

SortalGI plug-in for Grasshopper

User manual

SortalGI version 0.5
Manual update 25 February 2019
Written by Rudi Stouffs

Table of content

1. About the SortalGI plug-in	2
2. Installation and update	3
3. Starting on a SortalGI-based parametric model	5
4. Creating a shape object	7
5. Manipulating a shape object	10
6. Creating a rule	13
7. Applying a rule	16
8. Specifying shape descriptions	20
9. Specifying predicates	27
10. Specifying directives	28
Appendix A. A formal notation for shape descriptions	29
Appendix B. Description functions	33
Appendix C: FAQ	36

1. About the SortalGI plug-in

A shape rule combines a specification of recognition and manipulation. A shape rule is commonly specified in the form $lhs \rightarrow rhs$, where the left-hand-side (*lhs*) of the rule specifies the pattern to be recognised and the manipulation of the current shape then involves replacing the recognised *lhs* by the right-hand-side (*rhs*) of the shape rule in the shape under investigation. Recognition necessarily applies under some transformation, for example, a similarity transformation, and the resulting manipulation must occur under the same transformation for both *lhs* and *rhs*. That is, applying a rule $a \rightarrow b$ to a given shape s involves determining a transformation f such that $f(a)$ is a part of s ($f(a) \leq s$), following which s is replaced by $s - f(a) + f(b)$.

A shape grammar generally defines a collection of rules together with an initial shape; then, the language defined by a shape grammar is the set of shapes generated by the rules from the initial shape. However, from a user's point of view, any collection of rules that serves a particular purpose can be considered a shape grammar, whether or not it requires a particular initial shape or, instead, can be applied to a wide variety of (initial) shapes.

Sortal grammars extend on shape grammars. Where shape grammars commonly rely on a combination of line segments and labelled points, *sortal* grammars take a modular representational approach, allowing for a wide variety of geometric and non-geometric elements to be included in the specification of shape rules and grammars. *Sortal* grammars utilise *sortal* structures as representational structures, where these structures are defined as formal compositions of other, primitive, *sortal* structures, termed *sorts*. As such, *sortal* grammars constitute a class of formalisms for design grammars and benefit from the fact that every component sort specifies a partial order relationship on its individuals and forms, defining both the matching operation and the arithmetic operations for rule application.

A shape grammar interpreter is the engine that supports the application of shape rules, including recognition and manipulation. The SortalGI plug-in for Grasshopper encapsulates the SortalGI *sortal*/shape grammar interpreter and makes part of its functionality available within Rhino/Grasshopper. It allows the user to create and apply shape and description rules within the Grasshopper environment.

Plug-in development by Bianchi Dy
System development by Bui Do Phuong Tung
Under the supervision of Rudi Stouffs

2. Installation and update

Installation takes three steps. The first step only needs to be performed once. The second step is also required for any major update (e.g., from v0.4.1 to v0.5.0), while the third step should be performed for any update, though in case of a minor update (e.g., from v0.4.0 to v0.4.1), you may be able to simply use the SGI Update component (see below).

You can find the latest update from Food4Rhino (<http://www.food4rhino.com/app/sortalgi-shape-grammar-interpreter>) or sortal.org (<http://www.sortal.org/downloads/plugin.html>)

Step 1: Installing GhPython and updating Rhino's Module Search Paths

If you are using Rhino 5, you must install GhPython onto Rhinoceros Grasshopper. This is not necessary if you are using Rhino 6. However, for both Rhino 5 and Rhino 6, you must update Rhino's Module Search Paths and enable Frames (steps b and e-j).

- a) Download the most recent GhPython Grasshopper Assembly file (gha) from Food4Rhino: <http://www.food4rhino.com/app/ghpython>
- b) Open Rhino and Grasshopper.
- c) In Grasshopper, choose File > Special Folders > Components folder. Save the gha file in this folder.
- d) In the finder window, right-click the gha file > Properties and make sure there is no "blocked" text.
- e) Type EditPythonScript in the Rhino Command box.
- f) In the Rhino Python Editor window, select 'Options...' from the Tools menu.
- g) Add the Plug-ins\IronPython\Lib\site-packages folder of your Rhino installation folder into the 'Module Search Paths'.
- h) Switch from the 'Files' tab to the 'Script Engine' tab (in the Python Options window).
- i) Check the 'Frames Enabled' option and click 'OK'.
- j) Close Grasshopper and Rhino completely.

Step 2: Installing the SortalGI library

As the SortalGI library may change with a major update (e.g., from v0.4.1 to v0.5.0) and there may be dependencies between the plug-in and such changes, it is strongly advised to re-install the SortalGI library with every major update. This installation may be achieved in one of two ways.

- a) If you have not yet done so, download the latest SortalGI update Food4Rhino (<http://www.food4rhino.com/app/sortalgi-shape-grammar-interpreter>) or sortal.org (<http://www.sortal.org/downloads/plugin.html>) and unzip the file.
- b) (in Windows) Run the setup widget inside the folder 'sortal-setup'. The computer may prompt for whether to allow the widget to make changes; click 'Yes' or 'Allow'. Wait for it to finish installing the packages.
- c) If you are unable to run the 'setup' widget, you may manually copy-paste the files in their respective locations:
 - i. Copy the content of the folder 'sortal-setup\site-packages' into the location C:\Program Files\Rhinoceros 5.0 (64-bit)\Plug-ins\IronPython\Lib\site-packages or equivalent on your computer
 - ii. Copy the folder 'sortal' (inside 'sortal-setup\sortal-packages') into the location C:\Program Files\Rhinoceros 5.0 (64-bit)\Plug-ins\IronPython\Lib

Step 3: Installing the SortalGI plug-in

With any update of the SortalGI plug-in, you must update the SortalGI components in Grasshopper. You can:

- a) Open Rhino and Grasshopper.
- b) In Grasshopper, choose File > Special Folders > User Objects folder.
- c) Copy all files from the folder 'components' and paste these into the folder 'UserObjects'.

The result should be automatically reflected in Grasshopper. There should be an 'SGI' in the Grasshopper Components Tab Panel and if you select the tab it should include all the User Objects. If not, you may want to restart Grasshopper and Rhino for the changes to take effect.

In case of a minor update (e.g., from v0.4.0 to v0.4.1), you can also use the SGI Update component to update the SortalGI components in the Grasshopper Components Tab Panel as well as in the current parametric model (see section 3. Starting on a SortalGI-based parametric model).

3. Starting on a SortalGI-based parametric model

Creating a new parametric model using SortalGI components

Before adding any other SGI component, you should first add the SGI Setup component. This component initialises the SortalGI engine and makes all functionality available to the model.

If, instead, you add the SGI Setup component after other SGI components, you should use CTRL+B in order to ensure the SGI Setup component is executed before all other components.



The SGI Setup component initialises the SortalGI engine and allows for some global settings.

Inputs:

- *displacementX*: optional displacement value along the X-axis for the purpose of translating any shape resulting from a rule application; if no displacement value is specified, then the rule application will automatically derive the translation distance from the bounding box of the shape (see section 7. Applying a rule)
- *displacementY*: optional displacement value along the Y-axis for the purpose of translating and spacing multiple shapes resulting from a rule application; if no displacement value is specified, then the rule application will automatically derive the translation distance from the bounding box of the shape (see section 7. Applying a rule)
- *text size*: the text size to visualise any labels or shape descriptions that are attributes to geometries resulting from a SortalGI component
- *descriptions*: a list of shape description types, each identified by its name (see section 8. Specifying shape descriptions for a specification of descriptions)

Outputs:

- *check*: True or False value indicating success of the setup

Opening an existing parametric model using SortalGI components

If you find any errors with SortalGI components upon opening an existing parametric model, these might be caused by having older components embedded in the existing model when compared with the SortalGI version installed.

