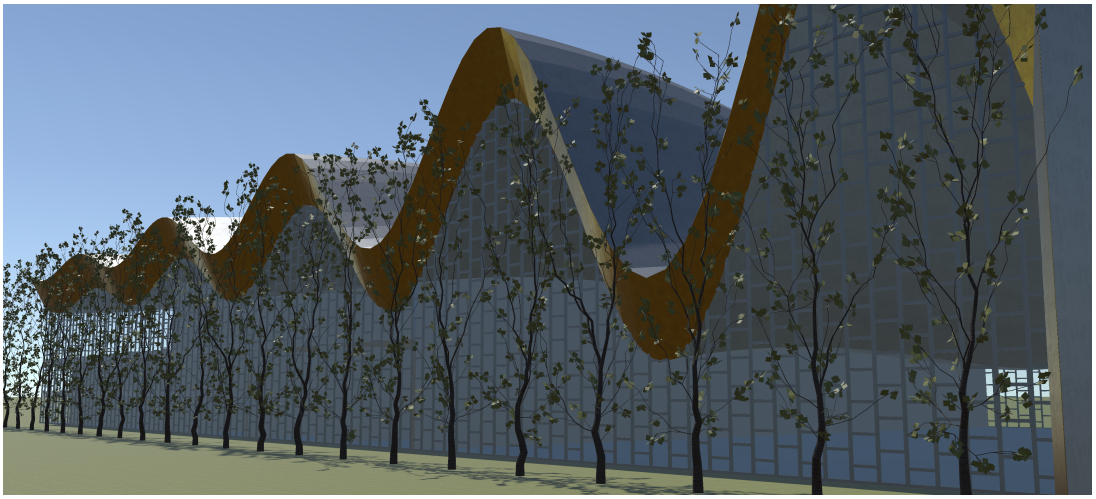
```
using PlutoUI
```

Rhythmic Gymnastics Pavilion

The project presented in this notebook is an adaptation of the Irina Viner-Usmanova Rhythmic Gymnastics Centre, originally designed by CPU Pride for Moscow, Russia. Its most prominent feature is the wavy roof-structure, inspired by the movement of a rhythmic gymnastic's strip. The program elaborated here is a personal interpretation of the original design, developed in a 5 day collaborative sprint. This notebook uses the **Julia** programming language and the **Khepri** algorithmic design tool to model the building's geometry.



SET UP

```
using WebIO
```

```
using Khepri
```

Khepri backends size:

```
(700, 400)
```

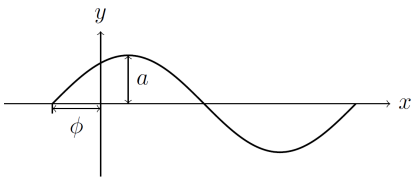
```
render_size(700, 400)
```

Khepri `render_dir` command defines where the render images are saved in your PC. Use `render_view` to save renders to the chosen file path.

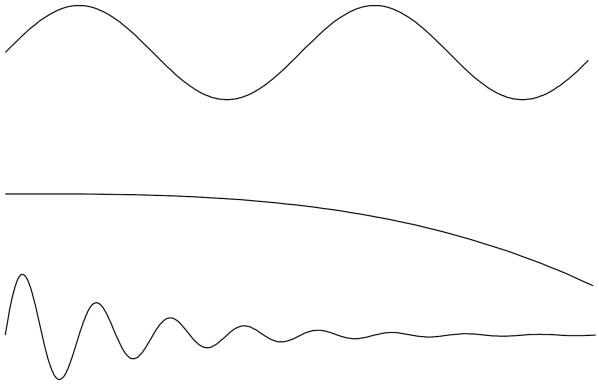
```
# render_dir("C:\\Users\\Renata\\Documents\\GitHub\\GymnasticsPavilion_Moscow\\Plots")
```

Sinusoidal Curves

Sinunoisal wave parameters



Other sinusoidal curves



`sinusoidal` parameters explained:

- a is the amplitude
- omega is the frequency
- fi is the phase

```
sinusoidal (generic function with 1 method)
```

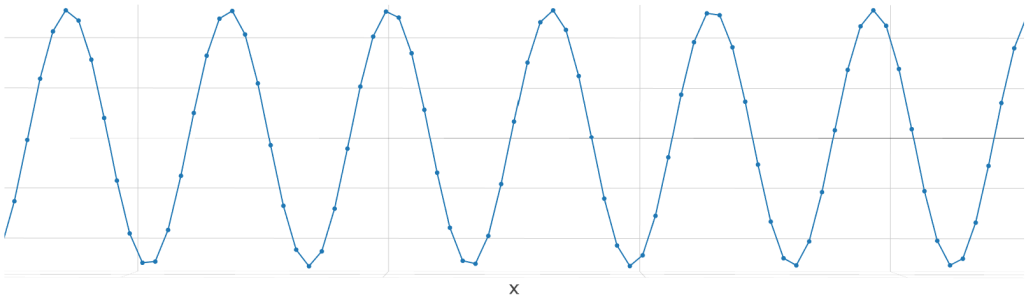
```
sinusoidal(a, omega, fi, x) = a*sin(omega*x+fi)
```

```
sin_array_y (generic function with 1 method)
```

```
sin_array_y(p, a, omega, fi, dist, n) = [p+vxy(i, sinusoidal(a, omega, fi, i)) for i in division(0, dist, n)]
```

```
#=
begin
    backend(notebook)
    new_backend()
    line(sin_array_y(u0(), 5, 1, 0, 50, 100))
end
=#
```

Expected result:



`damped_sin_wave`'s parameters explained

- a is the initial amplitude (the highest peak)
- b is the decay constant
- omega is the angular frequency

```
damped_sin_wave (generic function with 1 method)
```

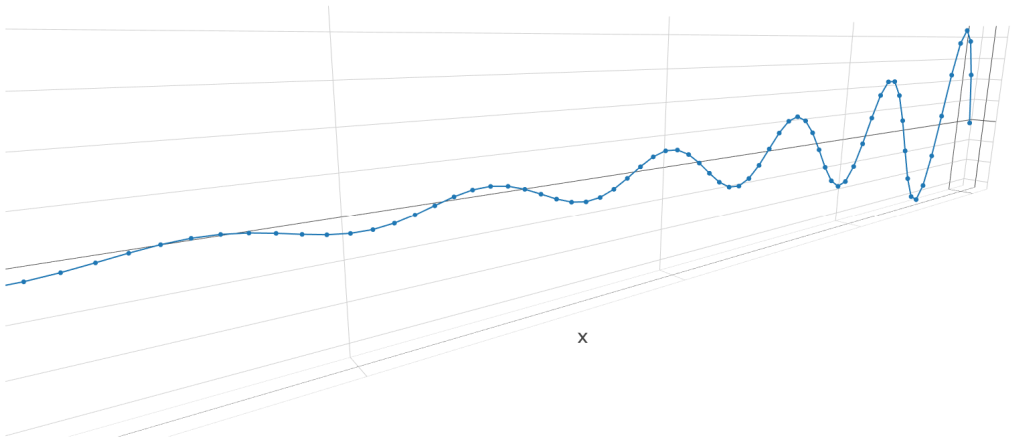
```
damped_sin_wave(a, d, omega, x) = a*exp(-(d*x))*sin(omega*x)
```

```
damped_sin_array_z (generic function with 1 method)
```

```
damped_sin_array_z(p, a, d, omega, dist, n) = [p+vxz(i, damped_sin_wave(a, d, omega, i)) for i in division(0, dist, n)]
```

```
#=
begin
    backend(notebook)
    new_backend()
    line(damped_sin_array_z(u0(), 5, 0.1, 1, 50, 100))
end
=#
```

Expected result:




```
damped_sin_roof_pts (generic function with 1 method)
```

```
damped_sin_roof_pts(p, h, a_x, a_y_min, a_y_max, fi, decay, om_x, om_y, dist_x, dist_y, n_x, n_y) =
    map_division((x, y) ->
                y <= d_i ?
                p + vxyz(x,
                         -sin(y/d_i*(1*pi)),
                         y*h/d_i + sin(x/dist_x*pi)sinusoidal(a_x, om_x, fi-y*pi/dist_y, x)*
(y*a_x/d_i)) :
                p + vxyz(x,
                         y,
                         h + sin(x/dist_x*pi)*sinusoidal(a_x, om_x, fi-y*pi/dist_y, x) +
                         damped_sin_wave(a_y_max - (a_y_max-a_y_min)/dist_x*x, decay, om_y, y)),
             0, dist_x, n_x,
             0, dist_y, n_y)
```

`d_i` is the distance between the pavilion starting point and the beginning of the dumped sine curve.

```
#=
begin
    backend(meshcat)
    new_backend()
end
=#
```

```
# surface_grid(damped_sin_roof_pts(u0(), 20, 3, 10, 15, pi, 0.03, pi/50, pi/10, 60, 100, 120, 800))
```

Expected result:

Amplitude x 2.6

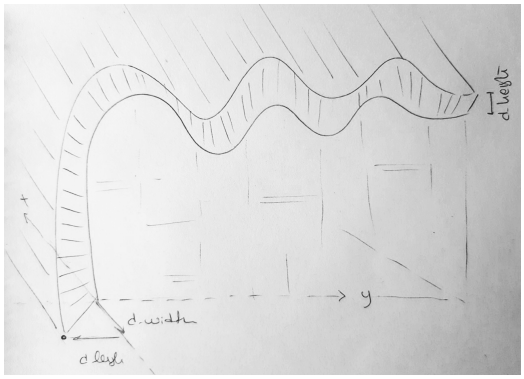
Minimum Amplitude y 13.5

Maximum Amplitude y 13.1

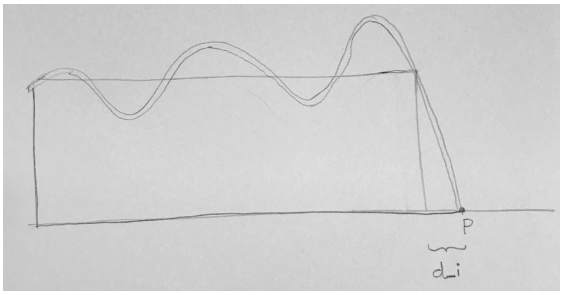
Height 17

Pavilion Dimensions

Roof dimentions explained



`d_i` **explained**



Double sinuoid parameters:

