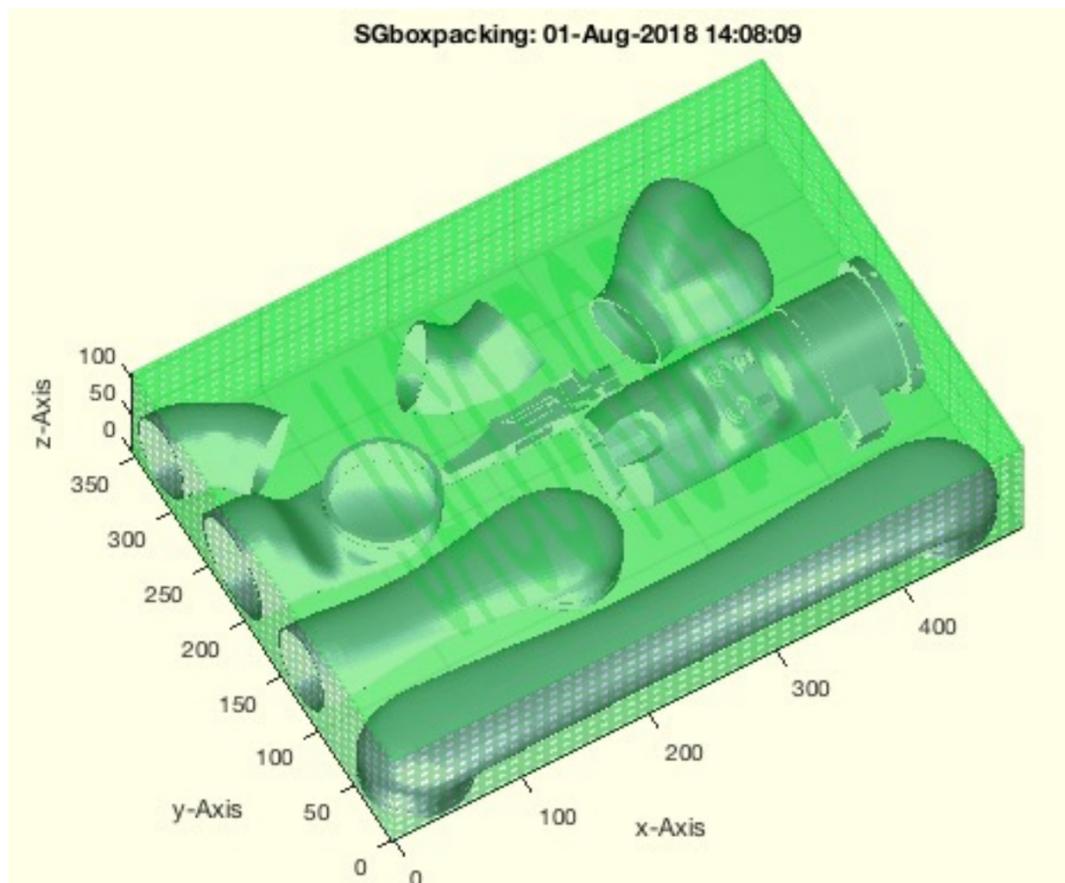
The dynamic simulation of multibody models in the SG library is based on the automated generation of SimulinkSimscapeMultibody models via the programming interface of SimulinkSimscape. Since SimulinkSimscape is also subject to continuous changes, these functions are particularly dependent on the respective Matlab release.



8 STL & 3D Printing & Voxel Models: Handling of STL, DICOM, CVG for 3D printing and lasercutter

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models)

Since the SG library was originally designed for the automatic design of additive-manufactured, patient-specific medical robots, there are a number of import functions for design data and medical data as well as export functions for controlling 3D printers (solid-state structural elements) and laser cutters (textiles or layer-based additive manufacturing (LOM)).



The functions are separated into the following toolbox sections:

- **8.1 STL Import/Export:** Reading and writing STL files
- **8.2 STL Packaging:** Spatial arrangement of SG
- **8.3 STL Surfaces Analysis:** Analysis of closed surfaces
- **8.4 SVG Export:** Export of cut contours
- **8.5 Voxel Models:** Conversion between SG and Voxel models

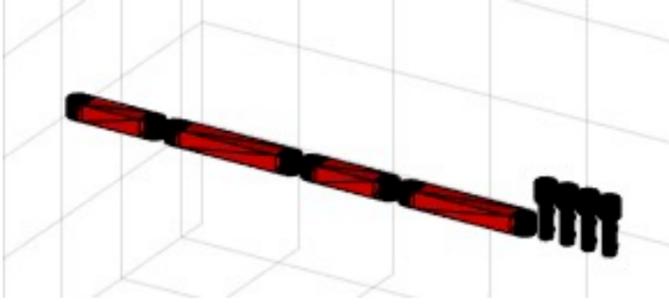
8.1 STL Import/Export: Reading and writing STL files

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> STL Import/Export)

The import of STL files is necessary to create design programs such as CATIA, Solidworks, AutoCAD and the STL libraries of online vendors such as Conrad Electronics or CAD archives such as GrabCAD.

The export of STL files is necessary to control 3D printers. For this reason, the functions also support the compilation of print jobs and the separation or combination of individual components into one print job.

The functions VLFL functions return the vertex list and facet list separately in contrast to the SG functions. If possible, the VLFL functions should be avoided if there is a comparable SG function.



The following toolbox functions belong to this group:

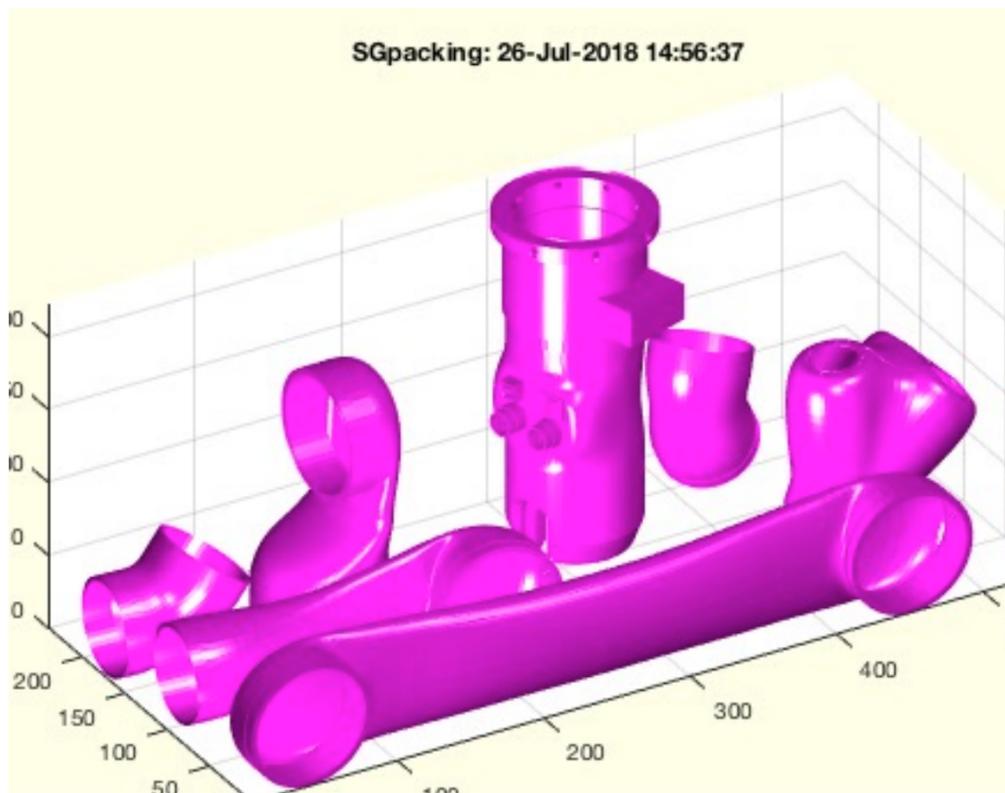
- **VLFLwriteSTL (VL,FL,FNAME,ONAME)** - writes a STL object given by vertex list and facet list in a STL-file
- **VLFLreadSTL(FName,mag,check)** - reads an ascii STL-File as vertex & facet list
- **VLFLreadSTLb(FName,mag,check)** - reads a STL-File in binary format
- **VLFLwriteSTLb(VL,FL,FNAME,ONAME,vcol)** - writes a STL object in binary mode given by a vertex list and facet list into a STL-file
- **STLAsctoBin (fname)** - reads and STL-File in ASCII format and writes it in binary format
- **STLseparate(fname)** - separates all independent objects of a given STL-File into a set of individual STL files
- **VLFLwriteSTLb(VL,OL,i)** - writes a separated object as binary stl file
- **SGwriteSTL(SG,FNAME,ONAME,vcol)** - Writes a STL file for a solid geometry
- **VLFLwriteSTL (VL,FL)** - writes a STL object given by vertex list and facet list in a STL-file
- **SGwriteMultipleSTL (SG,FNAME,ONAME)** - writes solid geometry in different STL files

8.2 STL Packaging: Spatial arrangement of SG

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> STL Packaging)

This function group is used to prepare 3D print jobs. Multiple solids can be combined into one print job (SG Cptainer), they are automatically arranged on minimal volume and possibly enclosed by an optionally labeled box.

This group of functions also includes the functions for duplicating solid geometries in symmetric arrangements as well as the analysis of solid geometries and the detection of independent, non-penetrating individual solids.



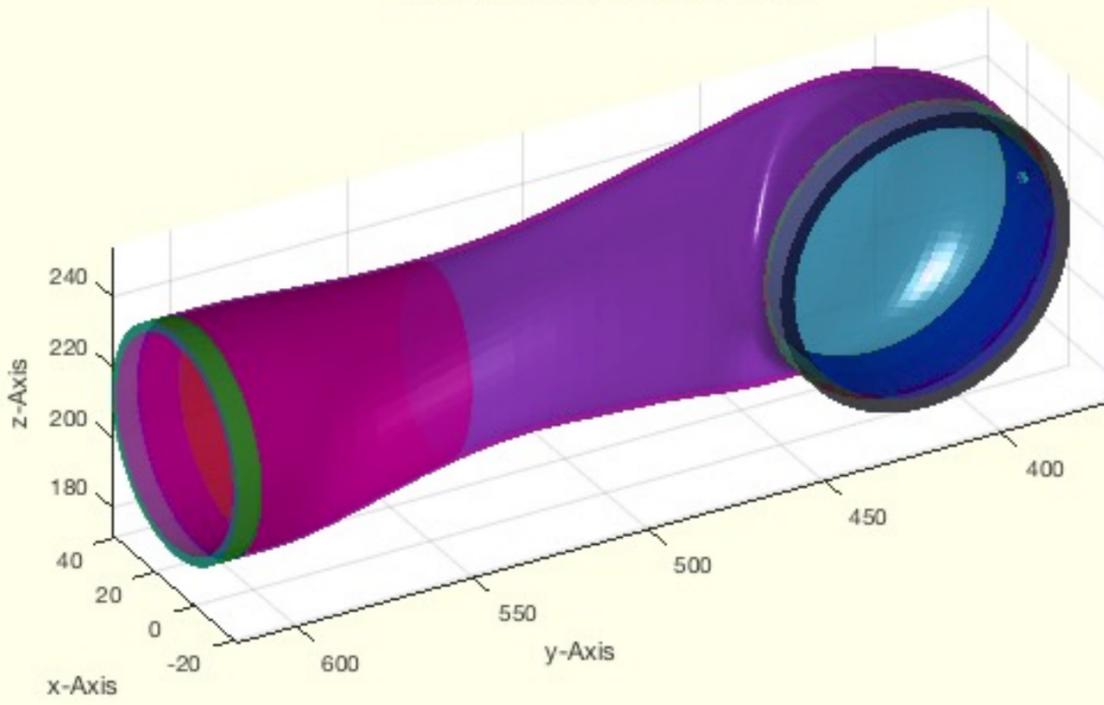
The following toolbox functions belong to this group:

- **SGarrangeSGC(C,Vol3D,Dist3D)** - arranges all parts of a SG container
- **SGboxing(SG,wall,slot,stext,ms,ha)** - returns a case for boxing a SG model
- **SGpatternXYZ(iSG,n,t)** - copies solid geometries along xyz-axis
- **SGcopyrotZ(SG,rotangz,t,ndist,n)** - copies a solid around the z-axis
- **SGarrangeSG(SGc,dist,adim)** - arranges a cell list of solids in a single row
- **SGboxpacking(SG,tstr,dim,turn)** - combines SGpacking and SGboxing

8.3 STL Surfaces Analysis: Analysis of closed surfaces

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> STL Surfaces Analysis)

After reading STL files created by a program like CATIA, Solidworks, AutoCAD, it is helpful to analyze the elements whether they are "waterproof" objects or several independent closed or open surfaces.