Firstly, check the version number of the specific component. If it is an older (or different) version number, you can use the SGI Update component to automatically update this and any other components to the installed version. Note that any embedded component in the parametric model contains its own Python code and updating the SortalGI components in the 'UserObjects' folder does not automatically update the embedded components in the model. The SGI Update component will update both the SortalGI components in the 'UserObjects' folder (if instructed to do so) and the embedded components in the current parametric model.

Secondly, if the version number does correspond to the installed version, instead, the problem may relate to a difference in inputs and/or outputs between the specific embedded

component in the model and the component present in the Grasshopper Components Tab Panel. In this case, you must replace the embedded component and all its connections using the available component.



The SGI Update component updates the Python codes in the embedded components in the parametric model to the specified SortalGI version. If specified, it will also update the components in the Grasshopper Components Tab Panel.

Inputs:

- *sourceDirectory*: an optional source directory where the SortalGI components should be copied from and into the 'UserObjects' folder; if you omit this source directory, then only the Python codes of the embedded components in the parametric model will be updated to the current SortalGI version as available in the Grasshopper Components Tab Panel
- *updateThisFile*: True or False; setting this value to True will execute the SGI Update component; setting it to False will keep it from executing over and over again

Outputs:

- *success*: True or False value indicating success of the update

4. Creating a shape object

Creating shape objects using the SGI Shape or SGI dShape components serves different purposes. A shape object can be used to define the left-hand-side or the right-hand-side of a rule. Rule application also requires a shape object as the input shape and, optionally, as the input subshape (see section 7. Applying a rule).

A shape object may consist of points, line segments and plane segments, circles and ellipses, circular arcs and quadratic Bezier curves, as well as shape descriptions. Points may have labels or shape descriptions assigned as attributes. The Text Point, Text Curve and Text Surface components allows one to assign a label or shape description as a text to a point, curve/line segment or surface/plane segment. Note that the resulting geometry is only recognised by any of the SGI components, specifically SGI Shape or SGI dShape. Other Grasshopper components will not recognise the labelled geometry.

The SGI Shape and SGI dShape components differ in the fact that the latter accepts shape descriptions using an extra input, while the former does not.



The Text Point component creates a labelled point object, that is, a point with a label or shape description as attribute. This component can also be used to tag a point with a hashtag, if the point will form part of the left-hand-side or right-hand-side of a shape rule. Within the same rule, the hashtag can then be used to reference the point in a description rule, predicate or directive.

Inputs:

- *P*: a point specifying the position of the object
- *label*: a text specifying the label, shape description or hashtag of the object (see section 8. Specifying shape descriptions for a specification of descriptions); a label must be enclosed in double quotes; a hashtag should contain only letters, digits and the underscore (and not start with a digit)

Outputs:

- *G*: the resulting text point object



The Text Curve component creates a labelled curve/line object, that is, a curve/line with a label or shape description as attribute. The label is visualised as attached to a point. This component can also be used to tag a curve/line with a hashtag, if this geometry will form part of the left-hand-side or right-hand-side of a shape rule. Within the same rule, the hashtag can then be used to reference the curve/line in a description rule, predicate or directive.

Inputs:

- *C*: a curve/line object
- *label*: a text specifying the label, shape description or hashtag of the object (see section 8. Specifying shape descriptions for a specification of descriptions); a label

must be enclosed in double quotes; a hashtag should contain only letters, digits and the underscore (and not start with a digit)

Outputs:

- *G*: the resulting text curve/line object



The Text Surface component creates a labelled surface object, that is, a surface with a label or shape description as attribute. The label is visualised as attached to a point. This component can also be used to tag a surface with a hashtag, if this surface will form part of the left-hand-side or right-hand-side of a shape rule. Within the same rule, the hashtag can then be used to reference the surface in a description rule, predicate or directive.

Inputs:

- *S*: a surface object
- *label*: a text specifying the label, shape description or hashtag of the object (see section 8. Specifying shape descriptions for a specification of descriptions); a label must be enclosed in double quotes; a hashtag should contain only letters, digits and the underscore (and not start with a digit)

Outputs:

- *G*: the resulting text surface object



The SGI Shape component creates a shape object from a geometry and an optional reference point.

Inputs:

- *G*: a geometry of points, text points, lines, polylines, (flat) surfaces, meshes, boundary representations, circles, ellipses, (circular) arcs and/or quadratic Bezier curves; any part of the geometry not recognised will be ignored
- *refP*: an optional reference point; if specified, the geometry will be moved from the reference point to the origin, allowing a shape that will serve as the left-hand-side or right-hand-side to a rule to be drawn or specified spatially separated from the other side of the rule

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the shape object



The SGI dShape component creates a shape object from a geometry, descriptions and an optional reference point. The descriptions may be omitted, so may be the geometry, though not both at the same time.

Inputs:

- *G*: a geometry of points, text points, lines, polylines, (flat) surfaces, meshes, boundary representations, circles, ellipses, (circular) arcs and/or quadratic Bezier curves; any part of the geometry not recognised will be ignored

- *D*: one or more shape descriptions, each item preceded by the shape description type (name) and a colon; multiple shape descriptions of the same type can be combined into a single item by separating them with a vertical bar
- *refP*: an optional reference point; if specified, the geometry will be moved from the reference point to the origin, allowing a shape that will serve as the left-hand-side or right-hand-side to a rule to be drawn or specified spatially separated from the other side of the rule

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the shape object
- *D*: the shape descriptions of the shape object (note that any shape description that is assigned as an attribute to part of the geometry is not included as it already forms part of the geometry)

SGI Shape to Geometry



The SGI Shape to Geometry (S2G) component converts any shape object into its geometry and shape descriptions.

Inputs:

- *S*: a shape object

Outputs:

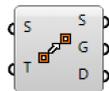
- *G*: the geometry of the shape object
- *D*: the shape descriptions of the shape object (note that any shape description that is assigned as an attribute to part of the geometry of the shape object is not included as it already forms part of the geometry)

5. Manipulating a shape object

Following the creation of a shape object, various geometrical operations are available as SortalGI components to act upon a shape object; e.g., to translate/move a shape, rotate a shape, reflect/mirror a shape and scale a shape. Each of these components takes as input a shape object and any additional data required to inform and apply the transformation, and returns the resulting shape object as well as the corresponding geometry and shape descriptions. Their operation is quite identical to the corresponding Grasshopper components, except that they act upon a shape object.

In addition, there are SortalGI components to union/sum two shapes, union/sum a list of shapes, intersect/take the product of two shapes and take the difference of one shape with respect to another.

SIG Move Shape



The SIG Move Shape component moves a shape object along a vector. This component is very useful to ensure the visualisation of shape objects resulting from rule application do not overlap and are properly spaced (see section 7. Applying a rule).

Inputs:

- *S*: a shape object
- *T*: a translation vector

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SIG Rotate Shape



The SIG Rotate Shape component rotates a shape object about the normal vector of a base plane by a specified angle.

Inputs:

- *S*: a shape object
- *A*: a rotation angle in radians
- *P*: a rotation plane

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SIG Mirror Shape



The SIG Mirror Shape component mirrors a shape about a base plane.