- amp_x = amplitude of the sinusoid along the x axis
- amp*y*min_top = minimum amplitude of the damped sinusoid along the y axis for the top layer of the roof
- amp*y*max_top = maximum amplitude of the damped sinusoid along the y axis for the top layer of the roof
- amp*y*max_bottom = maximum amplitude of the damped sinusoid along the y axis for the bottom layer of the roof
- amp*y*min_bottom = minimum amplitude of the damped sinusoid along the y axis for the bottom layer of the roof
- fi = sinusoid's phase along the x axis
- decay = damped sinusoid's decay along the y axis
- om_x = frequency of the sinusoid in x
- om_y = frequency of the damped sinusoid in y

General pavilion parameters:

- pav_width = pavilion's width (along x axis)
- pav_length = pavilion's lenght (along y axis)
- pav_height = pavilion's height (z axis)
- d_width = distance between roof layers in the x axis (top layer is wider)
- d_length = distance between roof layers in the y axis (top layer is longer)
- d_height = distance between roof layers in the z axis (height of the roof truss)
- d_i = distance before the damped sinusoid starts shaping the roof

Construction elements parameters:

- glass*panel*height = façade glass panel's height (width is defined by the number of points in the `damped_sinusoid` array)
- n*panels*y = number of row subdivisions for triangular roof panels and glass wall vertical lines in length
- n*panels*x = number of row subdivisions for triangular roof panels and glass wall vertical lines in width
- n*glass*verts = number of vertical panels per glass line
- pinwheel*rec*level = number of times the pattern gets recursively subdivided
- pav*slab*thickness = floor slab thickness
- pav*struct*thickness = inner structural wall's thickness
- n_floors = number of floors inside the pavilion
- n*wall*in_width = number of transverse walls on each floor

- n*wall*in_length = number of longitudinal walls on each floor

6

```
begin
    amp_x = 2.5
    amp_y_min_top = 4
    amp_y_max_top = 11
    amp_y_max_bottom = 10
    amp_y_min_bottom = 3
    fi = pi
    decay = 0.03

    pav_width = 60
    pav_length = 100
    pav_height = 14
    d_width = 1.5
    d_length = 1
    d_height = 3
    d_i = d_length

    om_x = pi/pav_width
    om_y = 10*pi/pav_length
    om_y_bottom = 10*pi/(pav_length - 2*d_length)

    glass_panel_height = 1
    n_panels_y = 100
    n_panels_x = 50
    n_glass_verts = 10
    pinwheel_rec_level = 3
    pav_slab_thickness = 0.5
    pav_struct_thickness = 0.3
    n_floors = 3
    n_wall_in_width = 4
    n_wall_in_length = 6
end
```

BIM families

BIM families for truss elements:

```
free_node_fam = truss_node_family_element(default_truss_node_family(),
support=Khepri.truss_node_support(), radius=0.1);
```

```
sup_node_fam = truss_node_family_element(default_truss_node_family(),
support=Khepri.truss_node_support(ux=true, uy=true, uz=true), radius=0.1);
```

BIM families for roof panels:

```
roof_panel_fam = panel_family_element(default_panel_family());
```

```
yellow_panel_fam = panel_family_element(default_panel_family());
```

Frame BIM family:

frame_width = 0.1

```
frame_width=0.1
```

```
frame_fam = column_family_element(default_column_family(), profile=rectangular_profile(frame_width,
frame_width));
```

BIM families for walls and slabs:

```
pav_slab_fam = slab_family_element(default_slab_family(), thickness=pav_slab_thickness);
```

```
pav_wall_struct_fam = wall_family_element(default_wall_family(), thickness=pav_struct_thickness);
```

Ground family:

```
ground_fam = slab_family_element(default_slab_family());
```

BIM family materials for Unity backend:

Dict()

```
begin

# TRUSS FAMILY MATERIALS

set_backend_family(default_truss_bar_family(), unity,
unity_material_family("Default/Materials/Aluminum"))
set_backend_family(free_node_fam, unity, unity_material_family("Default/Materials/Aluminum"))
set_backend_family(sup_node_fam, unity, unity_material_family("materials/metal/Copper"))

# GLASS WALLS

set_backend_family(default_panel_family(), unity,
unity_material_family("Default/Materials/GlassBlue"))
set_backend_family(frame_fam, unity, unity_material_family("Default/Materials/Steel"))

# ROOF SURFACE PANELS
```

```
set_backend_family(roof_panel_fam, unity, unity_material_family("Default/Materials/Aluminum"))
set_backend_family(yellow_panel_fam, unity, unity_material_family("materials/metal/YellowCopper"))
set_backend_family(pav_slab_fam, unity, unity_material_family("Default/Materials/Plaster"))

# GROUND MATERIAL

# set_backend_family(ground_fam, unity, unity_material_family("Default/Materials/Concrete")) # -- concrete ground
set_backend_family(ground_fam, unity, unity_material_family("Default/Materials/Grass")) # -- grass ground
# set_backend_family(ground_fam, unity, unity_material_family("Default/Materials/White")) # -- white ground
# set_backend_family(ground_fam, unity, unity_material_family("Default/Materials/WhiteUnlit")) # -- white ground no shadows

end
```

Roof Truss

Basic truss elements

The following functions create truss elements:

- `free_node` and `fixed_node` create truss nodes
- `bar` creates truss bars
- `panel` creates truss panels

Truss elements:

```
fixed_node (generic function with 1 method)
```

```
fixed_node(p) = truss_node(p, family=sup_node_fam)
```

```
free_node (generic function with 1 method)
```

```
free_node(p) = truss_node(p, family=free_node_fam)
```

```
bar (generic function with 1 method)
```

```
bar(p, q) = truss_bar(p, q)
```

Spatial truss

`truss_ptss` receives two sets of points, the bottom and top points defining the shape of the truss to create. It returns the points defining the truss structure.

```
truss_ptss (generic function with 1 method)
```

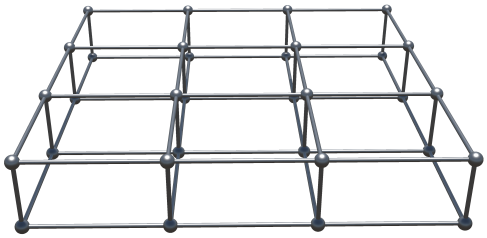
```
truss_ptss(bottom_ptss,top_ptss) =
    length(top_ptss) == length(bottom_ptss) ?
    vcat([[pts,qts] for (pts,qts) in zip(bottom_ptss,top_ptss)]...) :
    vcat([[pts,qts] for (pts,qts) in zip(top_ptss[1:end-1],bottom_ptss)]..., [top_ptss[end]])
```

`truss` receives the type of truss to create, as well as both bottom and top points defining its shape. It creates a 3D spatial truss.

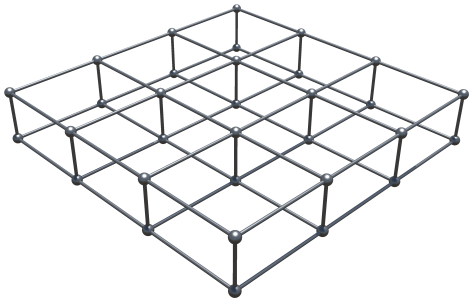
```
truss (generic function with 1 method)
```

```
truss(truss_type; bottom_ptss=planar(p=x(0)), top_ptss=planar(p=z(1))) =
    let ptss = truss_ptss(bottom_ptss, top_ptss)
      truss_type(ptss)
  end
```

Vierendeel modular block front



Vierendeel modular block side



`vierendeel` creates a vierendeel truss structure.

```
vierendeel (generic function with 2 methods)
```

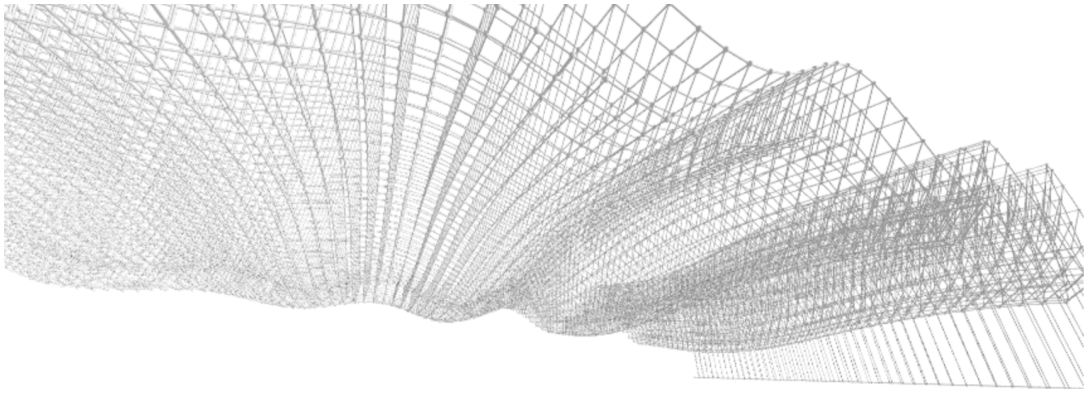
```
vierendeel(ptss, first=true) =
    let ais = ptss[1],
        bis = ptss[2],
        cis = ptss[3],
        dis = ptss[4]
      (first ? fixed_node : free_node).(ais)
      free_node.(bis)
      bar.(ais, bis)
      bar.(ais, cis)
      bar.(bis, dis)
      bar.(ais[2:end], ais[1:end-1])
      bar.(bis[2:end], bis[1:end-1])
      if ptss[5:end] == []
          fixed_node.(cis)
```

```
            free_node.(dis)
            bar.(cis[2:end], cis[1:end-1])
            bar.(dis[2:end], dis[1:end-1])
            bar.(dis, cis)
        else
            vierendeel(ptss[3:end], false)
        end
    end
```

```
#=
begin
    backend(meshcat)
    new_backend()
end
=#
```