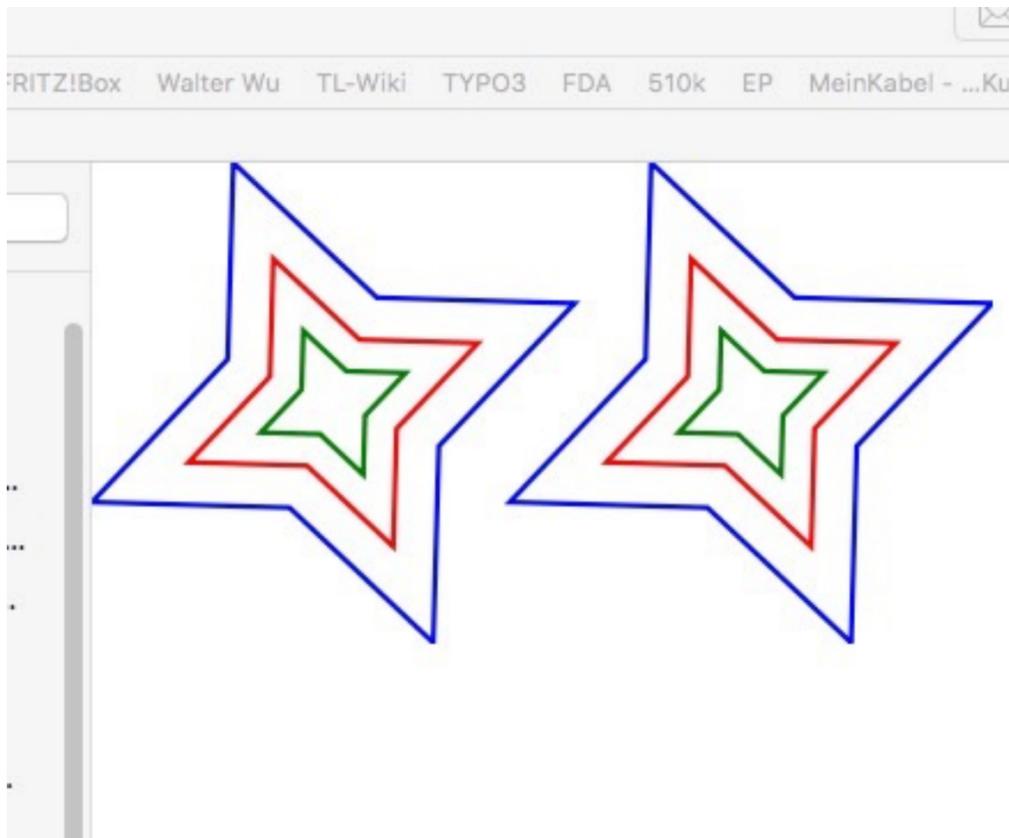
The following toolbox functions belong to this group:

- **SGpacking(SGC,dim,dist,ez,turn)** - returns a package of all solids of a cell list
- **SGanalyzeGroupParts(SG,gmethod)** - returns parts of penetrating solids group colored
- **SGwriteSeparatedSTL (SG,FNAME,ONAME)** - writes solid geometry in different STL files
- **SGsurfaceplot(SG,SIL,si)** - plots the separated surfaces of SG in different colors
- **SGsurfaces(SG,slct)** - returns a cell list of separated CLOSED surfaces similar to SGseparate
- **SGsurfacehistogram(B,si,be)** - plots a surface area histogram of selected surfaces
- **surfacesofSG(TR,alpha)** - returns all feature surfaces (open boundaries) that have a limited angle between their normal vectors

8.4 SVG Export: Export of cut contours

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> SVG Export)

The SVG file format can be used to convert contours into cut files for laser cutters. It can be used to cut textiles or neoprene that have been precisely designed to fit exoskeletons or to cut Solid Geometries into layers for laminar production and then produce them layer by layer on a laser cutter.

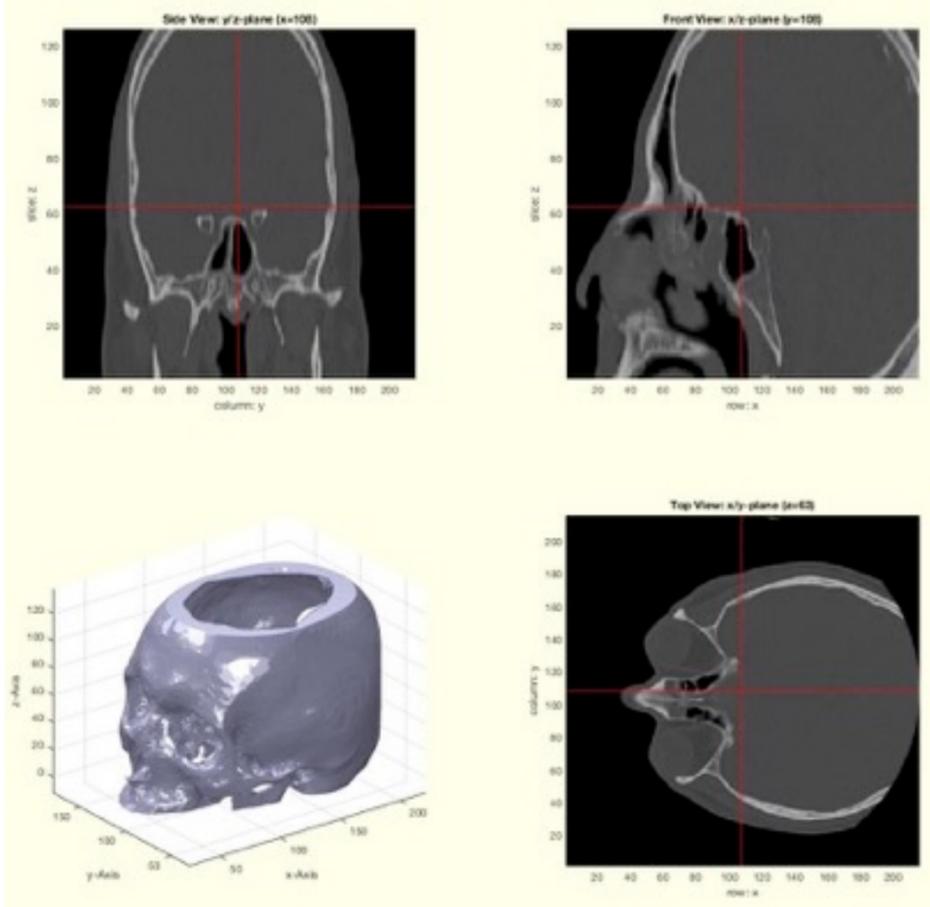


The following toolbox functions belong to this group:

- **CPLwriteSVG (CPL,FNAME,ONAME,cutter,colmap,stkwd)** - writes a SVG file for a laser cutter

8.5 Voxel Models: Conversion between SG and Voxel models

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> Voxel Models)

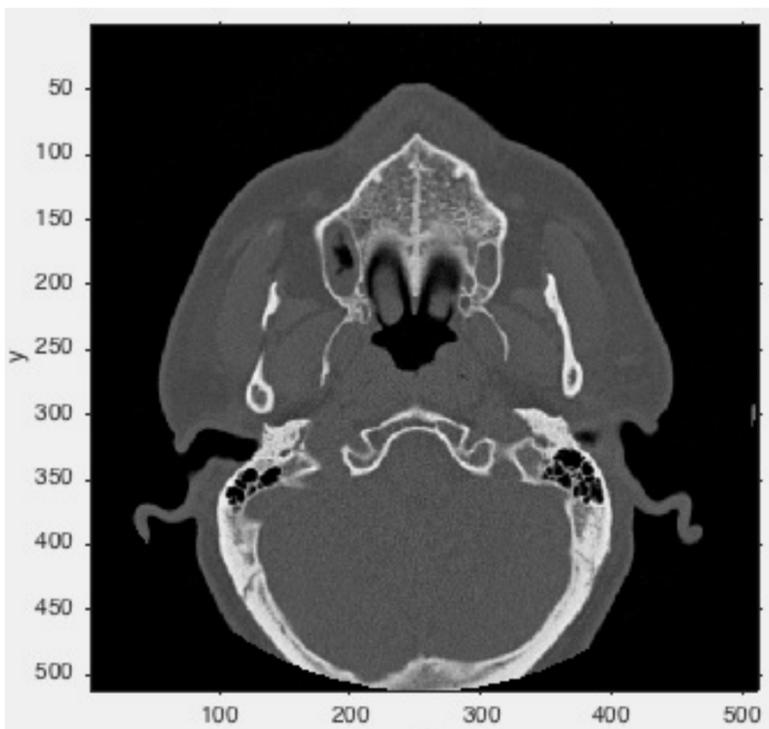


The functions are separated into the following toolbox sections:

- 8.5.5 VM Import & Scaling:
- 8.5.6 VM Visualization:
- 8.5.7 VM to VL, CPL:
- 8.5.8 VM to SG Surface Model:

8.5.5 VM Import & Scaling:

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> Voxel Models -> VM Import & Scaling)



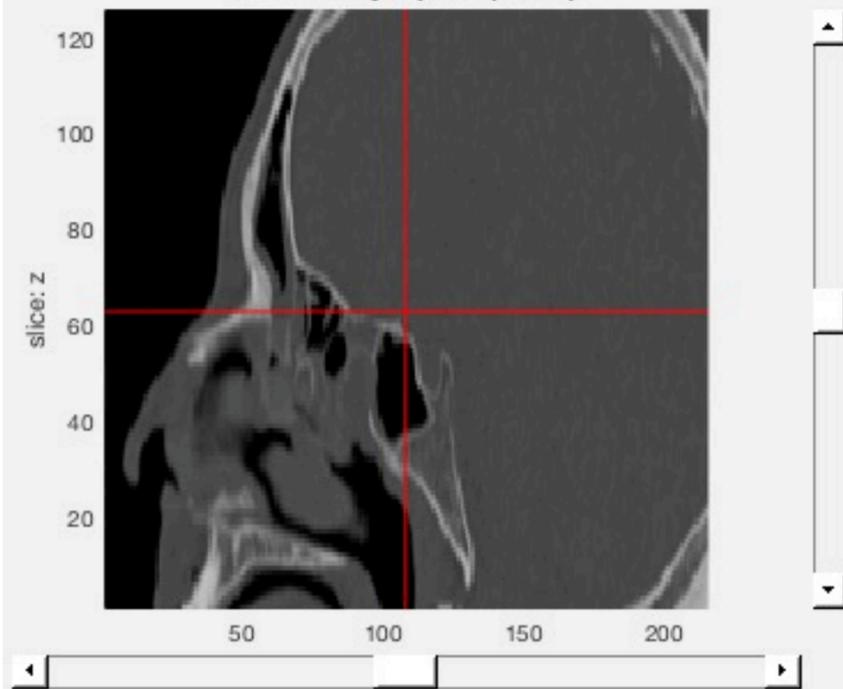
The following toolbox functions belong to this group:

- **VMreaddicom(pathname,filename,xsiz)** - reads an image (nxn) or image stack (nxnxm) from a dicom directory
- **VMuidicom(filename)** - reads in a dicom file or opens a dialog first
- **VMreaddicomdir(pathname)** - reads a dicom directory into an image stack
- **VM(I)** - returns a matrix of reduced size if required (squeeze)
- **VMresize(VM,dm,vs)** - resizes a voxel image model

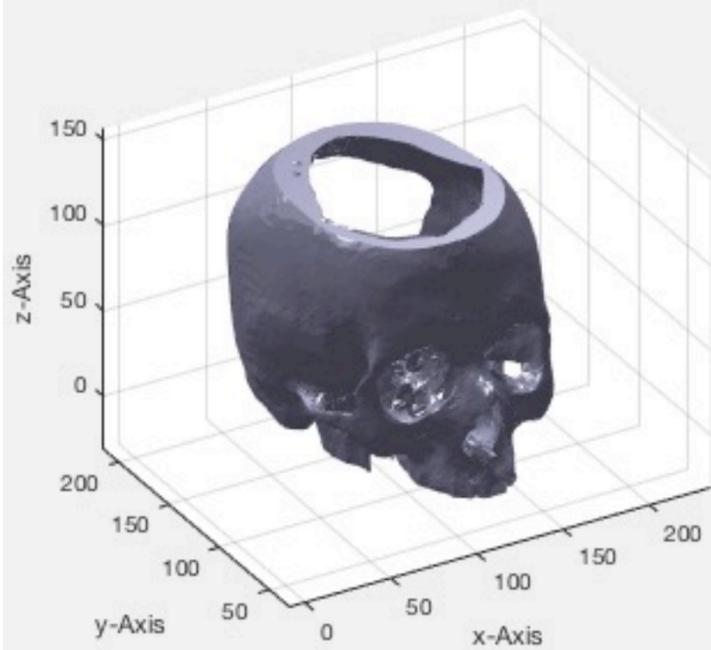
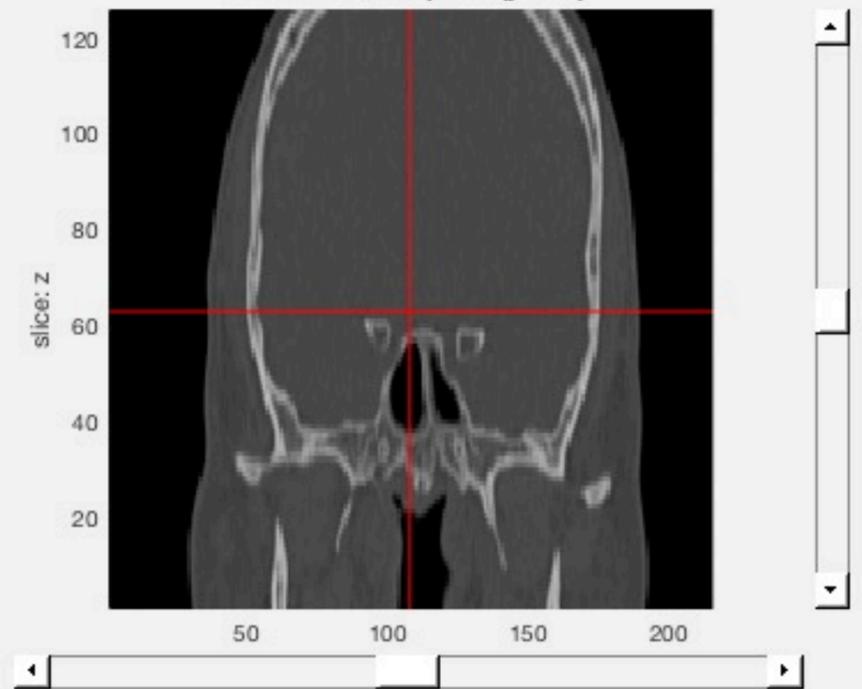
8.5.6 VM Visualization:

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> Voxel Models -> VM Visualization)

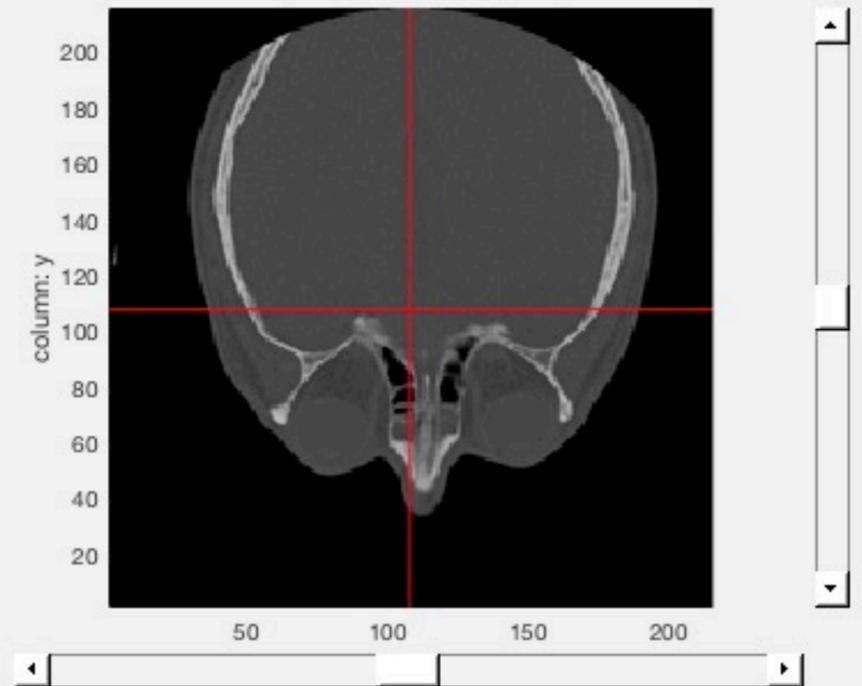
Side View: y/z-plane (x=108)



Front View: x/z-plane (y=108)



Top View: x/y-plane (z=63)

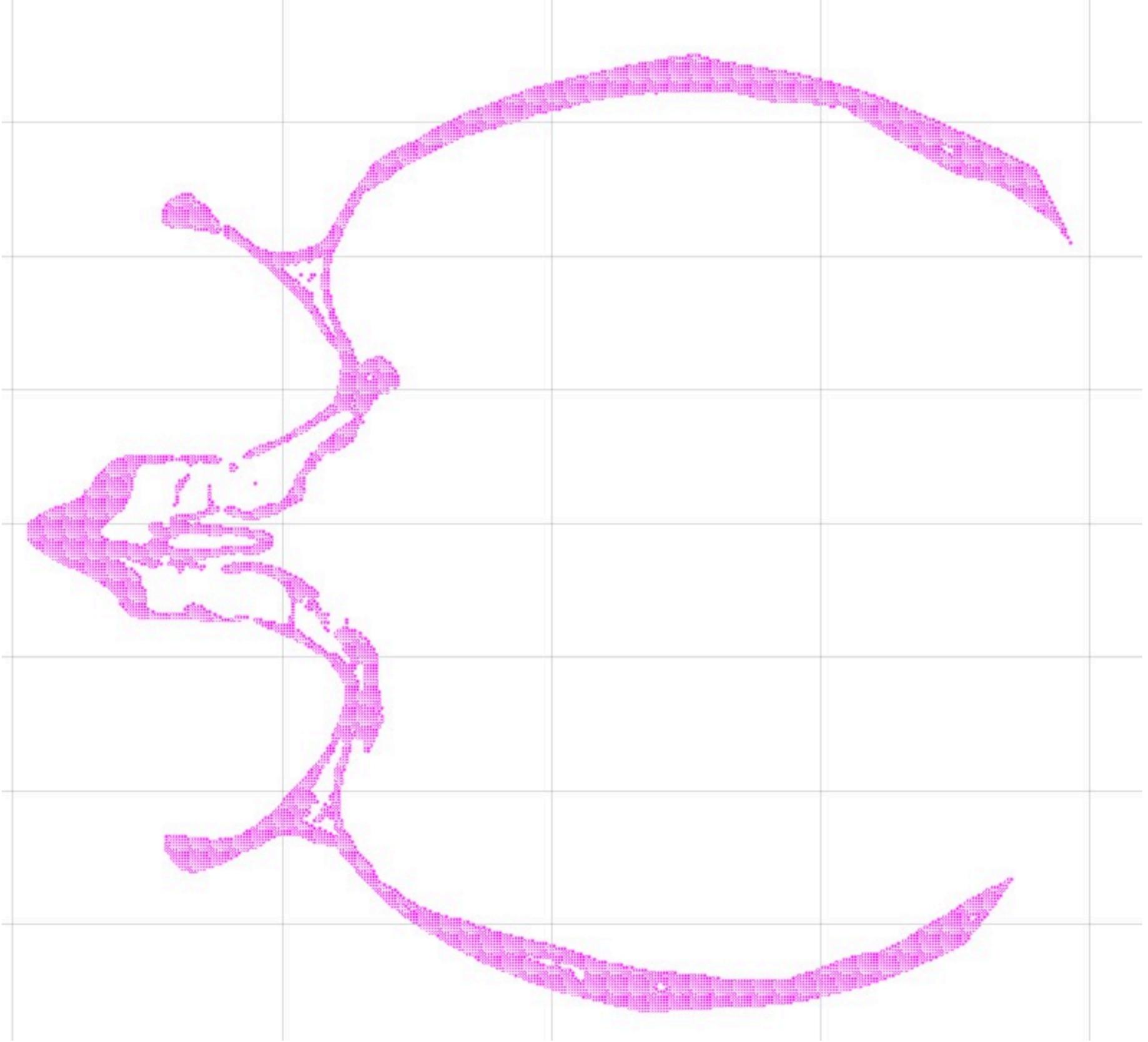


The following toolbox functions belong to this group:

- **VMplot_2012 (IM,p,SG)** - plots a 3D volumetric matrix in 2x2 view
- **VMimage (IM,p)** - returns three crosssectional views of an image stack (voxel model)
- **VMimrot90(l)** - returns an 90 degree rotated image (nxm) or image stack (nxmxk)
- **VMmontage(V)** - plots all images of an image stack into one figure
- **VMpseudo3D(V,lim,maxc,s)** - returns an 2D image of pseudo 3D rendered surface
- **VMplot (IM,p,SG)** - plots a 3D volumetric matrix in 2x2 view
- **VMginput(n,u)** - returns a point position by clicking into VMplot
- **VMgetSubplot** - returns the current active subplot
- **VMintensityscale(V,cax)** - returns an intensity scaled voxel image
- **VMcaxis(cax)** - adjusts the caxis of the VMplot diagram
- **VMwindowplot(V,cax,minv,maxv)** - plots a voxel model using the window caxis function