Inputs:

- *S*: a shape object

- *P*: a mirror plane

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SGI Scale Shape



The SGI Scale Shape component scales a shape object about a centre of scaling uniformly by a specified scaling factor.

Inputs:

- *S*: a shape object
- *C*: a centre of scaling
- *F*: a scaling factor

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SGI Sum



The SGI Sum component sums (combines) two shape objects together.

Inputs:

- *S1*: a shape object
- *S2*: another shape object

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SGI Product



The SGI Product component determines the product (intersection) of two shape objects.

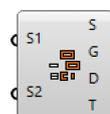
Inputs:

- *S1*: a shape object
- *S2*: another shape object

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SGI Difference



The SGI Difference component takes the difference (complement) of one shape object with respect to another shape object.

Inputs:

- *S1*: a shape object
- *S2*: another shape object

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

SGI Sum All



The SGI Sum All component sums (combines) a list of shape objects together.

Inputs:

- *L*: a list of shape objects

Outputs:

- *S*: the resulting shape object
- *G*: the geometry of the resulting shape object
- *D*: the shape descriptions of the resulting shape object

6. Creating a rule

A rule is conceptually specified in the form $lhs \rightarrow rhs$, where the left-hand-side (*lhs*) of the rule specifies the pattern to be matched under some transformation and the right-hand-side (*rhs*) specifies the resulting pattern that replaces the matched pattern under the same transformation. That is, applying a rule $a \rightarrow b$ to a given shape s involves determining a transformation f such that $f(a)$ is a part of s ($f(a) \leq s$), following which s is replaced by $s - f(a) + f(b)$.

A shape rule is commonly understood to imply that both *lhs* and *rhs* constitute a geometry, possibly including non-geometric attributes, e.g., labels or descriptions. A description rule, then, implies that both *lhs* and *rhs* constitute a shape description of the same shape description type. Combining a shape rule with one or more description rules specifies a compound rule, where the different component rules operate in parallel, although they may interact with each other.

A rule object specifies such a compound rule although it can be used to specify a shape rule or, alternatively, one or more description rules. That is, which component rules are included depends on the shape objects that are provided as *lhs* and *rhs* of the (compound) rule. If the *lhs* does not include any geometry, then the *rhs* may not include any geometry either, as no matching transformation can be determined from an empty shape. With respect to shape descriptions, if either the *lhs* or *rhs* includes a shape description type but the other side does not, then an empty shape description of that type is automatically included in the other side to ensure a full correspondence between shape description types.

Two types of rules are distinguished, parametric-associative rules and non-parametric rules. The latter are the easiest to understand. In the case of a non-parametric rule, the pattern specified by the *lhs* of the rule must match a part of the given shape under a similarity transformation (translation, rotation, reflection and/or uniform scaling). That is, when matching for a square of line segments, any square of line segments from the given shape will do, even if these line segments extend beyond the corner points of the square. The same applies when matching for a rectangle, however, only rectangles with the same ratio between length and width will be matched.

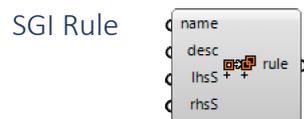
A parametric-associative rule matches a much larger variety of shapes. In principle, when matching a triangle of line segments, any triangle of line segments in the given shape will be matched, irrespective of its shape. The corresponding transformation is a topological transformation though there is no mathematical representation for such a transformation (unlike for a similarity transformation). However, some constraints do apply. Specifically, parallel and perpendicular lines are automatically identified in the *lhs* and considered as constraints for matching. Thus, specifying a right-angled triangle as the *lhs* will only match right-angled triangles in the given shape, however, specifying an equilateral or isosceles triangle as the *lhs* will have no effect, any triangle in the given shape will be matched.

While in some cases it may be difficult to predict the exact matching results of the *lhs* of a parametric rule, the matching mechanism broadly follows the following steps:

1. Identify all (infinite) lines that carry any line segment in the *lhs*.
2. Identify all (infinite) lines that carry any line segments in the given shape.

3. Enumerate all combinations of lines from the given shape that match the number of lines for the *lhs*.
4. Eliminate all combinations that do not preserve parallelism and perpendicularity between lines as specified by the *lhs*.
5. Identify all intersection points of (infinite) lines in the *lhs* and note whether the intersection point falls inside, outside or is an endpoint of any line segment on each infinite line.
6. Do the same for the remaining combinations of (infinite) lines for the given shape:
 - a. Eliminate any combinations where an inside intersection point for the *lhs* is not matched with an inside intersection point for the given shape.
 - b. Eliminate any combinations where an intersection point that is an endpoint for the *lhs* is not matched with an intersection point that is either an endpoint or an inside point for the given shape.
7. For the *lhs*, identify all endpoints of line segments on these (infinite) lines and note their ordering also with respect to the intersection points.
8. Do the same for the given shape and eliminate any remaining combinations where two intersection points in the *lhs* are contained within a single line segment and the corresponding intersection points in the given shape are not.
9. Check additional constraints as specified by any predicates (see section 9. Specifying predicates)

A similar mechanism applies to plane segments.



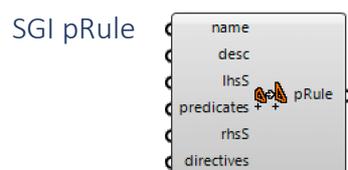
The SGI Rule component creates a **non-parametric** rule object from a left-hand-side (*lhs*) and a right-hand-side (*rhs*), a name and a brief descriptive text. If a shape description type is present as part of one shape object (*lhs* or *rhs*) but absent from the other shape object, an empty shape description of that type is automatically added to the other shape object within the rule.

Inputs:

- *name*: a rule name; this rule name should be unique and should contain only letters, digits and the underscore (and not start with a digit)
- *desc*: a brief explanation of the rule
- *lhs*: a shape object representing the left-hand-side of the rule
- *rhs*: a shape object representing the right-hand-side of the rule

Outputs:

- *rule*: the non-parametric rule object



The SGI pRule component creates a **parametric-associative** rule object from a left-hand-side (*lhs*) and a right-hand-side (*rhs*), a name and a brief descriptive text, and optional predicates and directives. If a shape description type is present as part of one shape object (*lhs* or *rhs*)

but absent from the other shape object, an empty shape description of that type is automatically added to the other shape object within the rule.

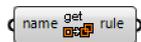
Inputs:

- *name*: a rule name; this rule name should be unique and should contain only letters, digits and the underscore (and not start with a digit)
- *desc*: a brief explanation of the rule
- *lhs*: a shape object representing the left-hand-side of the rule
- *predicates*: an optional list of predicates (see section 9. Specifying predicates)
- *rhs*: a shape object representing the right-hand-side of the rule
- *directives*: an optional list of directives (see section 10. Specifying directives)

Outputs:

- *pRule*: the parametric-associative rule object

SGI Get Rule



The SGI Get Rule component retrieves a rule object (parametric-associative or non-parametric) by its given name.

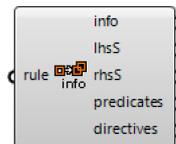
Inputs:

- *name*: a rule name

Outputs:

- *rule*: a rule object (or null)

SGI Rule Info



The SGI Rule Info component deconstructs any rule object (parametric-associative or non-parametric) into its left-hand-side and right-hand-side shape objects, and predicates and directives, if any, and provides a multi-line text containing the rule object's GUID, name and description.