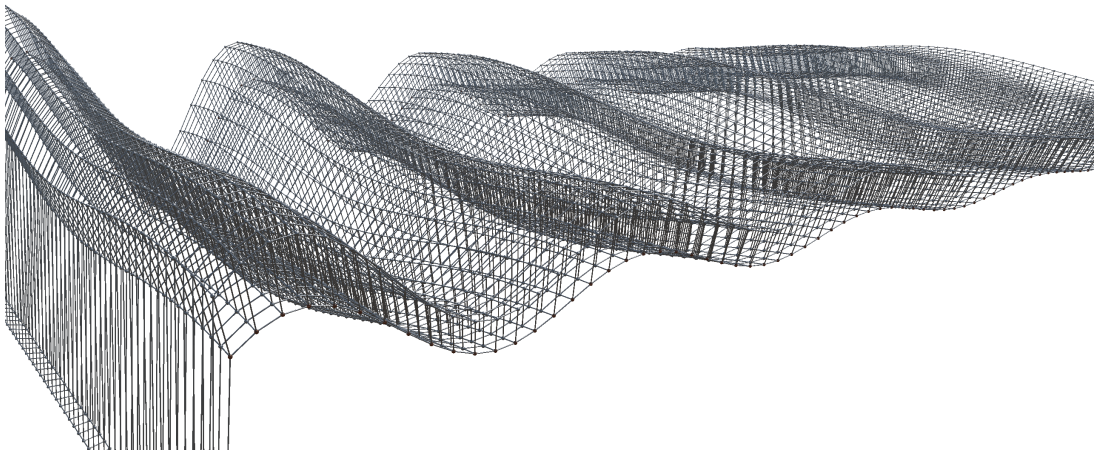
```
#=
begin
    ampx = 3
    ampy_top_min = 10
    ampy_top_max = 15
    ampy_bottom_min = 10
    ampy_bottom_max = 12
    h = 20
    truss(vierendeel,
      top_ptss=damped_sin_roof_pts(u0(), pav_height,
                                   ampx, ampy_top_min, ampy_top_max,
                                   fi, decay, om_x, om_y,
                                   pav_width, pav_length-d_length, 50, 80),
      bottom_ptss=damped_sin_roof_pts(xy(d_width,d_length), pav_height-d_height,
                                  ampx, ampy_bottom_min, ampy_bottom_max,
                                  fi, decay, om_x, om_y_bottom,
                                  pav_width - d_width*2, pav_length-2*d_length, 50, 80))
end
=#
```

Expected result:



```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    truss(vierendeel,
      top_ptss=damped_sin_roof_pts(u0(), pav_height,
                                   amp_x, amp_y_min_top, amp_y_max_top,
                                   fi, decay, om_x, om_y,
                                   pav_width, pav_length-d_length, 5, 8),
      bottom_ptss=damped_sin_roof_pts(xy(d_width,d_length), pav_height-d_height,
                                  amp_x, amp_y_min_bottom, amp_y_max_bottom,
                                  fi, decay, om_x, om_y_bottom,
                                  pav_width - d_width*2, pav_length-2*d_length, 5, 8))
#     render_view("truss_roof_unity")
end
=#
```

Expected result:



Roof Surface

Auxiliar functions

`transpose_array` receives an array of arrays and transposes it.

```
transpose_array (generic function with 1 method)
```

```
transpose_array(arrays) =
    [[row[i] for row in arrays]
     for i in 1:length(arrays[1])]
```

`pts_distances` receives an array of points and returns an array with the distances between ordered points.

```
pts_distances (generic function with 2 methods)
```

```
pts_distances(pts, last_pt=true) =
    let n =  last_pt ? 0 : 1
      [distance(p,q)
       for (p,q) in zip(pts,[pts[2:end]...,pts[1]])][1:end-n]
       end
```

```
shape_grid_polygon_vertices (generic function with 1 method)
```

```
shape_grid_polygon_vertices(pts) =
    () -> pts
```

`itera_2triangs` receives an array of arrays of points. It returns the same points rearranged to create a triangular grid of points.

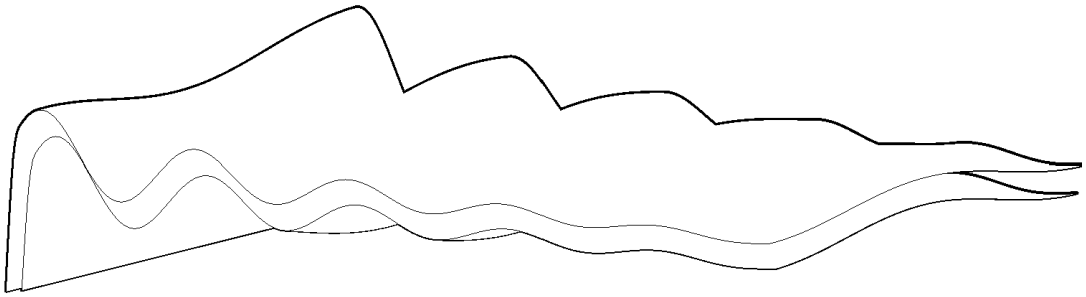
```
itera_2triangs (generic function with 1 method)
```

```
itera_2triangs(ptss) =
    vcat([vcat([[[p0,p1,p3],[p1,p2,p3]]
                for (p0,p1,p2,p3)
                in zip(pts0[1:end-1], pts1[1:end-1], pts1[2:end], pts0[2:end])]...)
          for (pts0, pts1) in zip(ptss[1:end-1], ptss[2:end])]...)
```

Roof option 1: simple surfaces

```
#=
begin
    backend(autocad)
    delete_all_shapes()
    top_roof_test = damped_sin_roof_pts(x(0), 15,
                                    3, 6, 9,
                                    fi, decay, om_x, om_y,
                                    pav_width, pav_length-d_length, 50, 100)
    bottom_roof_test = damped_sin_roof_pts(xy(d_width,d_length*1), 15-d_height,
                                       3, 6, 8,
                                       fi, decay, om_x, om_y_bottom,
                                       pav_width - d_width*2, pav_length-2*d_length, 50, 100)
    surface_grid(top_roof_test)
    surface_grid(bottom_roof_test)
end
=#
```

Expected result:

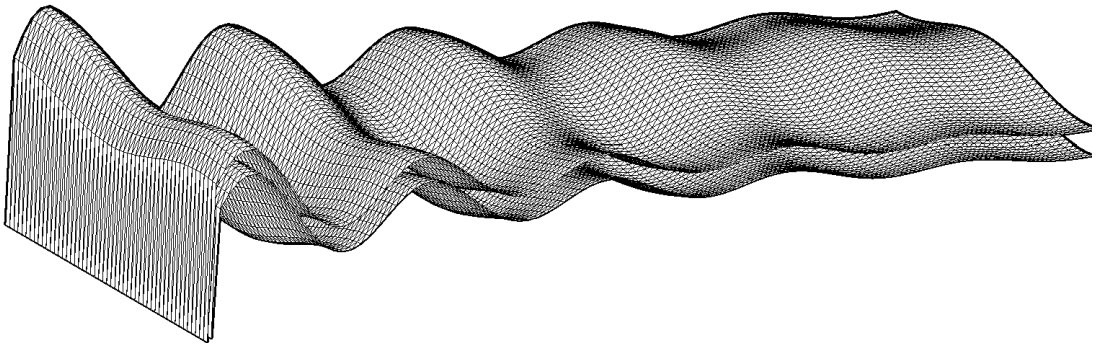


Roof option 2: triangular roof panels

CAD version: using `surface_polygon` subdivision

```
#=
begin
    backend(autocad)
    new_backend()
    map(ps->surface_polygon(ps), itera_2triangs(top_roof_test))
    map(ps->surface_polygon(ps), itera_2triangs(bottom_roof_test))
end
=#
```

Expected result:

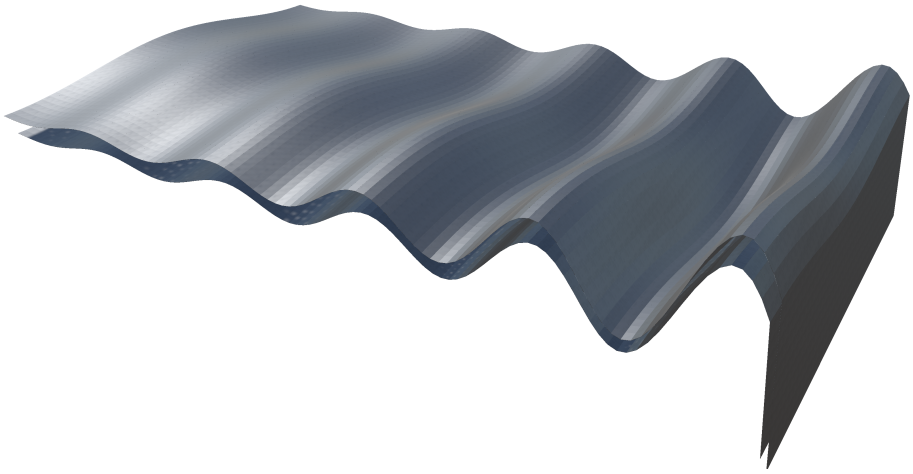


BIM version: using `panel` subdivision

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    map(ps->panel(ps, family=roof_panel_fam), itera_2triangs(top_roof_test))
    map(ps->panel(ps, family=roof_panel_fam), itera_2triangs(bottom_roof_test))
end
=#
```

