

# Package ‘volesti’

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**Type** Package

**License** LGPL-3

**Title** Volume Approximation of Convex Polytopes

**Description** Package provides an R interface for VolEsti C++ package. VolEsti computes approximations of volume of polytopes given as a set of points or linear inequalities or Minkowski sum of segments (zonotopes). There are two algorithms for volume approximation as well as algorithms for sampling, rounding and rotating polytopes.

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CheBall	<i>Compute the Chebychev ball of a H-polytope</i>
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## Description

For a H-polytope described by a  $m \times d$  matrix  $A$  and a  $m$ -dimensional vector  $b$ , s.t.:  $Ax \leq b$ , this function computes the largest inscribed ball (Chebychev ball) of that polytope by solving the corresponding linear program.

## Usage

```
CheBall(A, b)
```

## Arguments

$A$	The matrix of the H-polytope.
$b$	The $m$ -dimensional vector $b$ that contains the constants of the $m$ facets.

## Value

A  $(d+1)$ -dimensional vector that contains the Chebychev ball. The first  $d$  coordinates corresponds to the center and the last one to the radius of the Chebychev ball.

## Examples

```
# compute the Chebychev ball of a 2d unit simplex
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
ball_vec = CheBall(A,b)

# compute the Chebychev ball of 10-dimensional cross polytope
PolyList = GenCross(10, 'H')
ball_vec = CheBall(PolyList$A, PolyList$b)
```

---

ExactZonoVol

*Compute the exact volume of a zonotope*


---

**Description**

Given the  $m \times d$  matrix that contains the  $m$  segments that define the  $d$ -dimensional zonotope, this function computes the sum of the absolute values of the determinants of all the  $d \times d$  submatrices.

**Usage**

```
ExactZonoVol(ZonoMat)
```

**Arguments**

ZonoMat      The  $m \times d$  matrix that contains the segments that define the zonotope.

**Value**

The exact volume of the zonotope

**Examples**

```
# compute the exact volume of a 5-dimensional zonotope defined by the Minkowski sum of 10 segments
ZonoMat = GenZonotope(5, 10)
vol = ExactZonoVol(ZonoMat)
```

---

fileToMatrix

*function to get a ine file and returns a numerical matrix A*


---

**Description**

This function takes the path for an ine or an ext file and returns the corresponding numerical matrix and vector that are compatible with volesti package's functions.

**Usage**

```
fileToMatrix(path)
```

**Arguments**

path      A string that contains the path to an ine or a ext file. The ine file describes a H-polytope and ext file describes a V-polytope or a zonotope.

**Value**

If the path corresponds to an ine file then the return value is a list that contains elements "A" and "b", i.e. the numerical  $m \times d$  matrix  $A$  and the numerical  $m$ -dimensional vector  $b$ , defining H-polytope  $P$ , s.t.:  $Ax \leq b$ . If it corresponds to an ext file (V-polytopes or zonotopes) then the return value is a  $m \times d$  matrix that contains row-wise the vertices or the segments respectively.

**Examples**

```
# give the path to birk4.ine
path = system.file('extdata', package = 'volesti')
ListPoly = fileToMatrix(paste0(path, '/birk4.ine'))
```

GenCross

*Generator function for cross polytopes***Description**

This function can be used to generate a  $d$ -dimensional cross polytope in H or V representation.

**Usage**

```
GenCross(dimension, repr)
```

**Arguments**

dimension	The dimension of the cross polytope.
repr	A string to declare the representation. It has to be 'H' for H-representation or 'V' for V-representation.

**Value**

A cross polytope in H or V-representation. For an H polytope the return value is a list with two elements: the "matrix" containing a  $2^d \times d$  matrix  $A$  and the "vector" containing a  $2^d$ -dimensional vector  $b$ , s.t.  $Ax \leq b$ . When the V-representation is chosen the return value is a  $2d \times d$  matrix that contains the vertices row-wise.