Inputs:

- *rule*: a rule object

Outputs:

- *info*: a multi-line text including the rule's GUID, name and description
- *lhsS*: the left-hand-side shape object
- *rhsS*: the right-hand-side shape object
- *predicates*: a list of predicates (see section 9. Specifying predicates), only in case of a parametric-associative rule
- *directives*: a list of directives (see section 10. Specifying directives), only in case of a parametric-associative rule

7. Applying a rule

Applying a rule to a given shape object involves determining a transformation under which the left-hand-side (*lhs*) of the rule is a part of the given shape. That is, rule application involves two steps: recognition and manipulation; recognition implies matching the *lhs* of the rule under some transformation to a part of the given shape and manipulation implies replacing the recognised *lhs* by the right-hand-side (*rhs*) of the shape rule under the same transformation.

Obviously, the *lhs* of a shape rule may match multiple parts of the same given shape. These matches may correspond to different but similar parts, e.g., if the *lhs* of a non-parametric rule specifies a square, the rule will match any square in the given shape independent of its location, rotation, reflection or scale (a similarity transformation). However, these matches may also apply to the same part in different ways. Again, if the *lhs* of a non-parametric rule specifies a square, which has 90° rotational symmetry, and the *rhs* specifies the same square moved diagonally, then any square in the given shape will amount to four matches as the square may be moved into any of its four diagonal directions.

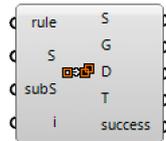
The SortalGI plug-in distinguishes four (or five) rule application components: the first one, SGI Apply, applies only a single match (either randomly selected or specified by its index); the second one, SGI Apply All, applies all matches in parallel, returning as many results as there are matches; and the third one, SGI Apply All Together, applies all matches in parallel while combining all the results into a single shape. The fourth one, SGI Derive, takes a series of rules as input and applies each rule in sequence, returning all intermediate results as well as the final result. The fifth component, SGI Matches, does not actually apply the rule but, instead, returns all the matches. Note that the actual number of matches returned may be influenced by the (a)symmetry of the *rhs*.

All four components (except SGI Matches) accept both a shape object and an optional subshape object. If specified, the latter must be a subshape, that is, part of, the former. If a subshape object is specified then recognition/matching is restricted to the subshape. This allows one to reduce the number of matches where appropriate. Manipulation will always apply to the entire shape object.

Every resulting shape is accompanied by a translation vector. In the case of SGI Apply, the translation vector allows the resulting shape to be visualised aside from the original shape, along the X-axis. In the case of SGI Apply All, the translation vectors allow the resulting shapes to be visualised one above the other, along the Y-axis, and aside from the original shape, along the X-axis. In the case of SGI Derive, the translation vectors allow the resulting shapes to be visualised one aside from the other, and from the original shape, along the X-axis. The extent of the translation vector is specified by the *displacementX* and *displacementY* values provided to the SGI Setup component or, if no value is provided, by the bounding box of the original shape (see section 3. Starting on a SortalGI-based parametric model).

All rule application components accept parametric-associative and non-parametric rules.

SGI Apply



The SGI Apply component determines all possible matches but applies only a single one, either randomly selected or as specified by an index value.

Inputs:

- *rule*: a rule object
- *S*: a shape object to apply the rule to
- *subS*: an optional shape object to restrict matches to; if specified, this shape object must be a subshape, that is, part of, the shape object *S*
- *i*: an optional index to select which match to consider for rule application; a value of -1 (default) selects a random match, any number outside the index range yields the last one among the list of matches

Outputs:

- *S*: the resulting shape object upon rule application; if no match is found then the original shape is returned
- *G*: the geometry of the resulting shape object
- *D*: the descriptions of the resulting shape object
- *T*: a translation vector to allow the resulting shape to be drawn next to the original shape, along the X-axis
- *success*: True or False indicating whether a match was found or not

SGI Apply All



The SGI Apply All component determines and applies all possible matches.

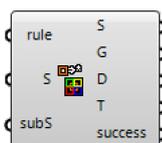
Inputs:

- *rule*: a rule object
- *S*: a shape object to apply the rule to
- *subS*: an optional shape object to restrict matches to; if specified, this shape object must be a subshape, that is, part of, the shape object *S*

Outputs:

- *L*: a list of resulting shape objects corresponding to the number of matches found; if no match is found then the original shape is returned
- *n*: the number of matches found, corresponds to the length of the lists *L* and *Ts*
- *Ts*: a list of translation vectors to allow the resulting shapes to be drawn one above the other, along the Y-axis, and next to the original shape, along the X-axis
- *success*: True or False indicating whether at least one match was found or not

SGI Apply All Together



The SGI Apply All Together component determines and applies all possible matches and combines all the results together.

Inputs:

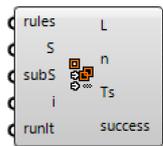
- *rule*: a rule object

- *S*: a shape object to apply the rule to
- *subS*: an optional shape object to restrict matches to; if specified, this shape object must be a subshape, that is, part of, the shape object *S*

Outputs:

- *S*: the resulting shape object upon rule application; if no match is found then the original shape is returned
- *G*: the geometry of the resulting shape object
- *D*: the descriptions of the resulting shape object
- *T*: a translation vector to allow the resulting shape to be drawn next to the original shape, along the X-axis
- *success*: True or False indicating whether a match was found or not

SGI Derive



The SGI Derive component acts as a sequence of SGI Apply components. Given a list of rule objects, it applies each in sequence.

Inputs:

- *rules*: a list of rule objects
- *S*: a shape object to apply the first rule to
- *subS*: an optional shape object to restrict the first match to, or a list of shape objects to restrict consecutive matches to; if specified, the shape object must be a subshape, that is, part of, the input shape of the respective rule object
- *i*: an optional index to select which matches to consider for rule application; a value of -1 (default) selects a random match, any number outside the index range yields the last one among the list of matches; may be specified as a list of indices
- *runIt*: True or False indicating whether to execute the component or not

Outputs:

- *L*: a list of resulting shape objects, one for each rule object; if no match is found for a specific rule object then the input shape for that rule is returned
- *n*: the length of the lists *L*, *Ts* and *success*
- *Ts*: a list of translation vectors to allow the resulting shapes to be drawn one next to the other and to the original shape, along the X-axis
- *success*: a list of True or False values indicating for each rule object whether at least one match was found or not

SGI Matches



The SGI Matches component determines all possible matches and returns these.

Inputs:

- *rule*: a rule object
- *S*: a shape object to apply the rule to (determine the matches of)

Outputs:

- *L*: a list of resulting shape objects corresponding to the number of matches found; if no match is found then the original shape is returned
- *n*: the number of matches found, corresponds to the length of the lists *L* and *Ts*

- T_s : a list of translation vectors to allow the resulting shapes to be drawn one next to the other and to the original shape, along the X-axis
- *success*: True or False indicating whether a match was found or not

8. Specifying shape descriptions

Shape descriptions allow for verbal descriptions of a shape. They follow a prescribed format that allows them to be interpreted and matched by the SortalGI engine (see Appendix A. A formal notation for shape descriptions for an explication of the format).

Parametric shape descriptions

Shape descriptions are parametric in nature, that is, when adopted as the left-hand-side (*lhs*) of a (shape) description rule, a shape description may contain one or more parameters that can be matched onto parts of the description under investigation. When adopted as the right-hand-side (*rhs*) of a (shape) description rule, a shape description may also contain parameter references although the parameters should have already been specified in the corresponding *lhs*, such that the value of the parameter reference in the *rhs* can be taken from the matching of the *lhs*. Obviously, shape descriptions that do not form part of a shape description rule should not contain any parameters or parameter references, otherwise matching will necessarily fail.