8.5.7 VM to VL, CPL:

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> Voxel Models -> VM to VL, CPL)

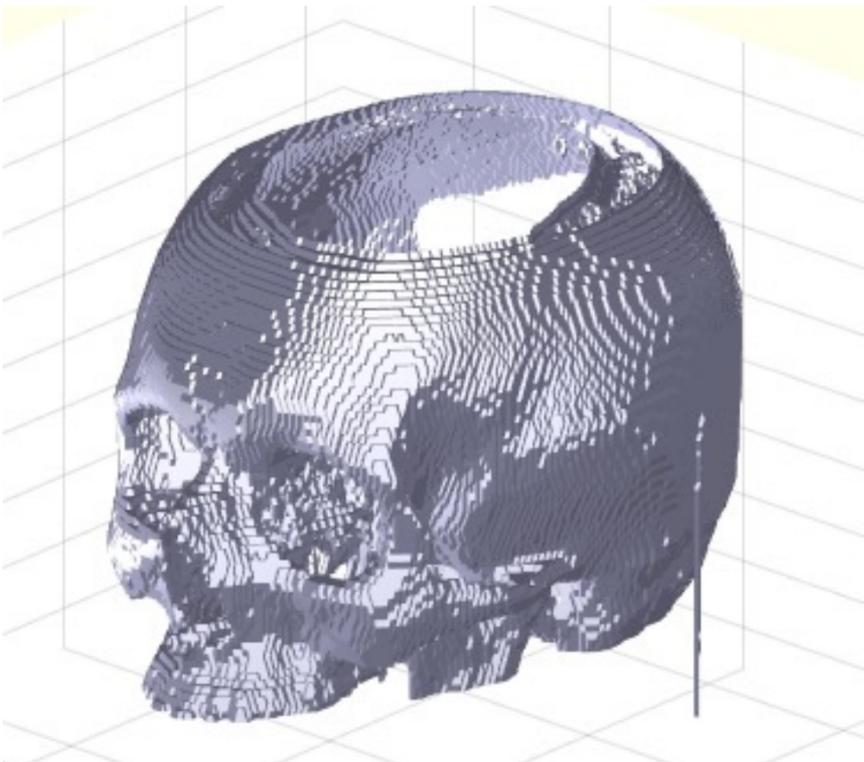


The following toolbox functions belong to this group:

- **VLoFVM(VM,vs)** - returns the voxel coordinates as point list (can be long)

8.5.8 VM to SG Surface Model:

(SG-Library 4.7 Documentation -> STL & 3D Printing & Voxel Models -> Voxel Models -> VM to SG Surface Model)



The following toolbox functions belong to this group:

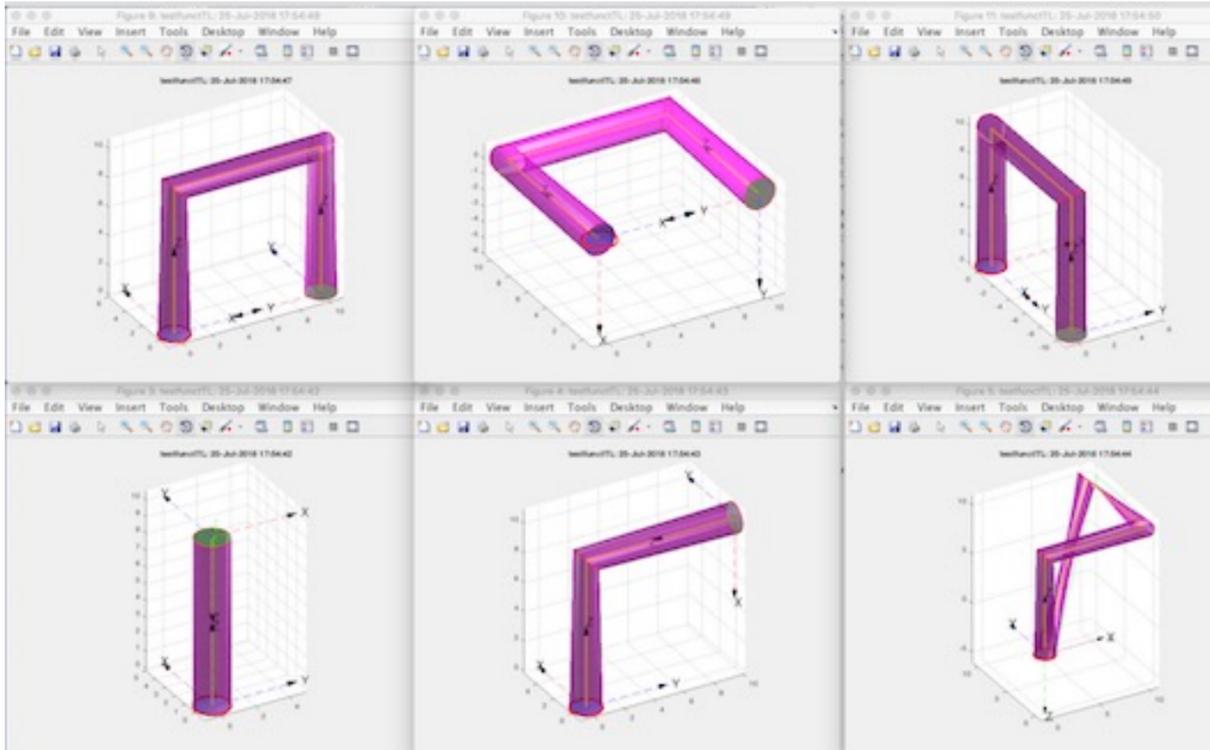
- **TR3oFVM(V,vs,s)** - returns a
- **VLFLoFVMmarchcube(V,vs)** - returns a surface model by the marching cubes

- **VLFLoFVMdelaunay(V,vs,s)** - returns a surface model for a delaunay reconstructed volume model
- **SGofVMmarchcube(V,vs,cl)** - returns a surface model by the marching cubes
- **SGofVMdelaunay(V,vs,s)** - returns a surface model for a delaunay reconstructed volume model
- **VMofSG(SG,n,adjxy,shsl)** - returns a voxel model of a Solid Geoemtry
- **SGofVMisosurface(V,vs,cl)** - returns a surface model by the marching cubes

9 Testing and Test Generation: Systematic testing of geometries and functions

(SG-Library 4.7 Documentation -> Testing and Test Generation)

When developing new functions and compiling a new toolbox version, it is necessary to test the new functions or the functionality of the functions in a new Matlab release. For this purpose, there are a number of tools that are constantly being supplemented and expanded



The functions are separated into the following toolbox sections:

- **9.1 Sample Generation:** Generation of PL, CPL, VL, CVL, VLFL, SG, CSG etc.
- **9.2 Test Generation:** Methods for the systematic testing of functions

```
% * *9.3 SG Check:* Detection and repair of defects in surface models
% * *9.4 SG Repair:*
% * *9.5 Software Development:*
```

9.1 Sample Generation: Generation of PL, CPL, VL, CVL, VLFL, SG, CSG etc.

(SG-Library 4.7 Documentation -> Testing and Test Generation -> Sample Generation)

Sample data with defined properties can be generated for testing a wide variety of functions.