**Examples**

```
# generate a 10-dimensional cross polytope in H-representation
PolyList = GenCross(10, 'H')

# generate a 15-dimension cross polytope in V-representation
PolyList = GenCross(15, 'V')
```

---

GenCube	<i>Generator function for hypercubes</i>
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---

**Description**

This function can be used to generate a  $d$ -dimensional Hypercube  $[-1, 1]^d$  in H or V representation.

**Usage**

```
GenCube(dimension, repr)
```

**Arguments**

dimension	The dimension of the hypercube
repr	A string to declare the representation. It has to be 'H' for H-representation or 'V' for V-representation.

**Value**

A hypercube in H or V-representation. For an H polytope the return value is a list with two elements: the "matrix" containing a  $2d \times d$  matrix  $A$  and the "vector" containing a  $2d$ -dimensional vector  $b$ , s.t.  $Ax \leq b$ . When the V-representation is chosen the return value is a  $2^d \times d$  matrix that contains the vertices row-wise.

**Examples**

```
# generate a 10-dimensional hypercube in H-representation
PolyList = GenCube(10, 'H')

# generate a 15-dimension hypercube in V-representation
PolyList = GenCube(15, 'V')
```

---

GenProdSimplex	<i>Generator function for product of simplices</i>
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---

**Description**

This function can be used to generate a  $2d$ -dimensional polytope that is defined as the product of two  $d$ -dimensional unit simplices in H-representation.

**Usage**

```
GenProdSimplex(dimension)
```

**Arguments**

dimension	The dimension of the simplices.
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**Value**

A polytope defined as the product of two unit simplices in H-representation. The return value is a list with two elements: the "matrix" containing a  $(2d+1) \times 2d$  matrix  $A$  and the "vector" containing a  $(2d+1)$ -dimensional vector  $b$ , s.t.  $Ax \leq b$ .

**Examples**

```
# generate a product of two 5-dimensional simplices.
PolyList = GenProdSimplex(5)
```

---

GenSimplex

*Generator function for simplices*


---

**Description**

This function can be used to generate a  $d$ -dimensional unit simplex in H or V representation.

**Usage**

```
GenSimplex(dimension, repr)
```

**Arguments**

dimension	The dimension of the simplex.
repr	A string to declare the representation. It has to be 'H' for H-representation or 'V' for V-representation.

**Value**

A simplex in H or V-representation. For an H polytope the return value is a list with two elements: the "matrix" containing a  $(d+1) \times d$  matrix  $A$  and the "vector" containing a  $(d+1)$ -dimensional vector  $b$ , s.t.  $Ax \leq b$ . When the V-representation is chosen the return value is a  $(d+1) \times d$  matrix that contains the vertices row-wise.

**Examples**

```
# generate a 10-dimensional simplex in H-representation
PolyList = GenSimplex(10, 'H')

# generate a 20-dimensional simplex in V-representation
PolyList = GenSimplex(20, 'V')
```

---

GenSkinnyCube	<i>Generator function for skinny hypercubes</i>
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---

**Description**

This function can be used to generate a  $d$ -dimensional skinny hypercube only in H-representation.

**Usage**

```
GenSkinnyCube(dimension)
```

**Arguments**

dimension	The dimension of the skinny hypercube.
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**Value**

A  $d$ -dimensional skinny hypercube in H-representation. The return value is a list with two elements: the "matrix" containing a  $2d \times d$  matrix  $A$  and the "vector" containing a  $2d$ -dimensional vector  $b$ , s.t.  $Ax \leq b$ .

**Examples**

```
# generate a 10-dimensional skinny hypercube.
PolyList = GenSkinnyCube(10)
```

---

GenZonotope	<i>Generator function for zonotopes</i>
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---

**Description**

This function can be used to generate a  $d$ -dimensional zonotope defined by the Minkowski sum of  $m$  segments. We consider the  $e_1, \dots, e_d$  generators and  $m - d$  random generators. Then we shift the zonotope in order to contain the origin. The origin is the center of symmetry as well. It might need rounding before the volume approximation using SequenceOfBalls or CoolingGaussian algorithms.