Example ('description' is the description type name and 'a' is a parameter):
description: a

Shape description types

A single shape object or rule object may specify more than one description. For example, one description may be used to constrain rule application while another may serve to count the number of rule applications performed on the shape object. In order to be able to correctly match shape descriptions belonging to the *lhs* and the *rhs* of the rule object, shape descriptions must be typed, that is, each shape description that is not used as an attribute to a point must be preceded by its type name (type name and description are separated by a colon). Shape description types must be prescribed in the SGI Setup component (see section 3. Starting on a SortalGI-based parametric model).

Multiple descriptions may share the same description type. These can be collected in a single line, using a vertical bar to separate the various descriptions.

Examples:
min_width: 10
colors: "black" | "white"

Description literals

Literal values in description may be numbers, double quoted strings or predefined keywords. The latter include *e*, *nil*, *pi*, *true* and *false*. *e* and *nil* are equivalent and represent an 'empty' entity. Depending on the context, the 'empty' entity may be interpreted to denote zero, an empty string or an empty tuple. The literals *pi*, *true* and *false* denote the numbers ' π ', 1 and 0, respectively.

Examples:
status: true
list: e

Description tuples

While shape descriptions are specified in textual form, they can be structured as nested lists/tuples. Tuples should be enclosed using either parentheses, angle brackets or square brackets. A top-level tuple may have the enclosing brackets omitted. The entities within a tuple should be separated using either commas or semicolons. Again, a top-level tuple may have the separating marks omitted.

Examples:

segment: <(0, 0), (1, 0)>

cubes: (“l:”, 10, “c:”, (0, 0), “r:”, 0) (“l:”, 10, “c:”, (5, 5), “r:”, 45)

Description parameters

A description parameter is a variable term that is specified by an identifier (any sequence of letters, digits and/or underscores starting either with a letter or underscore) and embedded in the *lhs* of a description rule. Under rule application, the parameter will be matched to a literal or a tuple. If the parameter forms part of a string expression (see “String expressions” below), this literal can be any part of a literal string. If the parameter forms part of a tuple, it matches a specific element of the tuple, unless it is signified by a Kleene star (*) or a Kleene plus (+), in which case it can match any subsequence of elements of the tuple, respectively, including or excluding an empty subsequence. The use of a Kleene star or Kleene plus signifier allows for the matching of variable length tuples.

Examples:

fixed_length: <“Fixed”, var1> <var2, var3> var4

variable_length: (0, 0) (x1, y1) remainder*

Parameter conditionals

Any description parameter may be specified a conditional that constrains the possible values of this parameter. The conditional must follow the parameter and both must be separated only by a question mark (?). The conditional may be either enumerative or equational, or specify a range. An enumerative conditional explicates a finite set of possible values. This set must contain either all numbers or all (double quoted) strings, and the set must be enclosed using curly brackets. An equational conditional specifies a numeric equality or inequality on the parameter, in the form of a conditional operator (=, <>, <, <=, >, or >=) and operand. The operand must be either a number or a numerical expression (see “Numerical expressions” below) operating on numbers, parameters—previously defined—functions (see “Functions” below) and/or references (see “References” below). Neither strictly enumerative, nor strictly conditional, it is possible to specify a range of numeric values using a minimum and maximum value enclosed in square brackets.

Examples:

yard: value?{nil, “default”}

rooms: <nrooms?>2, rooms>

range: a?[0, 10]

Numerical expressions

A numerical expression can be embedded in a parameter conditional (in the *lhs* of a description rule) or in the *rhs* of a description rule. A numerical expression can operate on literal keywords, numbers, numerical functions (see “Functions” below), parameters and

references (see “References” below). Numerical expressions may include the operators plus (+), minus (-), times (*), divided-by (/), modulo (%) and to-the-power-of (^), with the usual operator precedence rules applying and the use of parentheses to override these rules where necessary. Other operations are available in the form of numerical functions.

Example (‘vol’ and ‘length’ specify parameter references) :
volume: vol – pi² * radius * (length / 2)² + 4 / 3 * pi * (length / 2)³

String expressions

A string expression in the *lhs* of a description rule enables the identification of substrings in the matching process. Here, a string expression is a concatenation of literals and parameters (with or without conditional). A parameter can match any substring, conditioned by the literal components (and the conditional, if present). A concatenation of two parameters, without a literal separating the two parameters, would not be possible, unless the first parameter has an enumerative conditional.

A string expressions in the *rhs* of a description rule can include literals, parameter references (see “References” below), numerical expressions (enclosed in parentheses) and functions returning either numbers or strings (see “Functions” below). The result is the concatenation of all components upon their evaluation into literal numbers or strings.

Examples (the two lines below may form the *lhs* and *rhs* of the same description rule):
be: be1 be20.“, ”.be21.“-rafter beam in front, ”.be22.“-rafter beam in back” “with ”.c?=(be21 + be22).“ columns”
be: be1 be20.“, ”.be21.“-rafter beam abutting ”.be22 “with ”.(c + 1).“ columns”

Tuple expressions

Tuple expressions allow one to append or prepend an entity to a tuple, join two tuples or add two tuples. The operations to append, prepend and join all take the same format: two operands separated by a space. The appropriate interpretation is arrived at by looking at the structure of the two operands. If the entity shares a similar “structure” with the first element of the tuple, e.g., both are numbers or both are a tuple of similar structure, then the entity will be appended or prepended to the tuple depending on its position with respect to the tuple. If both operands are (nested) tuples, and the elements of both tuples have the same structure, then a join operation will be assumed, combining the elements from both tuples in a new, single tuple. If no structural similarity exists, then the expression will instead be interpreted as a tuple omitting enclosing brackets and separator.

Adding two tuples adds the respective entities: if both entities are numbers they are summed; if both entities are strings they must be identical; if both entities are tuples and have the same structure, then addition is applied recursively.

Examples (the latter also includes a function):

position: a + (1, 0)

positions: a last(a) + (0, 1)

Functions

Functions allow for additional operations on numbers, texts (strings) and tuples, or a combination thereof. A function returns a single value from any one of these three entity types. Strictly numerical functions include sqrt, sin, cos and tan, asin, acos and atan, taking a single number as argument and returning a number. Functions operating on texts (strings)

include determining the length of a text and determining a left and right subtext, with the length of the subtext specified as an additional argument to the function. Functions operating on tuples include determining the length of a tuple, retrieving the first or last element of a tuple, the minimum (`min`) and maximum (`max`) value inside a tuple, retrieving a tuple of only unique elements, a tuple of pairs extracting consecutive elements pairwise from the operand tuple, a tuple of pairs (`segments`) such that the i th pair is made up of the i th and $(i+1)$ th elements of the operand tuple, a tuple of tuples identifying loops in the operand tuple and a tuple of tuples representing an adjacencies matrix. The latter function takes two arguments, a tuple of 'enclosures' and a tuple of 'connecting' elements. Tuples of numbers can be considered as vectors, currently only vectors of length two or three are considered. Functions on vectors require the different vectors to have the same length. These functions include determining the magnitude (`mag`) of a vector or the distance (also `mag`) or angle between two vectors, adding (`vectoradd`) or subtracting (`vectorsubtract`) two vectors, taking the dotproduct or crossproduct of two vectors or scaling a vector by a number (`vectorscale`).

Finally, a function to generate a random number takes as input a tuple of two or three numbers, with the first two specifying the range and the optional third one the step. More information on functions is provided in Appendix B. Description functions.