```
# render_view("roof_panels_unity")
```

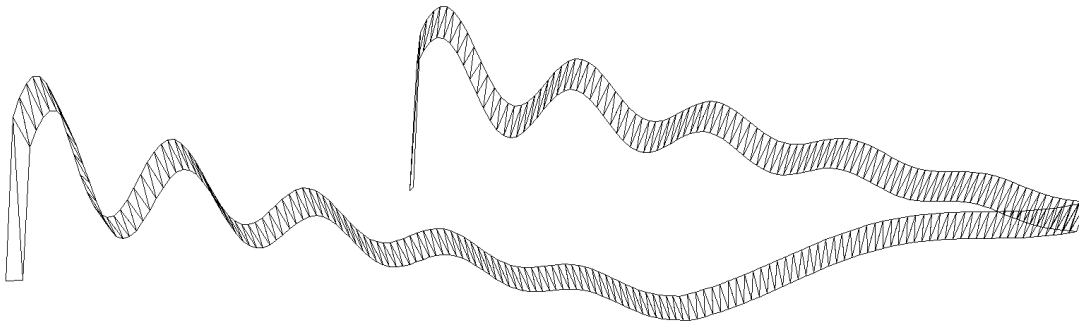
Expected result:



Roof lateral edges option 1: simple triangular panels

```
#=
begin
    backend(autocad)
    delete_all_shapes()
    map(ps->surface_polygon(ps), itera_2triangs([top_roof_test[1],bottom_roof_test[1]]))
    map(ps->surface_polygon(ps), itera_2triangs([top_roof_test[end],bottom_roof_test[end]]))
    map(ps->surface_polygon(ps), itera_2triangs([transpose_array(top_roof_test)[end],
transpose_array(bottom_roof_test)[end]]))
end
=#
```

Expected result:



Roof lateral edges option 2: Pinwheel tiling panels

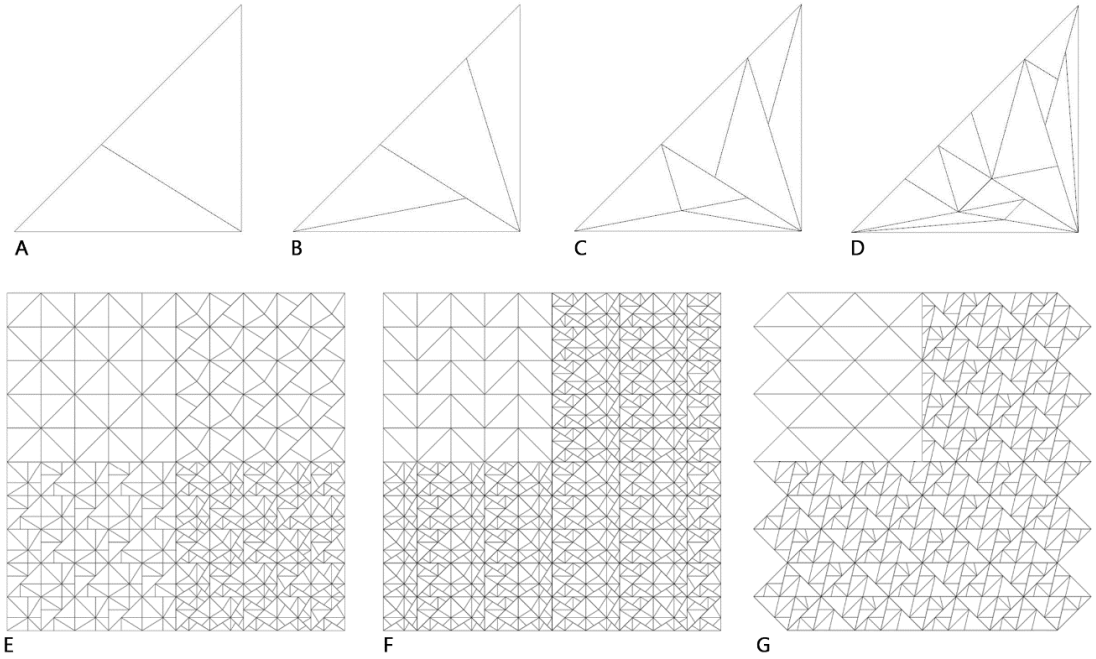
`pattern` creates different patterns on parametric surfaces

```
pattern (generic function with 1 method)
```

```
. pattern(fshape, pts...; args...) =
.   fshape(pts...)(; (k=>v(pts) for (k,v) in args)...)
```

`pinwheel_rule` defines the basic subdivision rule of the pinwheel tiling.

Pinwheel rule Tiling




```
pinwheel_rule (generic function with 2 methods)
```

```
. pinwheel_rule(pts, ratio1=0.383) =
.     let dists = pts_distances(pts)
.         max_dist = maximum(dists)
.         min_dist = minimum(dists)
.         ratio2 = 1 - ratio1
.      if max_dist == dists[1]
.          let pm = intermediate_loc(pts[1], pts[2], min_dist==dists[2] ? ratio1 : ratio2)
.            [[pts[1],pm,pts[3]],
.             [pts[2],pm,pts[3]]]
.          end
.      elseif max_dist == dists[2]
.          let pm = intermediate_loc(pts[2], pts[3], min_dist==dists[1] ? ratio1 : ratio2)
.            [[pts[1],pm,pts[2]],
.             [pts[1],pm,pts[3]]]
.          end
.      else
.         let pm = intermediate_loc(pts[1], pts[3], min_dist==dists[1] ? ratio1 : ratio2)
.           [[pts[1],pm,pts[2]],
.            [pts[2],pm,pts[3]]]
.         end
.      end
.   end
```

`pinwheel_recursive_rule` repeats the basic subdivision rule `pinwheel_rule` several times (value set by the parameter `level`).

```
pinwheel_recursive_rule (generic function with 3 methods)
```

```
pinwheel_recursive_rule(pts, ratio1=0.383, level=1) =
    let qts = pinwheel_rule(pts, ratio1)
      level == 1 ?
      qts :
      [qts...,
       pinwheel_recursive_rule(qts[1], ratio1, level-1)...,
       pinwheel_recursive_rule(qts[2], ratio1, level-1)...]
     end
```

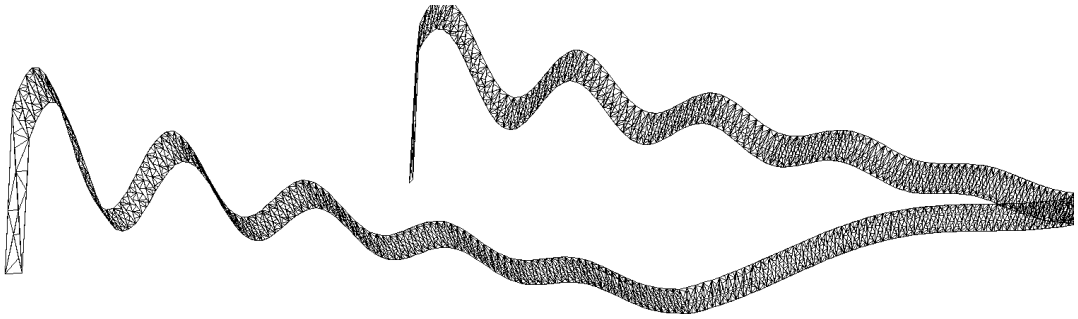
`pinwheel_tiling` receives a surface (described by its points) and creates the pinwheel tiling on it.

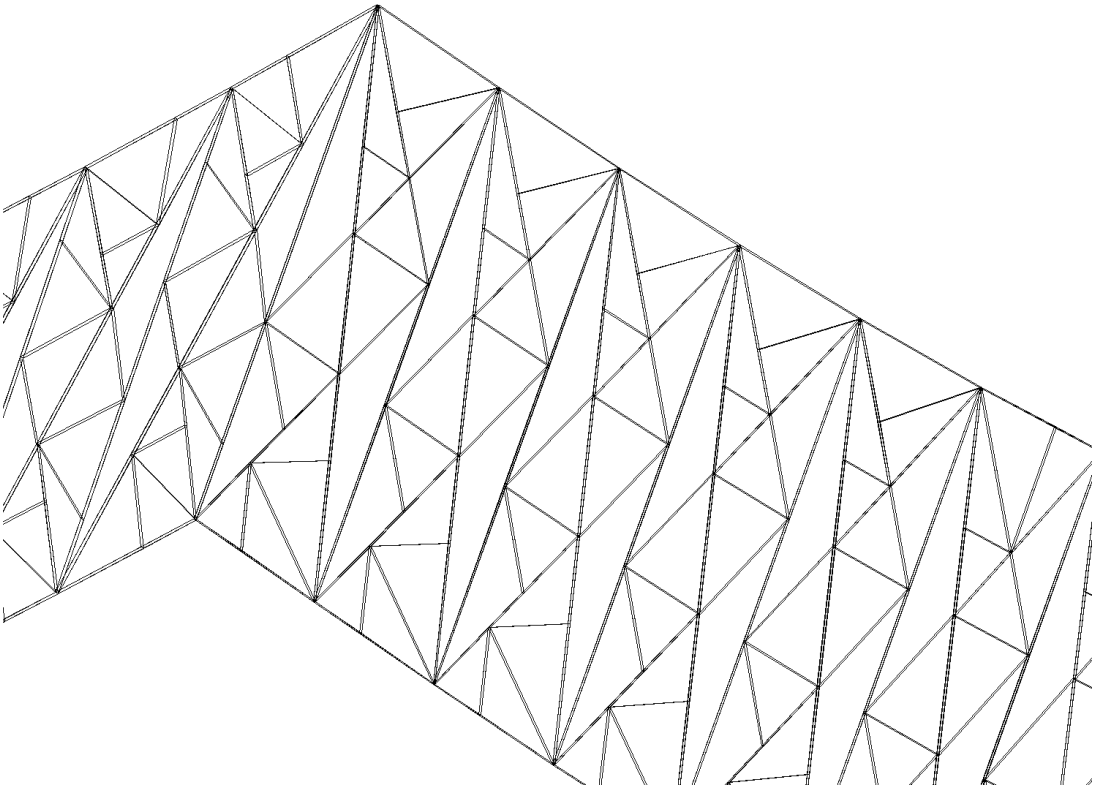
```
pinwheel_tiling (generic function with 1 method)
```