PLsample for point lists

CPLsample for nested contours

VLsample for point list

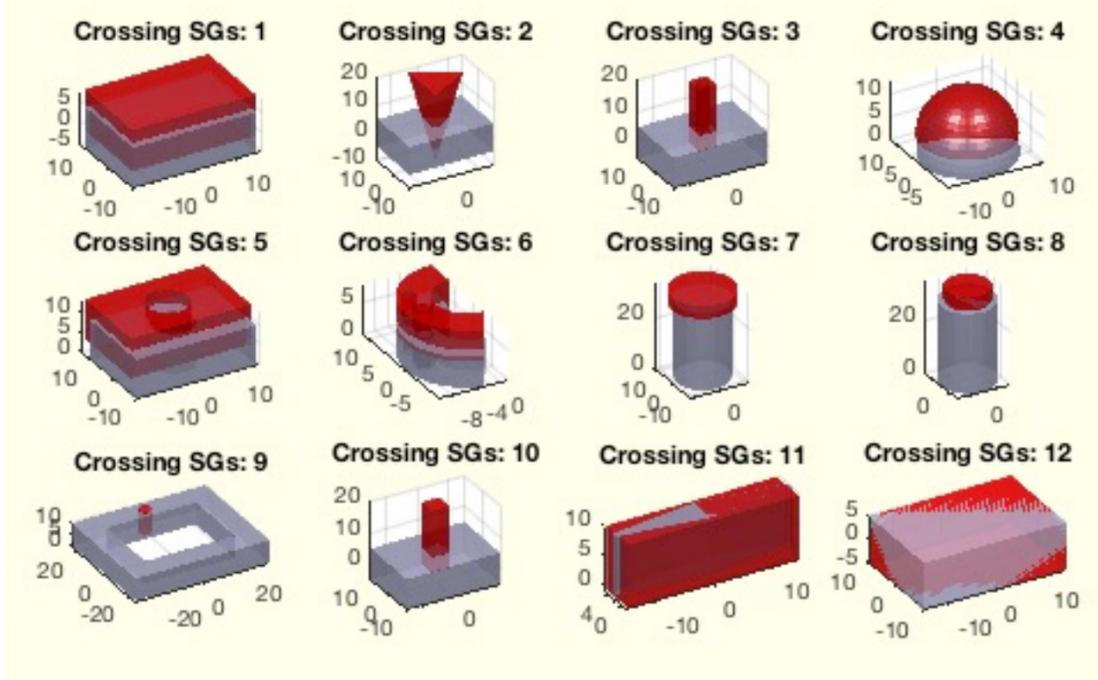
VLFLsample for open surfaces

SGsample for closed bodies

CSGsample for parsing bodies for boolean operation on SG

still lacking

ELsample for example for edge lists

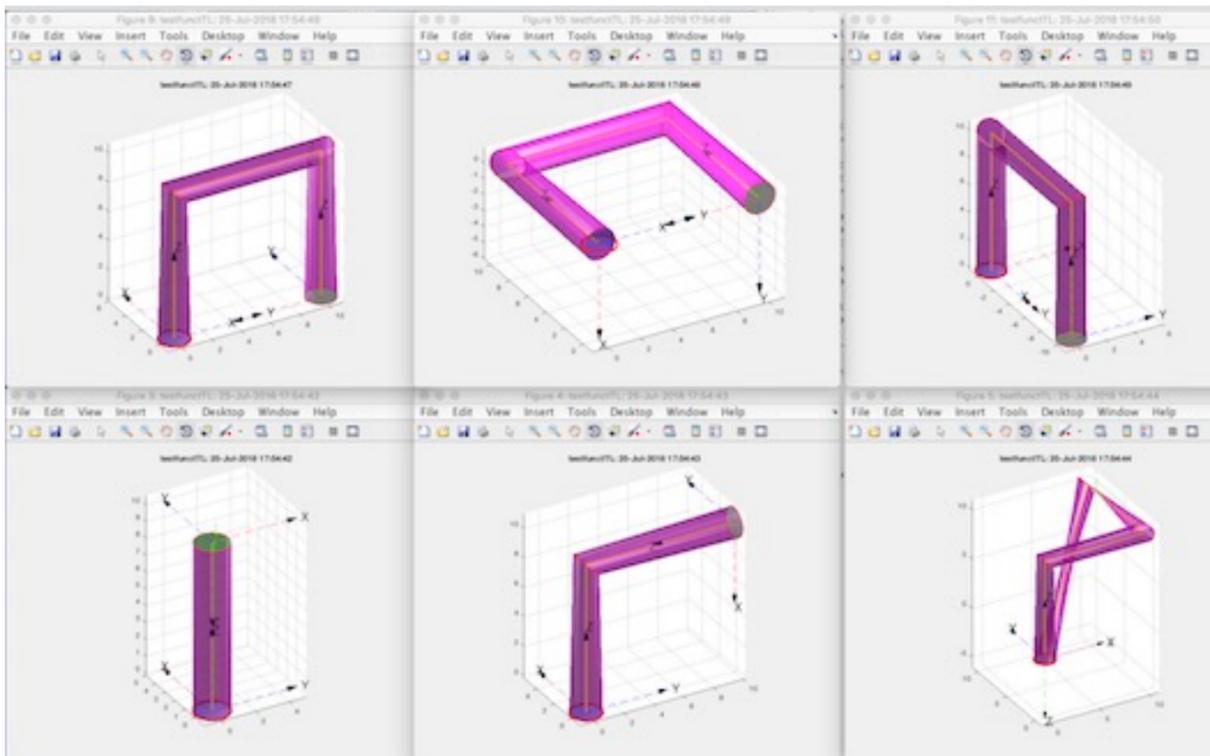


The following toolbox functions belong to this group:

- **SGsample(Nr,T)** - returns a solid geometry for sample bodies used for testing and experiments
- **CPLsample(Nr,T)** - returns a closed polygon list for different tests and experiments
- **VLsample(Nr,T)** - returns a sample vertex list for testing algorithms
- **PLsample(n)** - returns a 2D PL list similar to VLsample
- **VLFLsample(Nr,T)** - returns OPEN surfaces as samples for procedure testing
- **CSGsample(Nr,spatrel)** - Cross-Pair Samples returns two solids as examples for crossing solids

9.2 Test Generation: Methods for the systematic testing of functions

```
% (SG-Library 4.7 Documentation -> Testing and Test Generation -> Test Generation)
%
% The function of this group is to enable the creation of systematic tests and to re-test all Matlab functions after ch
anges, preferably improvements, with extensive parameter sets.
%
%
```



The following toolbox functions belong to this group:

- **VLFL_Toolbox_test (tnr)** - publishes all tutorials to test the compiled Toolbox version
- **imageofVLprojection(VL, isize, pc, pt, pixnum, cup)** - returns an image of a VL projection using the matlab camera view concept
- **testfunctTL(Eterm,)** - testing macro that executes creates a list of different parameter tests
- **subfig (p)** - creates subfigures on the screen similar to subplot