Examples:
positions: a (`random(0,10,1), 0`)

SGI Numeric Functions 

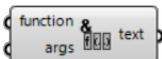
The SGI Numeric Functions component allows the user to select a single function name from a (drop-down) list of all functions operating on numbers (see Appendix B. Description functions).

SGI Text Functions 

The SGI Text Functions component allows the user to select a single function name from a (drop-down) list of all functions operating on texts (strings) (see Appendix B. Description functions).

SGI Tuple Functions 

The SGI Tuple Functions component allows the user to select a single function name from a (drop-down) list of all functions operating on tuples (see Appendix B. Description functions).

SGI Function Concat 

The SGI Function Concat component concatenates a function name and a list of arguments into with the argument list enclosed in parentheses.

Inputs:

- *function*: a text specifying the function name

- *args*: one or more arguments corresponding to the function's argument list, or a list thereof (see Appendix B. Description functions)

Outputs:

- *G*: the resulting function text (or list thereof)

References

We distinguish three kinds of references. Firstly, parameter references are variable terms in the *rhs* of a description rule that reference variable terms (parameters) in the *lhs* of the same (or another) description rule. The value of the parameter reference in the *rhs* is the value of the same parameter in the *lhs* upon the matching of the *lhs*.

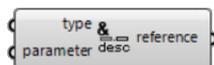
Secondly, a description reference is similar to a parameter reference but references a variable term in another description (that is part of the same rule). In such case, the parameter name must be preceded by the description type name in order to identify the appropriate description and parameter. Alternatively, rather than referencing a specific parameter, the entire value of the description can be referenced using the term *value*.

Finally, a shape reference similarly references data from the shape rule component of the rule. In order to reference shape data, you must refer to the element type name (see Shape element types below). However, this will only work if there is only one element of the specific type, otherwise the reference will be ambiguous. In the case of labelled shape elements, you can disambiguate the shape element either by assigning a hashtag to the element (see section 4. Creating a shape object) or by additionally specifying its label, provided the label is unique (see example below).

Example querying the distance between two points with given labels:

constraint: `a?>=mag(point3D.value:labelD.value="1", point3D.value:labelD.value="2")`

SGI Description Reference



The SGI Description Reference component composes a description text referencing a parameter of another description by concatenating the description type name with the parameter name separated by a dot.

Inputs:

- *type*: a description type name
- *parameter*: a parameter name that is defined within the *lhs* of the description rule; if omitted, the term 'value' is used referring to the entire value of the description

Outputs:

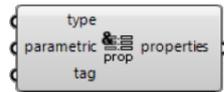
- *reference*: the resulting description reference text

SGI Spatial Types



The SGI Spatial Types component allows the user to select a spatial type from a (drop-down) list of all spatial types available. The spatial type is identified by a number. The possible values are 0 (point), 1 (line segment), 2 (plane segment), 3 (circle), 4 (ellipse), 5 (circular arc) and 6 (quadratic Bezier).

SGI Type Properties



The SGI Type Properties component composes description texts referencing each of the properties of a shape element type by concatenating the shape element type name with the property name separated by a dot. The shape element type is specified as a spatial type (either the corresponding numeric value or a text specifying the type name, see above). An additional boolean input argument ('parametric') distinguishes shape element type names within parametric-associative and non-parametric rules. Finally, the shape element type name may be replaced with a reference tag (see section 4. Creating a shape object on how to assign a hashtag to a spatial element).

Inputs:

- *type*: a number or (partial) text specifying a spatial type (0 - 'point', 1 - 'line', 2 - 'plane', 3 - 'circle', 4 - 'ellipse', 5 - 'arc', 6 - 'bezier')
- *parametric*: a boolean indicating the description will be used as part of a parametric-associative or non-parametric rule
- *tag*: a text specifying a hashtag referencing a spatial element

Outputs:

- *properties*: the resulting texts referencing each of the properties of a shape element type

Shape element types and their available properties

Every geometric shape element type, except for circular arcs, is identified by two names. The first one should be used within non-parametric rules and the second within parametric-associative rules (pRule). Note that circular arcs are not yet available within parametric-associative rules and, if specified, will be ignored.

type	name	property	output	value
points	point3D	value	vector tuple*	position
	pointP3D			
line segments	lineSeg3D	root	vector tuple*	root point (nearest point to the origin)
	lineSegP3D	direction unitDir start end midpoint length squareLength	vector tuple* vector tuple* vector tuple* vector tuple* vector tuple* number number	direction vector unit direction vector 'smallest' endpoint 'greatest' endpoint midpoint line length square value of line length
plane segments	planeSeg3D	normal	vector tuple*	normal vector
	planesegP3D	area outer	number tuple of vector tuples*	plane area list of outer boundary vertices
circles	circle3D	normal	vector tuple*	plane normal vector

	circleP3D	center radius diameter circumference area	vector tuple* number number number number	center point radius diameter circumference area of the circle
ellipses	ellipse3D	normal center foci radii area	vector tuple*	plane normal vector
	ellipseP3D		vector tuple* tuple of vector tuples* tuple of numbers number	center point list of focal points list of longer and shorter radii area of the ellipse
circular arcs	arc3D	normal center radius diameter circumference start end length angle area	vector tuple* vector tuple* number number number vector tuple* vector tuple* number number number	plane normal vector circle center point circle radius circle diameter circle circumference endpoint (ccw) endpoint (cw) arc length angle covered by the arc (in radians) area covered by the arc
quadratic Bezier curves	bezier3D	normal start controlPoint end vertex	vector tuple*	plane normal vector
	bezierP3D		vector tuple* vector tuple* vector tuple* vector tuple*	1st control point 2nd control point 3rd control point maximum or minimum of the curve
labels/ descriptions as point attribute	labelD	value	string	label or description string

*A vector tuple is a tuple of two or three numbers.

9. Specifying predicates

A predicate serves to express a special condition on the application of a parametric-associative rule. Such condition cannot simply be explicated within the left-hand-side shape. As an example, a predicate may specify that the line segment matching a given line segment must be the shortest line segment within the matching shape. Predicates are only applicable to parametric-associative rules.

SGI Void Predicate The diagram shows a rectangular box with a light gray background. On the left side, there is a small square icon containing a diagonal cross. To the right of this icon, the word 'polygon' is written in a small font. Further to the right, there is a small square icon containing a diagonal cross, followed by the word 'text' in a small font. The entire box is enclosed in a thin black border.

The SGI Void Predicate component composes a void predicate text for the given polygonal geometry (or geometries). During rule matching, the void predicate requires the specified area to contain no geometric shape (points, line segments, plane segments). Shapes on the border of the area are not counted. It is important that the polygon's vertices coincide with the infinite line carriers of line segments within the *lhs* of the rule, while at least some vertices should coincide with intersection points of infinite line carriers.

Inputs:

- *polygon*: a polygonal geometry specified as a list of vertices or points, a list of lines, a polyline, a surface or another geometry

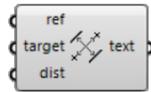
Outputs:

- *text*: the resulting void predicate text, for example, 'void: {{{(0,0,0),(1,2,0),(2,0,0)}}}'

10. Specifying directives

Directives are optional extra specifications for applying a parametric-associative rule that cannot be specifically expressed within the right-hand-side. As an example, a new line that is added in the *rhs* is specified to be at a certain distance from an existing point or line. Directives are only applicable to parametric-associative rules.