**Usage**

```
GenZonotope(dimension, NumGen)
```

**Arguments**

dimension	The dimension of the zonotope.
NumGen	The number of segments that generate the zonotope.

**Value**

A  $m \times d$  matrix that contains the  $m$   $d$ -dimensional segments.

**Examples**

```
# generate a 10-dimensional zonotope defined by the Minkowski sum of 20 segments
zonotope = GenZonotope(10, 20)
```

---

polytope_generator	<i>Internal function to generate polytopes</i>
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**Description**

This function is used by polytope generator functions. It is an internal function and it is not suggested to use it.

**Usage**

```
polytope_generator(Zono, repr, kind_gen, dim_gen, m_gen)
```

**Arguments**

Zono	A boolean parameter to declare if the generated polytope has to be zonotope or not.
repr	A string parameter to declare the representation of the polytope. Use 'H' for H-representation, 'V' for V-representation and 'zonotope' for zonotopes.
kind_gen	An integer to declare the kind of the polytope. Use '0' for zonotopes, '1' for cubes, '2' for cross polytopes, '3' for simplices, '4' for product of two simplices and '5' for skinny cubes. See polytope generator functions for more details.
dim_gen	An integer to declare the dimension of the polytope.
m_gen	Only for zonotopes. An integer to declare the number of segments.

**Value**

For H-polytopes the return value is a list that contains a  $m \times d$  matrix  $A$  and a  $m$ -dimensional vector  $b$  s.t.:  $Ax \leq b$ . For V-polytopes and zonotopes the return value is a  $m \times d$  matrix that contains row-wise the  $d$ -dimensional vertices or segments respectively.

**Examples**

```
# create a 5-dimensional zonotope that is defined by the Minkowski sum of 10 segments
ZonoMat = polytope_generator(TRUE, 'zonotope', 0, 5, 10)

# create a 20-dimensional unit simplex in V-representation
PolyMat = polytope_generator(FALSE, 'V', 1, 20, -1)
```



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rand_rotate	<i>Apply a random rotation to a convex polytope (H-polytope, V-polytope or a zonotope)</i>
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---

### Description

Given a convex H or V polytope or a zonotope as input this function applies a random rotation.

### Usage

```
rand_rotate(A, b, V, G)
```

### Arguments

A	Only for H-polytopes. The $m \times d$ matrix $A$ that contains the directions of the $m$ facets.
b	Only for H-polytopes. The $m$ -dimensional vector $b$ that contains the constants of the $m$ facets s.t.: $Ax \leq b$ .
V	Only for V-polytopes. The $m \times d$ matrix $V$ that contains row-wise the $m$ $d$ -dimensional vertices of the polytope.
G	Only for zonotopes. The $m \times d$ matrix $G$ that contains row-wise the $m$ $d$ -dimensional segments that define a zonotope.

### Value

A random rotation of the polytope that is given as an input. For H-polytopes the return value is a list that contains a  $m \times d$  matrix  $A$  and a  $m$ -dimensional vector  $b$  s.t.:  $Ax \leq b$ . For V-polytopes and zonotopes the return value is a  $m \times d$  matrix that contains row-wise the  $d$ -dimensional vertices or segments respectively.

### Examples

```
# rotate a H-polytope (2d unit simplex)
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
listHpoly = rand_rotate(A=A, b=b)

# rotate a V-polytope (3d cube)
Vmat = GenCube(3, 'V')
matVpoly = rand_rotate(V=Vmat)

# rotate a 5-dimensional zonotope defined by the Minkowski sum of 15 segments
Zmat = GenZonotope(5,15)
MatZono = rand_rotate(G=Zmat)
```

---

round_polytope	<i>Apply rounding to a convex polytope (H-polytope, V-polytope or a zonotope)</i>
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---

### Description

Given a convex H or V polytope or a zonotope as input this function computes a rounding based on minimum volume enclosing ellipsoid of a pointset.