```
pinwheel_tiling(pts; ratio1=0.383, level=1) =
        map(pts -> panel(pts, family=yellow_panel_fam), pinwheel_recursive_rule(pts, ratio1, level))
```

```
#=
begin
    backend(autocad)
    delete_all_shapes()
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([top_roof_test[1],bottom_roof_test[1]])),
                     level=3)
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([top_roof_test[end],bottom_roof_test[end]])),
                     level=3)
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([transpose_array(top_roof_test)
[end],transpose_array(bottom_roof_test)[end]])),
                     level=3)
end
=#
```

Expected result:





```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([top_roof_test[1],bottom_roof_test[1]])),
                     level=3)
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([top_roof_test[end],bottom_roof_test[end]])),
                     level=3)
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices,
                              itera_2triangs([transpose_array(top_roof_test)
[end],transpose_array(bottom_roof_test)[end]])),
                     level=3)
end
=#
```

```
# render_view("side_roof_panels_unity1")
```

Expected result:

Complete Roof structure

Abstracting `pinwheel_tiling` function for the roof sides:

```
pinwhell_broad (generic function with 1 method)
```

```
pinwhell_broad(pts1, pts2, rec_level) =
    pinwheel_tiling.(pattern.(shape_grid_polygon_vertices, itera_2triangs([pts1,pts2])),
level=rec_level)
```

Roof point matrices. `t_diff` defines the distance between the roof surface and the truss structure within. It's currently set to 20 cm:

```
top_roof_ptss (generic function with 1 method)
```

```
top_roof_ptss(p, n_x, n_y, truss)=
    let dist_y = pav_length-d_length
        t_diff = truss ? 0.2 : 0
        damped_sin_roof_pts(p, pav_height-t_diff,
                            amp_x, amp_y_min_top, amp_y_max_top,
                            fi, decay, om_x, om_y,
                            pav_width, dist_y, n_x, n_y)
```

```
    end
```

```
bottom_roof_pts (generic function with 1 method)
```

```
bottom_roof_pts(p, n_x, n_y, truss)=
    let dist_y = pav_length-d_length
         t_diff = truss ? 0.2 : 0
        damped_sin_roof_pts(p+vxy(d_width,d_length*1), pav_height-d_height+t_diff,
                            amp_x, amp_y_min_top, amp_y_max_top,
                            fi, decay, om_x, om_y_bottom,
                            pav_width - d_width*2, pav_length-2*d_length,  n_x, n_y)
    end
```

Complete roof surface with top, bottom, and side panels:

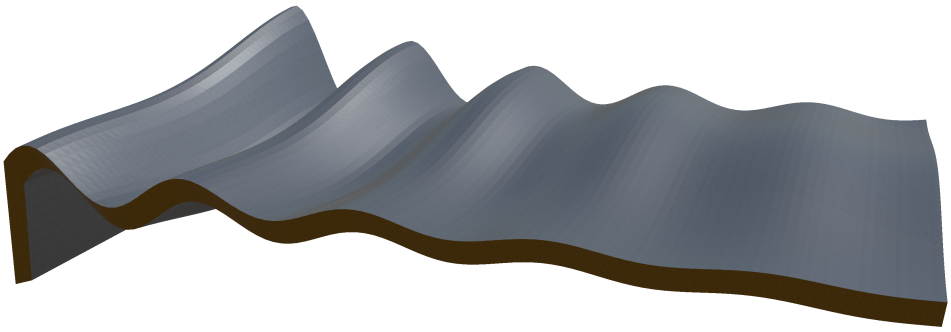
```
roof_surf (generic function with 1 method)
```

```
roof_surf(p, n_x, n_y)=
    let lev = pinwheel_rec_level
        top_roof = top_roof_ptss(p, n_x, n_y, false)
        bottom_roof = bottom_roof_pts(p, n_x, n_y, false)
        # top and bottom aluminum roof tiles
        map(ps->panel(ps, family=roof_panel_fam), itera_2triangs(top_roof))
        map(ps->panel(ps, family=roof_panel_fam), itera_2triangs(bottom_roof))
        # side yellow copper roof tiles
        pinwhell_broad(top_roof[1], bottom_roof[1], lev)
        pinwhell_broad(top_roof[end], bottom_roof[end], lev)
        pinwhell_broad(transpose_array(top_roof)[end], transpose_array(bottom_roof)[end], lev)
    end
```

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    roof_surf(u0(), 50, 100)
end
=#
```

```
# render_view("complete_roof_panels_unity")
```

Expected result:



Truss structure function using the new point matrices for the pavilion:

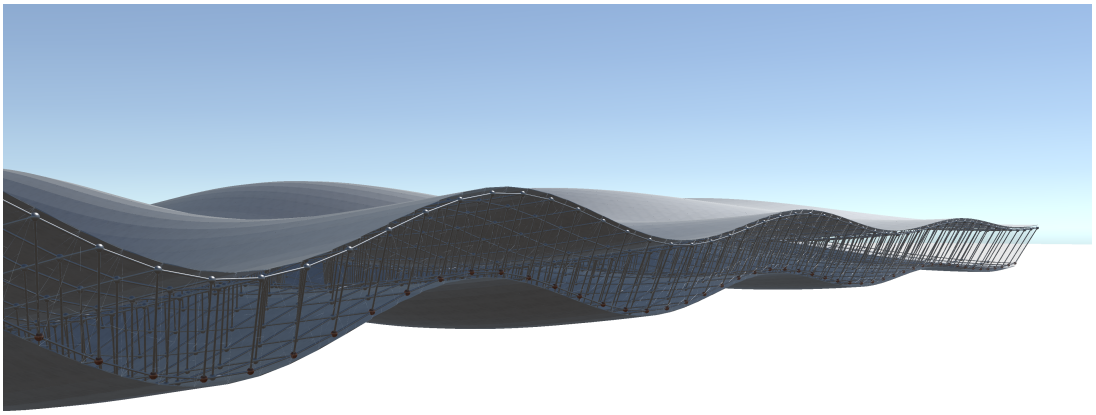
```
roof_truss (generic function with 1 method)
```

```
roof_truss(p, n_x, n_y)=
    let top_roof = top_roof_ptss(p, n_x, n_y, true)
        bottom_roof = bottom_roof_pts(p, n_x, n_y, true)
        truss(vierendeel, top_ptss=top_roof, bottom_ptss=bottom_roof)
    end
```

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    set_backend_family(yellow_panel_fam, unity, unity_material_family("Default/Materials/Glass"))
    roof_surf(u0(), 50, 100)
    roof_truss(u0(), 30, 70)
end
=#
```

```
# render_view("complete_roof_unity")
```

Expected result:



Glass Façade

`splines4surf` maps splines over a matrix of points, to visualise surfaces in the notebook backend faster.

```
splines4surf (generic function with 1 method)
```

```
function splines4surf(mtx)
    [spline(pts) for pts in mtx]
    [spline(pts) for pts in transpose_array(mtx)]
end
```

Wall points

`damped_sin_glass_wall` creates the pavilion's side glass wall matrices

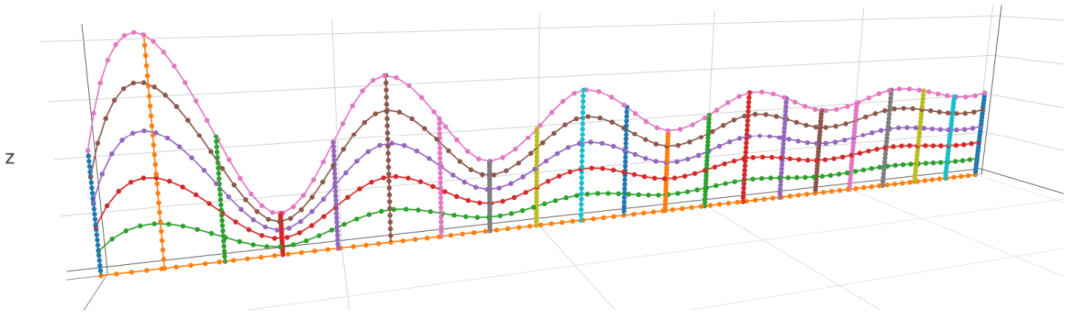
```
damped_sin_glass_wall (generic function with 1 method)
```

```
damped_sin_glass_wall(p, a_y, fi, decay, om_y, dist_y, dist_z, n_y, n_z) =
    map_division((y, z) ->
                    y <= d_i ?
                    p + vyz(-sin(y/d_i*(1*pi)), z) :
                    p + vyz(y,
                            z + (z/dist_z)*damped_sin_wave(a_y, decay, om_y, y)),
             0, dist_y, n_y,
             0, dist_z, n_z)
```