9.3 SG Check: Detection and repair of defects in surface models

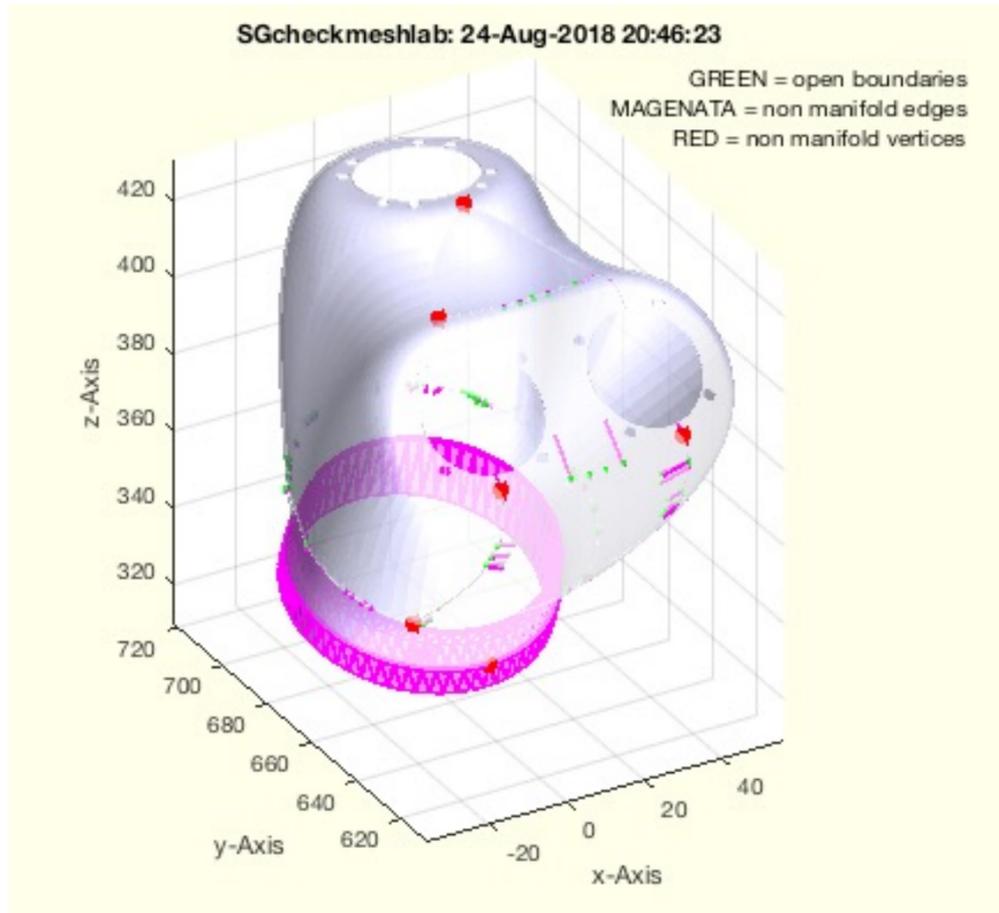
(SG-Library 4.7 Documentation -> Testing and Test Generation -> SG Check)

After reading in an STL file that was not created with the Toolbox or during the development of new Toolbox functions or in case of unexpected termination of already tested functions, it makes sense to test Surfaces or surfaces for their correctness or anomalies. These functions are used to get an overview of error types or to recognize the type of modeling. A well-known software tool for the evaluation of STI files is the program Meshlab. Similarly, the functions are examined here:

1. open edges of bodies or surfaces
2. non-manifold edges, i.e. edges used by more than one surface
3. non-manifold vertices, i.e. vertices used by more than one interface

In addition, there are other important tests such as:

4. test for self-penetration



The following toolbox functions belong to this group:

- **SGchecker(SG)** - performs a check of the vertex list and facet list to detect non manifold problems
- **SGcheckfacedist(SG,fnum,wlim,ilim)** - Checks the distance between the centers of the facets
- **VLFLchecknonmanifoldedges(VL,FL);** - returns the edges and facets with non manifold edges
- **VLFLchecknonmanifoldvertices(VL,FL);** - returns the non manifold vertices, i.e. identical points used in separated surfaces
- **SGmeshlab (SG,RBchange)** - opens a solid geoemtry in an STL viewer
- **SGchecknonmanifoldedges(SG)** - returns the edges and facets with non manifold edges
- **SGchecknonmanifoldvertices(SG)** - returns the non manifold vertices, i.e. identical points used in separated surfaces
- **VLFLcheckboundaryedges(VL,FL)** - returns the open boundaries of the surface
- **SGcheckboundaryedges(SG)** - returns the open boundaries of the surface
- **VLFLcheckmeshlab (VL,FL)** - performs the most important checks for STL files
- **SGcheckmeshlab (SG)** - performs the most important checks for STL files
- **VLcheckvertexaccuracy(VLorg)** - returns the sufficient number of digits for rounding the vertex coordinates of a solid

9.4 SG Repair:

(SG-Library 4.7 Documentation -> Testing and Test Generation -> SG Repair)

The occurrence of certain "errors" or rather "imperfections"

1. open surfaces
2. non manifold edges
3. non manifold practice
4. self-penetration of areas or points

and many other imperfections

usually goes unnoticed because the surfaces can be easily displayed on the screen and processed further with functions. Especially the additive production with the basis of slicing is quite insensitive. Boolean operations or the generation of tetrahedron meshed (PDE toolbox) are very sensitive.

For this reason heuristic strategies are needed that try to correct the surface tessellation. This is not always possible and not always clear. Nevertheless, there are classic problem cases that are generated by CAD programs or by shape optimization (SGshapeOptimization) or the generation of bodies from surfaces or voxel volume data.

The functions in this group are a collection of proposed solutions:

9.5 Software Development:

(SG-Library 4.7 Documentation -> Testing and Test Generation -> Software Development)

Dependencies play a role in software development when functions are packed into toolboxes or when the names of functions in the source code are changed. DAz concept has been changed several times over the years at matlab.

The idea is:

depuse - Who uses this function

depfun - On which functions is this function dependent?

The following toolbox functions belong to this group:

- **depfunTL_2014b(fname,par)** - returns all dependency files of a function that are not part of a toolbox
- **depuseTL2013(fname,dname,PrmStr)** - returns all files of a directory that use a named procedure
- **depusedTL(chdnum1,chdnum2)** - Generates a dependency report file for TODAY and the current working directory
- **depuseToolbox(fname)** - analyzes the current directory for the use of MATLAB Toolbox function
- **depuseString(sstr)** - searches for string using the system command grep
- **depfunTL(fname,par)** - returns all dependency files of a function that are not part of a toolbox
- **depuseToolbox(sstr)** - analyzes the current directory for the use of MATLAB Toolbox procedure
- **depuseTL(fname)** - return which fncts in the current directory uses a named fnct