### Usage

```
round_polytope(A, b, V, G, walk_length, ball_walk, delta, coordinate, verbose)
```

### Arguments

A	Only for H-polytopes. The $m \times d$ matrix $A$ that contains the directions of the $m$ facets.
b	Only for H-polytopes. The $m$ -dimensional vector $b$ that contains the constants of the $m$ facets s.t.: $Ax \leq b$ .
V	Only for V-polytopes. The $m \times d$ matrix $V$ that contains row-wise the $m$ $d$ -dimensional vertices of the polytope.
G	Only for zonotopes. The $m \times d$ matrix $G$ that contains row-wise the $m$ $d$ -dimensional segments that define a zonotope.
walk_length	Optional. The number of the steps for the random walk. Default value is $\lfloor 10 + d/10 \rfloor$ .
ball_walk	Optional. Boolean parameter to use ball walk, only for CG algorithm. Default value is false.
delta	Optional. The radius for the ball walk.
coordinate	Optional. A boolean parameter for the hit-and-run. True for Coordinate Directions HnR, false for Random Directions HnR. Default value is true.
verbose	Optional. A boolean parameter for printing. Default value is false.

### Value

For H-polytopes the return value is a list that contains a  $m \times d$  matrix  $A$  and a  $m$ -dimensional vector  $b$  s.t.:  $Ax \leq b$ . For V-polytopes and zonotopes the return value is a list with first element a  $m \times d$  matrix that contains row-wise the  $d$ -dimensional vertices or segments respectively. For all the representations the returned list contains element "round\_value" which is the determinant of the square matrix of the linear transformation that was applied on the polytope that is given as input.

**Examples**

```
# rotate a H-polytope (2d unit simplex)
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
listHpoly = round_polytope(A=A, b=b)

# rotate a V-polytope (3d cube) using Random Directions HnR
Vmat = GenCube(3, 'V')
ListVpoly = round_polytope(V=Vmat, coordinate=FALSE)

# rotate a 10-dimensional zonotope defined by the Minkowski sum of 20 segments
Zmat = GenZonotope(10,20)
ListZono = round_polytope(G=Zmat)
```

---

sample_points	<i>Sample points from a convex Polytope (H-polytope, V-polytope or a zonotope)</i>
---------------	--

---

**Description**

Sample  $N$  points from a H or a V-polytope or a zonotope with uniform or spherical gaussian - centered in an internal point- target distribution.

**Usage**

```
sample_points(A, b, V, G, walk_length, internal_point, gaussian, variance, N,
  ball_walk, delta, verbose, coordinate)
```

**Arguments**

$A$	Only for H-polytopes. The $m \times d$ matrix $A$ that contains the directions of the $m$ facets.
$b$	Only for H-polytopes. The $m$ -dimensional vector $b$ that contains the constants of the $m$ facets s.t.: $Ax \leq b$ .
$V$	Only for V-polytopes. The $m \times d$ matrix $V$ that contains row-wise the $m$ $d$ -dimensional vertices of the polytope.
$G$	Only for zonotopes. The $m \times d$ matrix $G$ that contains row-wise the $m$ $d$ -dimensional segments that define a zonotope.
walk_length	Optional. The number of the steps for the random walk. Default value is $\lfloor 10 + d/10 \rfloor$ .
internal_point	Optional. A $d$ -dimensional vector that contains the coordinates of an internal point of the polytope. If it is not given then for H-polytopes the Chebychev center is computed, for V-polytopes $d + 1$ vertices are picked randomly and the Chebychev center of the defined simplex is computed. For a zonotope that is defined by the Minkowski sum of $m$ segments we use the origin.

gaussian	Optional. A boolean parameter to sample with gaussian target distribution. Default value is false.
variance	Optional. The variance for the spherical gaussian. Default value is 1.
N	The number of points that the function is going to sample from the convex polytope. Default value is 100.
ball_walk	Optional. Boolean parameter to use ball walk for the sampling. Default value is false.
delta	Optional. The radius for the ball walk.
verbose	Optional. A boolean parameter for printing. Default value is false.
coordinate	Optional. A boolean parameter for the hit-and-run. True for Coordinate Directions HnR, false for Random Directions HnR. Default value is true.