```
#=
begin
    backend(notebook)
    new_backend()
    west_glass_wall_test = damped_sin_glass_wall(x(d_width),
                                        amp_y_max_top,
                                        fi, decay, om_y,
                                        pav_length-2*d_length, pav_height-d_height, 20, 5)
    splines4surf(west_glass_wall_test)
```

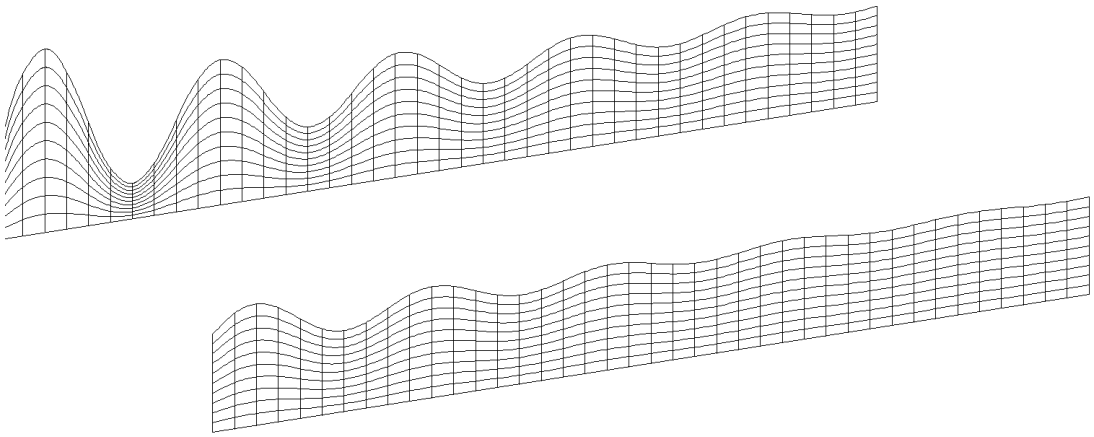
```
end
=#
```

Expected result:




```
#=
begin
    backend(autocad)
    delete_all_shapes()
    west_glass_wall_t1 = damped_sin_glass_wall(xy(d_width, d_length),
                                           amp_y_max_top,
                                           fi, decay, om_y_bottom,
                                           pav_length-2*d_length, pav_height-d_height, 40, 10)
    east_glass_wall_t1 = damped_sin_glass_wall(xy(pav_width-d_width, d_length),
                                           amp_y_min_bottom,
                                           fi, decay, om_y_bottom,
                                           pav_length-2*d_length, pav_height-d_height, 40, 10)
    splines4surf(west_glass_wall_t1)
    splines4surf(east_glass_wall_t1)
#     surface_grid(bottom_roof_pts(u0(), 40, 100, false))
end
=#
```

Expected result:



Vertical BIM panels

Given a list of points (closed polygon vertices), this function creates a polygonal glass panel surrounded by a thin metal framing all around:

```
framed_panel (generic function with 1 method)
```

```
framed_panel(pts)=
    begin
        panel(pts, family=default_panel_family())
        for (p,q) in zip(pts, [pts[2:end]...,pts[1]])
            free_column(p,q, family=frame_fam)
        end
    end
```

```
#=
begin
    backend(meshcat)
    new_backend()
end
=#
```

```
#=
begin
    sides = 3
    radius = 5
    angle = pi/4
    delete_all_shapes()
    framed_panel(regular_polygon_vertices(sides, x(-10), radius, angle))
    framed_panel(regular_polygon_vertices(sides+2, x(0), radius, angle))
    framed_panel(regular_polygon_vertices(sides+5, x(10), radius, angle))
end
=#
```

Expected result:

Radius 3

Sides 4

Angle 10

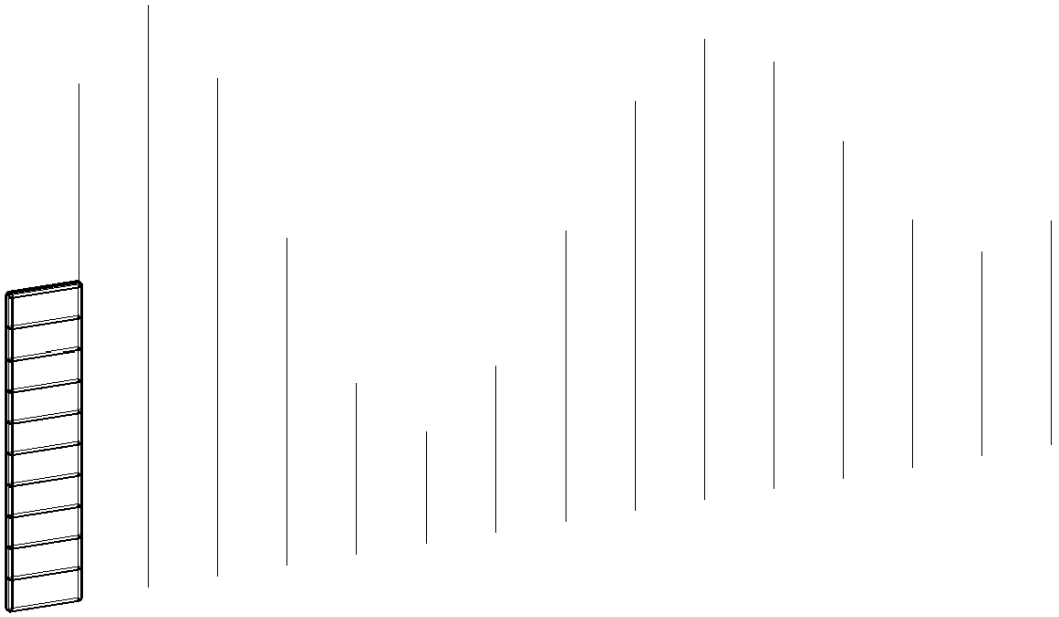
Creates a vertical line of `framed_panels` given a list of points in z. Vector `v` considers the panel width:

```
vertical_panel_line (generic function with 1 method)
```

```
vertical_panel_line(pts, v)=
    let pav_panel(p, q) = framed_panel([p, p+v, q+v, q])
        [pav_panel(p, q) for (p, q) in zip(pts[1:end-1], pts[2:end])]
    end
```

```
#=
begin
    backend(autocad)
    n_y = 40
    n_z = 10
    dist_y = pav_length-2*d_length
    dist_z = pav_height-d_height
    west_glass_wall = damped_sin_glass_wall(x(d_width),
                                            amp_y_max_top,
                                            fi, decay, om_y,
                                            dist_y, dist_z, n_y, n_z)
    east_glass_wall = damped_sin_glass_wall(x(pav_width-d_width),
                                            amp_y_min_bottom,
                                            fi, decay, om_y,
                                            dist_y, dist_z, n_y, n_z)
    panel_width = dist_y/n_y
    vertical_panel_line(west_glass_wall[1], vy(1), panel_width)
end
=#
```

Expected result:



Makes a `vertical_panel_line` for all lines in the matrix:

```
vertical_panel_lines (generic function with 1 method)
```

```
vertical_panel_lines(mtx)=
    let v = mtx[2][1]-mtx[1][1]
        [vertical_panel_line(pts, v) for pts in mtx]
    end
```

Predicate functions: is current `z` above the limit?

```
is_above_z_limit (generic function with 1 method)
```

```
is_above_z_limit(z, z_lim)= z > z_lim
```

`vert_pts` creates the orgin points for all vertical panels above p. Stops creating points in z when the set limit is reached:

```
vert_pts (generic function with 1 method)
```

```
vert_pts(p, panel_height, z_lim) = is_above_z_limit(p.z, z_lim) ? [p] : [p,
vert_pts(p+vz(panel_height), panel_height, z_lim)...]
```

Different starting point for vertical panels in the odd case:

```
vert_pts_odd (generic function with 1 method)
```

```
vert_pts_odd(p, panel_height, z_lim) = [p, vert_pts(p+vz(panel_height/2), panel_height, z_lim)...]
```

Interweaving 2 different functions depending on `count` being even or odd:

```
f_weave (generic function with 1 method)
```

```
f_weave(f1, f2, count) = isodd(count) ? f1 : f2
```

`damped_sin_glass_pts` creates a vertical line of panels for all points between `p` and `p+vy(dist_y)`. The `z_limit` for all vertical lines of panels is defined by the`z` value of the `damped_sin_wave` at any moment in the `y` progression. Interweaving of functions. Different starting height for the first panel of odd rows.

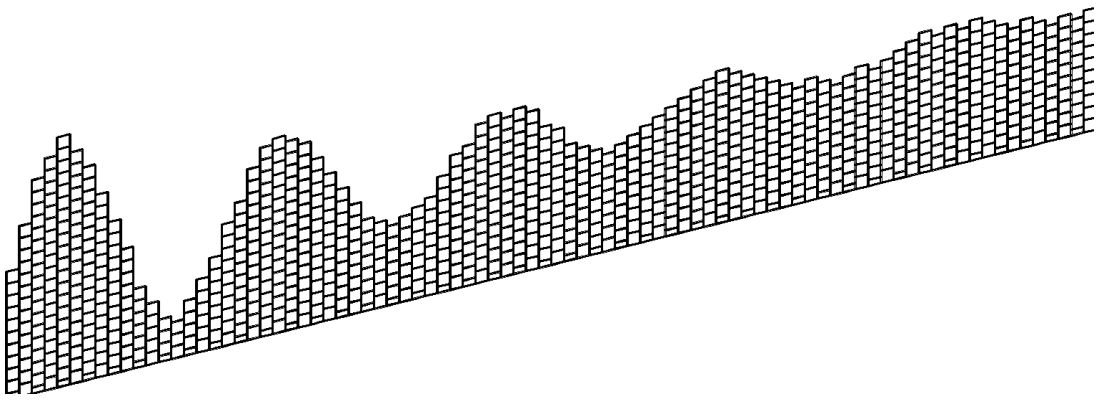
```
damped_sin_glass_pts (generic function with 1 method)
```