SGI Distance Directive



The SGI Distance Directive component composes a distance directive text for the given reference and target spatial element(s) and distance measure(s) or expression(s). During rule application, the distance directive serves to indicate the distance a new spatial element (the target point or the infinite carrier of a line segment) must be away from an existing spatial element (the reference point or the infinite carrier of a line segment). Four cases can be distinguished:

- *line-line distance*: a new line carrier is at a certain distance from an existing line carrier; the new line must be parallel to the existing line
- *line-point distance*: a new point is at a certain distance from an existing line carrier; the new point must be on another existing line carrier not parallel to the reference line carrier
- *point-line distance*: a new line carrier is at a certain distance from an existing point; the new line must pass through an existing point or intersection point or endpoint of a line
- *point-point distance*: a new point is at a certain distance from an existing point; the new point must be on an existing line carrier

Inputs:

- *ref*: a hashtag referencing a spatial element within the *lhs* of the shape rule (see section 4. Creating a shape object)
- *target*: a hashtag referencing a spatial element within the *rhs* of the shape rule
- *dist*: a numeric distance value or a numeric description expression (see section 8. Specifying shape descriptions)

Outputs:

- *text*: the resulting distance directive text, for example, 'distance: {(#line1, #newline1, 2)}'

Appendix A. A formal notation for shape descriptions

The table below presents a formal notation for shape descriptions and the left-hand-side (*lhs*) and right-hand-side (*rhs*) of shape description rules in Extended Backus-Naur-Form (EBNF), including examples. The same non-terminals serve to define the production rules for a description, an *lhs* and an *rhs*. Only when necessary are alternative production rules defined for the same non-terminal; these are then identified by adding the terms *description*, *lhs* and *rhs*, respectively, enclosed within angle brackets ('<...>'), as a prefix to the respective production rule.

<pre>typed-description = type-name ':' description . type-name = identifier . description = description-entity description-sequence . description-entity = literal top-level-tuple . description-sequence = '&' description-entity '&' { description-entity '&' } .</pre>
<pre>literal = keyword-literal number string . keyword-literal = 'e' 'nil' 'pi' 'true' 'false'. number = ['-'] digit-sequence ['.' digit-sequence] . digit-sequence = digit { digit } . digit = '0' '1' '2' '3' '4' '5' '6' '7' '8' '9' . string = '"' { string-character } '"' . string-character = any-character-except-quote '\ "' .</pre>
<p>Example description-entity: "centrally divided, double l-rafter beam in front and back"</p> <p>Example description-sequence: &e&0&"nothing"&</p>
<pre>top-level-tuple = tuple unmarked-tuple . tuple = '(' tuple-entities ')' '<' [tuple-entities] '>' '[' [tuple-entities] ']' . <description>tuple-entities = tuple-entity-sequence . <lhs>tuple-entities = tuple-entity-sequence tuple-expression . <rhs>tuple-entities = tuple-entity-sequence tuple-expression . tuple-entity-sequence = tuple-entity ({ ':' tuple-entity } { ';' tuple-entity }) . <description>tuple-entity = literal tuple . <lhs>tuple-entity = numeric-expression string-expression tuple . <rhs>tuple-entity = numeric-expression string-expression tuple function-returns-tuple . unmarked-tuple = tuple-expression tuple (tuple keyword-literal) { tuple-entity } .</pre>
<p>Example tuple: ("l:", 10, "c:", (0, 0), "r:", 0)</p> <p>Example unmarked-tuple: <"", "O", "R0", "R1"> <"O", 1, 1, 1> <"R0", 1, 1, 0> <"R1", 1, 0, 1></p>
<pre>description-rule-side = description-rule-entity description-rule-sequence . <lhs>description-rule-entity = literal parameter ['?' conditional] string-expression top-level-tuple . <rhs>description-rule-entity = numeric-expression string-expression function-returns-tuple tuple-expression . description-rule-sequence = '&' description-rule-entity '&' { description-rule-entity '&' } .</pre>

parameter = identifier .
 identifier = (letter | underscore) { (letter | underscore | digit) } .
 letter = 'A' | 'B' | 'C' | 'D' | 'E' | 'F' | 'G' | 'H' | 'I' | 'J' | 'K' | 'L' | 'M' | 'N' | 'O' | 'P' | 'Q' | 'R' | 'S' | 'T' | 'U' | 'V' | 'W' | 'X' | 'Y' | 'Z' | 'a' | 'b' | 'c' | 'd' | 'e' | 'f' | 'g' | 'h' | 'i' | 'j' | 'k' | 'l' | 'm' | 'n' | 'o' | 'p' | 'q' | 'r' | 's' | 't' | 'u' | 'v' | 'w' | 'x' | 'y' | 'z' .
 underscore = '_' .

Example **<lhs>description-rule-entity**:
 <"Fixed", var1> <var2, var3> remainder
 Example **description-rule-sequence**:
 &a1&a2&a3&a4&a5&a6&a7&a8&

conditional = enumeration | equation | range.
 enumeration = '{' (number-sequence | string-sequence) '}' .
 number-sequence = number { ',' number } .
 string-sequence = string { ',' string } .
 equation = comparator comparand .
 comparator = '=' | '<>' | '<' | '<=' | '>' | '>=' .
 comparand = number | '(' numeric-expression ')' | parameter | reference .
 range = '[' number ';' number ']' .

Example **<lhs>description-rule-entity with enumeration**:
 yard?{nil, "default"}
 Example **<lhs>description-rule-entity with equation**:
 <nrooms?>2, rooms>

numeric-expression = term { addition-operator term } .
 term = factor { multiplication-operator factor } .
 factor = base { exponentiation-operator exponent } .
 exponent = base .
 base = keyword-literal | number | '(' numeric-expression ')' | function-returns-number | parameter | reference .
 exponentiation-operator = '^' .
 multiplication-operator = '*' | '/' | '%' .
 addition-operator = '+' | '-' .

Example **numeric-expression**:
 $\text{vol} - \pi^2 * \text{radius} * (\text{length} / 2)^2 + 4 / 3 * \pi * (\text{length} / 2)^3$

string-expression = string-expression-entity { ' ' string-expression-entity } .
 <lhs>string-expression-entity = literal | parameter ['?' conditional] .
 <rhs>string-expression-entity = base | string | function-returns-string .

Example **<rhs>string-expression**:
 "with ".(c + 1). " columns"
 Example **<lhs>string-expression**:
 "with ".c?=(be21 + be22). " columns"

<lhs>tuple-expression = tuple-append | tuple-prepend .
 <rhs>tuple-expression = tuple-addition | tuple-extension .
 tuple-append = { tuple-entity } parameter ('*' | '+') tuple-entity { tuple-entity } [tuple-expression] .
 tuple-prepend = [tuple-expression] { tuple-entity } tuple-entity parameter ('*' | '+') { tuple-entity } .
 tuple-addition = [parameter] '+' basic-tuple-argument .
 tuple-extension = { tuple-entity } parameter { tuple-entity } [tuple-expression] .