### Value

A  $d \times N$  matrix that contains, column-wise, the sampled points from the convex polytope.

### Examples

```
# uniform distribution from a 3d cube described by a set of vertices
Vmat = GenCube(3, 'V')
points = sample_points(V=Vmat, N=1000)

# gaussian distribution from a 2d unit simplex in H-representation with variance = 2
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
points = sample_points(A=A, b=b, gaussian=TRUE, variance=2)
```

---

volume	<i>The main R function for volume approximation of a convex Polytope (H-polytope, V-polytope or a zonotope)</i>
--------	---

---

### Description

For the volume approximation can be used two algorithms. Either SequenceOfBalls or Cooling-Gaussian. A H-polytope with  $m$  facets is described by a  $m \times d$  matrix  $A$  and a  $m$ -dimensional vector  $b$ , s.t.:  $Ax \leq b$ . A V-polytope is described as a set of  $d$ -dimensional points. A zonotope is described by the Minkowski sum of  $d$ -dimensional segments.

### Usage

```
volume(A, b, V, G, walk_length, error, InnerVec, CG, win_len, C, N, ratio, frac,
      ball_walk, delta, verbose, coordinate, rounding)
```

**Arguments**

A	Only for H-polytopes. The $m \times d$ matrix $A$ that contains the directions of the $m$ facets.
b	Only for H-polytopes. The $m$ -dimensional vector $b$ that contains the constants of the $m$ facets s.t.: $Ax \leq b$ .
V	Only for V-polytopes. The $m \times d$ matrix $V$ that contains row-wise the $m$ $d$ -dimensional vertices of the polytope.
G	Only for zonotopes. The $m \times d$ matrix $G$ that contains row-wise the $m$ $d$ -dimensional segments that define a zonotope.
walk_length	Optional. The number of the steps for the random walk. Default value is $\lfloor 10 + d/10 \rfloor$ .
error	Optional. Declare the goal for the approximation error. Default value is 1 for SequenceOfBalls and 0.2 for CoolingGaussian.
InnerVec	Optional. A $d + 1$ vector that contains an inner ball. The first $d$ coordinates corresponds to the center and the last one to the radius of the ball. If it is not given then for H-polytopes the Chebychev ball is computed, for V-polytopes $d + 1$ vertices are picked randomly and the Chebychev ball of the defined simplex is computed. For a zonotope that is defined by the Minkowski sum of $m$ segments we compute the maximal $r$ s.t.: $re_i \in Z$ for all $i = 1, \dots, d$ , then the ball centered at the origin with radius $r/\sqrt{d}$ is an internal ball.
CG	Optional. A boolean parameter to use CoolingGaussian algorithm. Default value is false.
win_len	Optional. The size of the window for the ratios' approximation in CG algorithm. Default value is $4 \cdot dimension^2 + 500$ .
C	Optional. A constant for the lower bound of $variance/mean^2$ in schedule annealing of CG algorithm.
N	optional. The number of points we sample in each step of schedule annealing in CG algorithm. Default value is $500C + dimension^2/2$ .
ratio	Optional. Parameter of schedule annealing of CG algorithm, larger ratio means larger steps in schedule annealing. Default value is $1 - 1/dimension$ .
frac	Optional. The fraction of the total error to spend in the first gaussian in CG algorithm. Default value is 0.1.
ball_walk	Optional. Boolean parameter to use ball walk. Default value is false.
delta	Optional. The radius for the ball walk.
verbose	Optional. A boolean parameter for printing. Default value is false.
coordinate	Optional. A boolean parameter for the hit-and-run. True for Coordinate Directions HnR, false for Random Directions HnR. Default value is true.
rounding	Optional. A boolean parameter to activate the rounding option. Default value is false.

**Value**

The approximation of the volume of a convex polytope.