Example **tuple-prepend**:

h1 h2 H*

Example **tuple-extension**:

a1 last(a1) + (0, 1)

Example **tuple-addition**:

bedrooms + <1, [(“couple”, 0), (“double”, 0), (“single”, 1)]>

function = function-returns-number | function-returns-string | function-returns-tuple .
function-returns-number = numeric-function | length-function | string-function-untyped | tuple-
function-untyped | vector-function | round-function | random-function .
numeric-function = (‘sqrt’ | ‘sin’ | ‘cos’ | ‘tan’ | ‘asin’ | ‘acos’ | ‘atan’) ‘(’ numeric-expression ‘)’ |
‘atan2’ ‘(’ numeric-expression ‘,’ numeric-expression ‘)’ .
length-function = ‘length’ ‘(’ (string-argument | tuple-argument) ‘)’ .
<lhs>string-argument = string | function-returns-string | parameter | reference .
<rhs>string-argument = string-expression .
function-returns-string = string-function-returns-string | string-function-untyped | tuple-function-
untyped .
string-function-returns-string = (‘left’ | ‘right’) ‘(’ string-argument ‘,’ numeric-expression ‘)’ .
string-function-untyped = ‘eval’ ‘(’ string-argument ‘)’ .
tuple-function-untyped = (‘first’ | ‘last’ | ‘min’ | ‘max’) ‘(’ tuple-argument ‘)’ .
<lhs>tuple-argument = basic-tuple-argument .
<rhs>tuple-argument = basic-tuple-argument | tuple-expression .
basic-tuple-argument = tuple | function-returns-tuple | parameter | reference .
function-returns-tuple = tuple-function-returns-tuple | function-returns-vector | string-function-
untyped | tuple-function-untyped .
tuple-function-returns-tuple = (‘unique’ | ‘segments’ | ‘pairwise’ | ‘loops’) ‘(’ tuple-argument ‘)’ |
‘adjacencies’ ‘(’ tuple-argument ‘,’ tuple-argument ‘)’ .
function-returns-vector = two-vector-function | proj-vector-function | scale-vector-function |
round-function .
two-vector-function = (‘vectoradd’ | ‘vectorsubtract’ | ‘dotproduct’ | ‘crossproduct’) ‘(’ (vector-
argument ‘,’ vector-argument | two-vector-argument) ‘)’ .
vector-argument = ‘(’ numeric-expression ‘,’ numeric-expression [‘,’ numeric-expression] ‘)’ |
function-returns-vector | parameter | reference .
two-vector-argument = ‘(’ vector-argument ‘,’ vector-argument ‘)’ | parameter | reference .
proj-vector-function = ‘proj’ ‘(’ (vector-argument ‘,’ vector-argument ‘,’ vector-argument | three-
vector-argument) ‘)’ .
three-vector-argument = ‘(’ vector-argument ‘,’ vector-argument ‘,’ vector-argument ‘)’ | parameter
| reference .
scale-vector-function = ‘vectorscale’ ‘(’ (vector-argument ‘,’ numeric-expression | vector-number-
argument) ‘)’ .
vector-number-argument = ‘(’ vector-argument ‘,’ numeric-expression ‘)’ | parameter | reference .
vector-function = (‘mag’ | ‘angle’) (‘(’ vector-argument ‘,’ vector-argument ‘)’ | ‘(’ two-vector-
argument ‘)’) .
round-function = ‘round’ ‘(’ (numeric-expression | vector-argument) ‘)’ .
random-function = ‘random’ ‘(’ vector-argument ‘)’ .

Example **function-returns-number**:

length(“room”)

Example **function-returns-tuple**:

adjacencies(a4, a5 a6)

reference = reference-to-lhs | reference-to-rhs .
reference-to-lhs = ['lhs.'] reference-designator ':' ('value' | parameter | property) [':' filter] .
reference-to-rhs = 'rhs.' reference-designator ':' property [':' filter] .
reference-designator = identifier .
property = identifier .
filter = reference-designator ':' property filter-operator (number | vector | string) .
filter-operator = '=' | '<>' | '<=' | '>=' .
vector = [rational] '(' rational ';' rational ';' rational ')' .
rational = ['-'] digit-sequence ['/' digit-sequence] .

Example **reference-to-lhs**:

indices.value

Example **reference-to-rhs**:

rhs.sections.radius:labels.label="S"

Appendix B. Description functions

Numerical functions

function	input	output
abs	1 number	The absolute value of the number
sqrt	1 number	The square root of the number
sin	1 number	The sine value of the angle (in radians)
cos	1 number	The cosine value of the angle (in radians)
tan	1 number	The tangent value of the angle (in radians)
asin	1 number	The inverse sine of the number (in radians)
acos	1 number	The inverse cosine of the number (in radians)
atan*	1 number	The inverse tangent of the number (in radians)
atan2*	2 numbers	The inverse tangent of the ratio (in radians)
todegree	1 number	The value converted from radians in degrees
toradian	1 number	The value converted from degrees in radians
round	1 number	The value rounded to the nearest integer

*atan versus atan2:

- atan takes 1 input and returns a result from quadrants 1 and 4
- atan2 takes 2 inputs (u, v) that specify a ratio u/v and returns a result from all quadrants

For example:

u	v	x = u/v	atan(x)	atan2(u,v)
2	1	2	1.1071487177940904	1.1071487177940904
-2	1	-2	-1.1071487177940904	-1.1071487177940904
2	-1	-2	-1.1071487177940904	2.0344439357957027
-2	-1	2	1.1071487177940904	- 2.0344439357957027

String functions

function	input	output
length	1 string	The length of the string
left	1 string and 1 number	The left substring of the specified length
right	1 string and 1 number	The right substring of the specified length

Tuple functions

function	input	output
length	1 tuple	The number of elements in the tuple
first	1 tuple	The first element of the tuple
last	1 tuple	The last element of the tuple
min	1 tuple	The element of the tuple with minimum value
max	1 tuple	The element of the tuple with maximum value
unique	1 tuple	A tuple of only unique elements
pairwise	1 tuple	A tuple of pairs extracting consecutive elements pairwise from the operand tuple; e.g., (a, b, c, d) -> ((a, b), (c, d))
segments	1 tuple	A tuple of overlapping pairs extracting consecutive elements from the operand tuple; e.g., (a, b, c, d) -> ((a, b), (b, c), (c, d))
loops	1 tuple	A tuple of tuples identifying loops in the operand tuple; e.g., (a, b, c, d, a, e, f, c) -> ((a, b, c, d), (c, d, a, e, f))
adjacencies	2 tuples: a tuple of "enclosures" and a tuple of "connecting" elements	A tuple of tuples representing an adjacency matrix
random	1 tuple: either 2 or 3 numbers	A random number within the range specified by the first two operands; the optional third operand is considered as a step value for the random number generation
round	1 vector tuple*	A vector tuple with each value rounded to the nearest integer
mag	2 vector tuples*	The distance between the two vectors
angle	2 vector tuples*	The angle between the two vectors (counterclockwise angle from the first to the second vector) (in radians)
proj	3 vector tuples*: a direction vector, a root vector and a position vector	A vector tuple representing the projection of the position vector on the line specified by the direction vector and root vector
vectoradd	2 vector tuples*	A vector tuple representing the sum of the two vectors
vectorsubtract	2 vector tuples*	A vector tuple representing the difference of the two vectors
vectorscale	1 vector tuple* and 1 number	A vector tuple representing the product of the vector and the scalar

dotproduct	2 vector tuples*	The number resulting from the dot product of the two vectors
crossproduct	2 vector tuples*	A vector tuple representing the cross product of the two vectors

*A vector tuple is a tuple of two or three numbers; any function accepting (one or more) vector tuples will also accept a single tuple collecting all operands

Appendix C: FAQ

1. I get a warning or error that makes no sense to me. What can I do?

Please recompute the Grasshopper model (F5) or reconnect an input to the SGI Setup component to force this component to recompute. This may resolve the issue; sometimes, a disconnect may occur between the Grasshopper model and the SortalGI engine, which may result in a warning or error with little or no relation to the actual data.

2. Can I get some help?

You can post a message on the SortalGI forum (<http://sortal.org/feedback/>) or e-mail stouffs@sortal.org