## References

*I.Z.Emiris and V. Fisikopoulos, “Practical polytope volume approximation,” ACM Trans. Math. Soft., 2014.,*

*B. Cousins and S. Vempala, “A practical volume algorithm,” Springer-Verlag Berlin Heidelberg and The Mathematical Programming Society, 2015.*

## Examples

```
# calling SOB algorithm for a H-polytope (2d unit simplex)
A = matrix(c(-1,0,0,-1,1,1), ncol=2, nrow=3, byrow=TRUE)
b = c(0,0,1)
vol = volume(A=A, b=b)

# calling CG algorithm for a V-polytope (3d cube)
Vmat = GenCube(3, 'V')
vol = volume(V=Vmat, CG=TRUE)

# calling CG algorithm for a 5-dimensional zonotope defined as the Minkowski sum of 10 segments
zonotope = GenZonotope(5, 10)
vol = volume(G=zonotope, rounding=TRUE, CG=TRUE)
```

---

vol_R	<i>The main Rcpp function</i>
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## Description

All the R functions (except GenCubes, GenCross, GenProdSimplex, GenSimplex, Gen SkinnyCube and GenZonotope which call polytope\_generate) call this Rcpp function. This is an internal function and we do not suggest to use it.

## Usage

```
vol_R(A, walk_len, e, InnerVec, CG, win_len, N, C, ratio, frac, ball_walk,
      delta, Vpoly, Zono, exact_zono, gen_only, Vpoly_gen, kind_gen, dim_gen,
      m_gen, round_only, rotate_only, ball_only, sample_only, numpoints, variance,
      coord, rounding, verbose)
```

## Arguments

A	A matrix in ine format (for H-polytopes) or in ext format (for V-polytopes or zonotopes).
walk_len	The number of the steps for the random walk.
e	The goal for the approximation error.
InnerVec	A $d + 1$ vector that contains an inner ball. Or a $d$ vector for a internal point when sample_point calls vol_R, or a vector with different size when there is not an input for this feature.

CG	A boolean flag to use CoolingGaussian algorithm or to sample from spherical gaussian when sample_only flag is true.
win_len	The size of the window for the ratios' approximation in CG algorithm.
N	The number of points we sample in each step of schedule annealing in CG algorithm.
C	A constant for the lower bound of $variance/mean^2$ in schedule annealing of CG algorithm.
ratio	Parameter of schedule annealing of CG algorithm, larger ratio means larger steps in schedule annealing.
frac	The fraction of the total error to spend in the first gaussian in CG algorithm.
ball_walk	Boolean flag to use ball walk method for the random walk.
delta	The radius for the ball walk.
Vpoly	A boolean flag to declare if the input is a V-polytope.
Zono	A boolean flag to declare if the input is a V-polytope.
exact_zono	A boolean flag, it has to be true when the function is called to compute the exact volume of a zonotope.
gen_only	A boolean flag, it has to be true when the function is called to generate a polytope.
Vpoly_gen	A boolean flag, it has to be true when gen_only is true and the requested representation is the V-representation.
kind_gen	An integer parameter to declare the kind of the polytope when the gen_only flag is true.
dim_gen	An integer parameter to declare the dimension when the gen_only flag is true.
m_gen	An integer parameter to declare the number of segments that generate a zonotope when gen_only flag is true.
round_only	A boolean flag, it has to be true when the function is called only for rounding.
rotate_only	A boolean flag, it has to be true when the function is called only for a random rotation of a convex polytope.
ball_only	A boolean flag, it has to be true when the function is called only for the computation of an inner ball.
sample_only	A boolean flag, it has to be true when the function is called only to sample from a convex polytope.
numpoints	The number of points that the function is going to sample from the convex polytope when sample_only flag is true.
variance	The variance for the spherical gaussian when sample_only flag is true.
coord	A boolean flag for the hit-and-run. True for Coordinate Directions HnR, false for Random Directions HnR.
rounding	A boolean flag to activate the rounding option.
verbose	A boolean flag for printing.

**Value**

A numerical matrix. For polytope generation, rotating and rounding is a matrix in ine or ext format. For sampling is a  $d \times N$  matrix. For the volume approximation is  $1 \times 1$  numerical matrix.

**Examples**

```
# see the package's functions
```



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