```
damped_sin_glass_pts(p, a_y, fi, decay, om_y, dist_y, dist_z, n_y, n_z, panel_height) =
    let pts = map_division(y -> p+vy(y), 0, dist_y, n_y)
        zs = map_division(y -> dist_z+damped_sin_wave(a_y, decay, om_y, y), 0, dist_y, n_y)
        ns = 1:length(zs)
     [f_weave(vert_pts_odd(p, panel_height, z_lim),vert_pts(p, panel_height, z_lim), count) for (p,
z_lim, count) in zip(pts, zs, ns)]
    end
```

`glass_panel_height` defines façade glass panel's height (width is defined by the number of points in the `damped_sinusoid` array)

```
#=
begin
    backend(autocad)
    west_glass_wall = damped_sin_glass_pts(x(d_width),
                                           amp_y_max_top,
                                           fi, decay, om_y,
                                           dist_y, dist_z, n_y, n_z, glass_panel_height)
    east_glass_wall = damped_sin_glass_pts(x(pav_width-d_width),
                                           amp_y_min_bottom,
                                           fi, decay, om_y,
                                           dist_y, dist_z, n_y, n_z, glass_panel_height)
    delete_all_shapes()
    vertical_panel_lines(west_glass_wall)
end
=#
```

Expected result:



`vertical_panel_line` corrections to match roof wave:

`vertical_panel_line_centred (generic function with 1 method)`

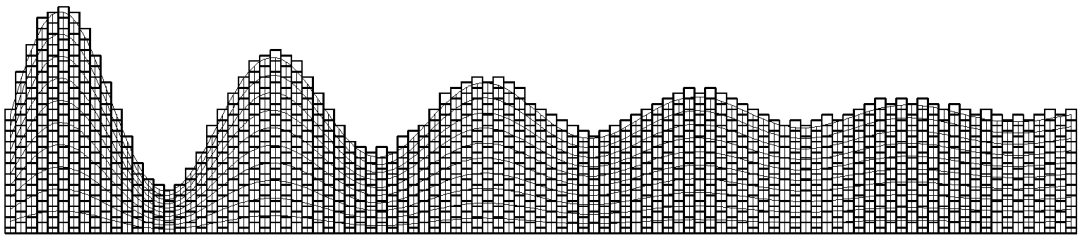
```
vertical_panel_line_centred(pts, v)=
    let pav_panel(p, q) = framed_panel([p, p+v, q+v, q])
        [pav_panel(p-v/2, q-v/2) for (p, q) in zip(pts[1:end-1], pts[2:end])]
    end
```

`centred_vertical_panel_lines (generic function with 1 method)`

```
centred_vertical_panel_lines(mtx)=
    let v = mtx[2][1]-mtx[1][1]
        [vertical_panel_line_centred(pts, v) for pts in mtx]
    end
```

```
#=
begin
    backend(autocad)
    delete_all_shapes()
    west_glass_wall_i = damped_sin_glass_wall(xy(d_width, d_length),
                                              amp_y_max_top,
                                              fi, decay,  om_y_bottom,
                                              dist_y, dist_z, n_y, n_z)
    west_glass_wall_r = damped_sin_glass_pts(xy(d_width, d_length),
                                              amp_y_max_top,
                                              fi, decay, om_y_bottom,
                                              dist_y, dist_z, n_y, n_z, glass_panel_height)
    splines4surf(west_glass_wall_i)
    centred_vertical_panel_lines(west_glass_wall_r)
end
=#
```

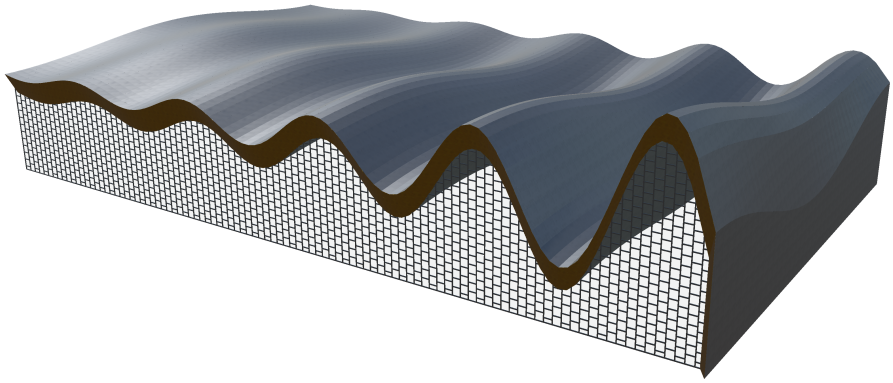
Expected result:



```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    roof_surf(u0(), 50, 100)
    centred_vertical_panel_lines(west_glass_wall)
    centred_vertical_panel_lines(east_glass_wall)
end
=#
```

```
# render_view("roof_side_walls_unity")
```

Expected result:



Front glass wall

```
damped_sin_front_wall (generic function with 1 method)
```

```
damped_sin_front_wall(p, a_x, fi, decay, om_x, dist_x, dist_z, n_x, n_z, panel_height) =
    let pts = map_division(x -> p+vx(x), 0, dist_x, n_x)
        zs = map_division(x -> dist_z+sin(x/dist_x*pi)*sinusoidal(a_x, om_x, fi-pi, x), 0, dist_x,
n_x)
        ns = 1:length(zs)
     [f_weave(vert_pts_odd(p, panel_height, z_lim),vert_pts(p, panel_height, z_lim), count) for (p,
z_lim, count) in zip(pts, zs, ns)]
    end
```

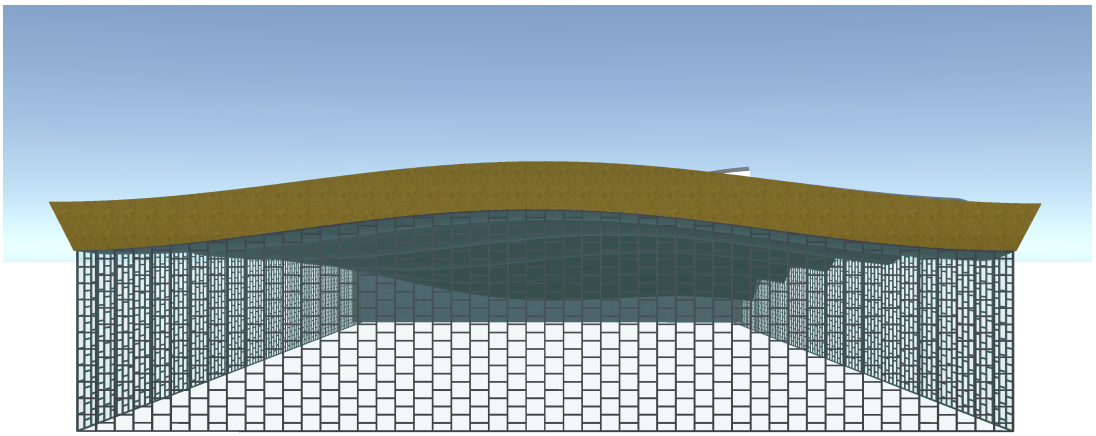
This function joins all glass walls in the pavilion (sides and front):

```
pav_walls (generic function with 1 method)
```

```
pav_walls(p, n_x, n_y, n_z)=
    let dist_y = pav_length-2*d_length
        dist_z = pav_height-d_height
        dist_x = pav_width-d_width*2
        west_glass_wall = damped_sin_glass_wall(p+vxy(d_width, d_length),
                                                amp_y_max_top,
                                                fi, decay, om_y_bottom,
                                                dist_y, dist_z, n_y, n_z, glass_panel_height)
        east_glass_wall = damped_sin_glass_wall(p+vxy(pav_width-d_width, d_length),
                                                amp_y_min_bottom,
                                                fi, decay, om_y_bottom,
                                                dist_y, dist_z, n_y, n_z, glass_panel_height)
        panel_w = norm(west_glass_wall[2][1]-west_glass_wall[1][1])
        north_glass_wall = damped_sin_front_wall(p+vxy(d_width, dist_y+panel_w/2),
                                                amp_x, fi, decay, om_x,
                                                dist_x, dist_z, n_x, n_z, glass_panel_height)
    centred_vertical_panel_lines(west_glass_wall[1:end-1])
    centred_vertical_panel_lines(east_glass_wall[1:end-1])
    vertical_panel_lines(north_glass_wall[1:end-1])
end
```

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    roof_surf(u0(), 50, n_panels_y)
    pav_walls(u0(), 50, n_panels_y, n_glass_verts)
    set_view(xyz(29.727153778076172,163.0078582763672,10.998817443847656),
xyz(29.728837966918945,162.0078582763672,10.998811721801758), 35.0)
#     render_view("all_walls_unity")
end
=#
```

Expected result:



Interior Plan

`pav_slabs` creates the main slabs

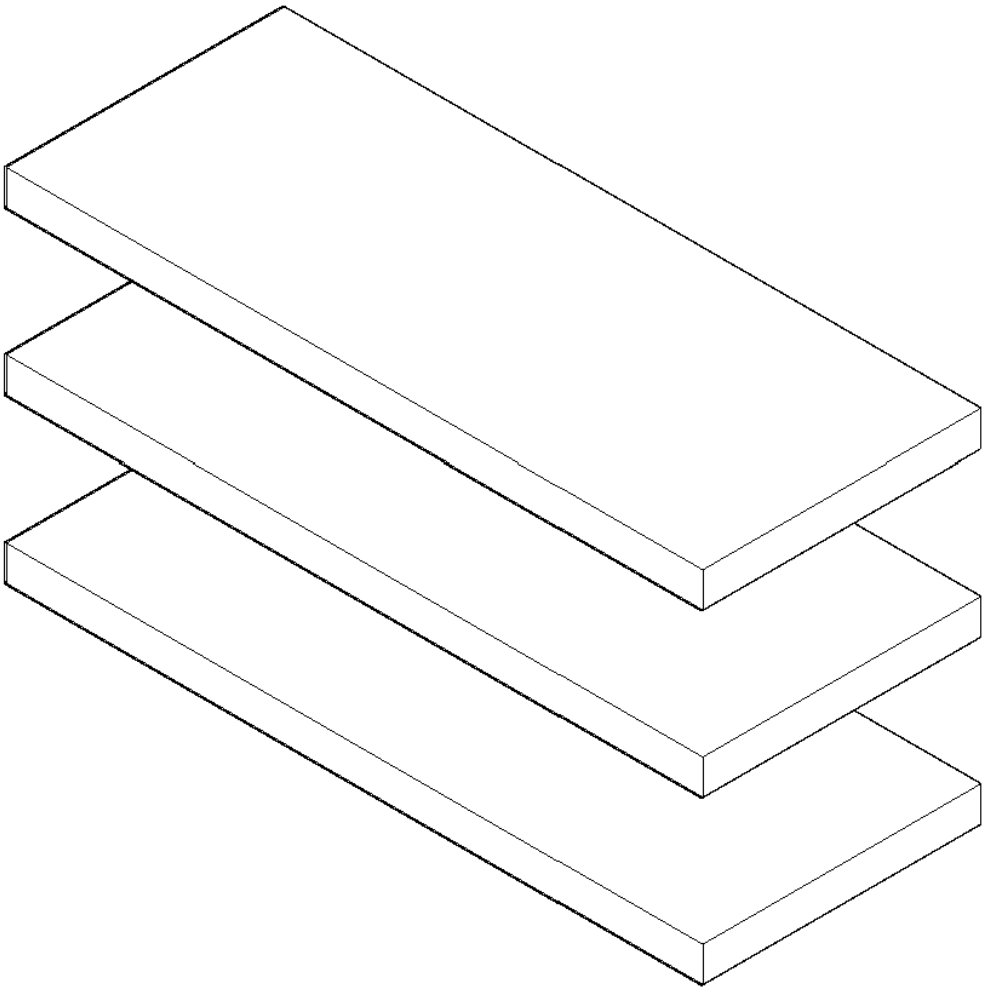
```
pav_slabs (generic function with 1 method)
```

```
pav_slabs(p, length, height, width, n_floors)=
    for i in division(0, height-2, n_floors, false)
        slab(rectangular_path(p, width, length), level=i, family=pav_slab_fam)
    end
```

```
#=
begin
    backend(autocad)
    delete_all_shapes()
    pav_slabs(u0(), 10, 7, 4, 3)
```

```
end
=#
```

Expected result:



Update `pav_slabs` to include interior walls:

```
pav_slabs_walls (generic function with 1 method)
```

```
pav_slabs_walls(p, length, height, width, n_floors, n_x, n_y)=
    let level_to_level_height = (height-2)/n_floors
        for i in division(0, height-2, n_floors, false)
            slab(rectangular_path(p, width, length), level=i, family=pav_slab_fam)
        end
        for i in division(0, height-2-level_to_level_height, n_floors-1, false)
            walls_x = [wall([p+vx(x), p+vxy(x, length)], bottom_level=i,
top_level=level_to_level_height+i)
                for x in division(width/n_x-1, width, n_x, false)]
            walls_y = [wall([p+vy(y), p+vxy(width, y)], bottom_level=i,
top_level=level_to_level_height+i)
                for y in division(length/n_y-1, length, n_y, false)]
        end
    end
```

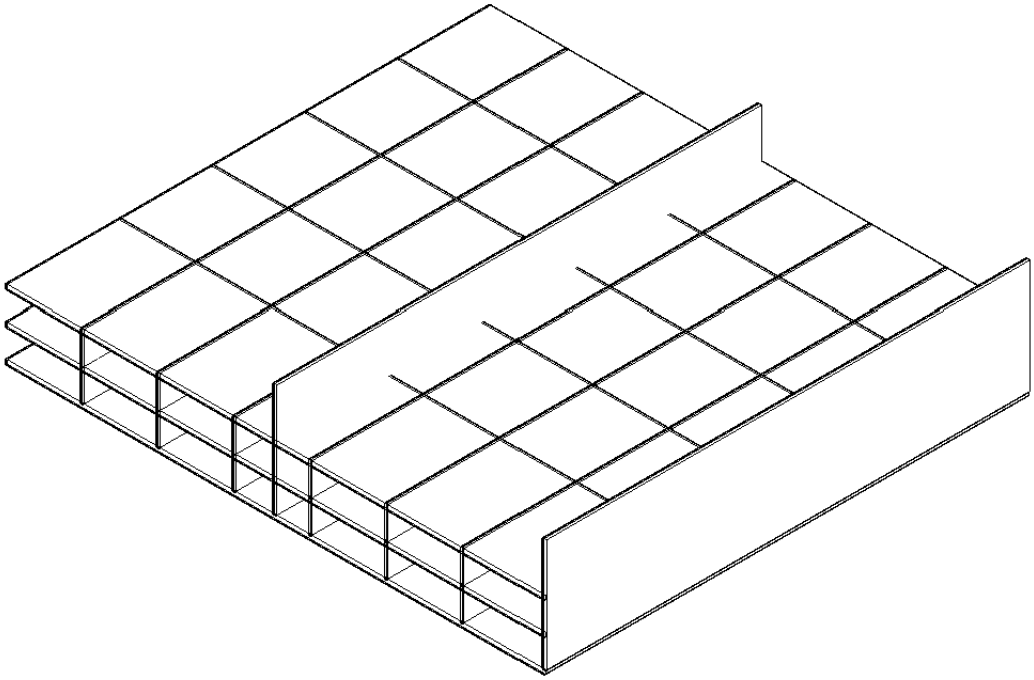
`floors` joins structural walls to the previous function:

```
floors (generic function with 1 method)
```

```
function floors(p)
    let panel_w = (pav_length-2*d_length)/n_panels_y
        dist_x = pav_width-d_width*2
        dist_y_1 = (pav_length-d_length*2)/3
        dist_y_2 = (pav_length-d_length*2)*2/3
        dist_z = pav_height-d_height

    # structural walls
    wall([p+vxy(d_width, dist_y_1), p+vxy(pav_width-d_width, dist_y_1)],
            top_level = level(dist_z), family=pav_wall_struct_fam)
    wall([p+vxy(d_width, dist_y_2), p+vxy(pav_width-d_width, dist_y_2)],
            top_level = level(dist_z), family=pav_wall_struct_fam)

    # floor plans
    pav_slabs_walls(p+vxy(d_width, dist_y_1), dist_y_2+panel_w/2, dist_z,
        dist_x, n_floors, n_wall_in_width, n_wall_in_length)
    slab(rectangular_path(p+vx(d_width), dist_x, dist_y_1), level=0, family=pav_slab_fam)

    end
end
```

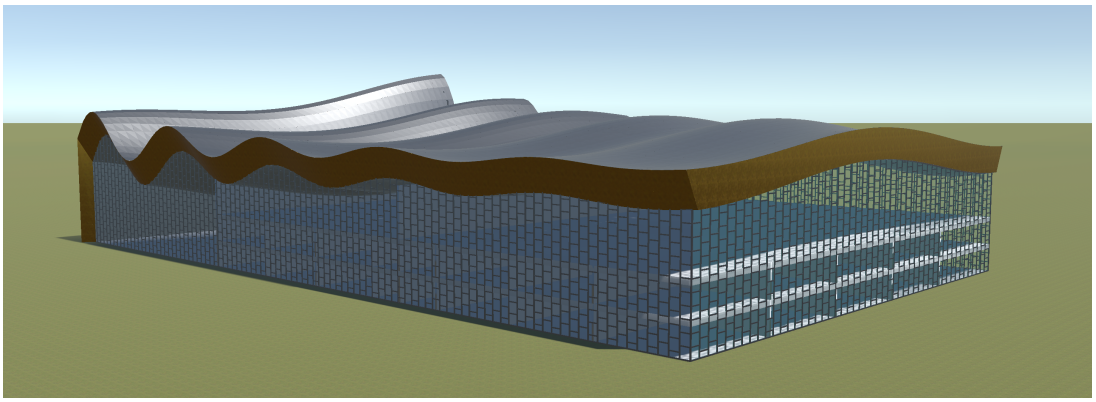
```
#=
begin
    backend(autocad)
    delete_all_shapes()
    floors(u0())
end
=#
```

Expected result:



```
#=
begin
    backend(unity)
    delete_all_shapes()
    set_backend_family(ground_fam, unity, unity_material_family("Default/Materials/Grass"))
    ground()
    pav_walls(u0(), n_panels_x, n_panels_y, n_glass_verts)
    roof_surf(u0(), n_panels_x, n_panels_y)
    floors(u0())
    set_view(xyz(120.72909545898438,142.31788635253906,18.540668487548828),
xyz(120.00056457519531,141.63906860351562,18.4487361907959), 35.0)
#     render_view("interior_walls_unity")
end
=#
```

Expected result:



Site

Ground:

```
ground (generic function with 1 method)
```

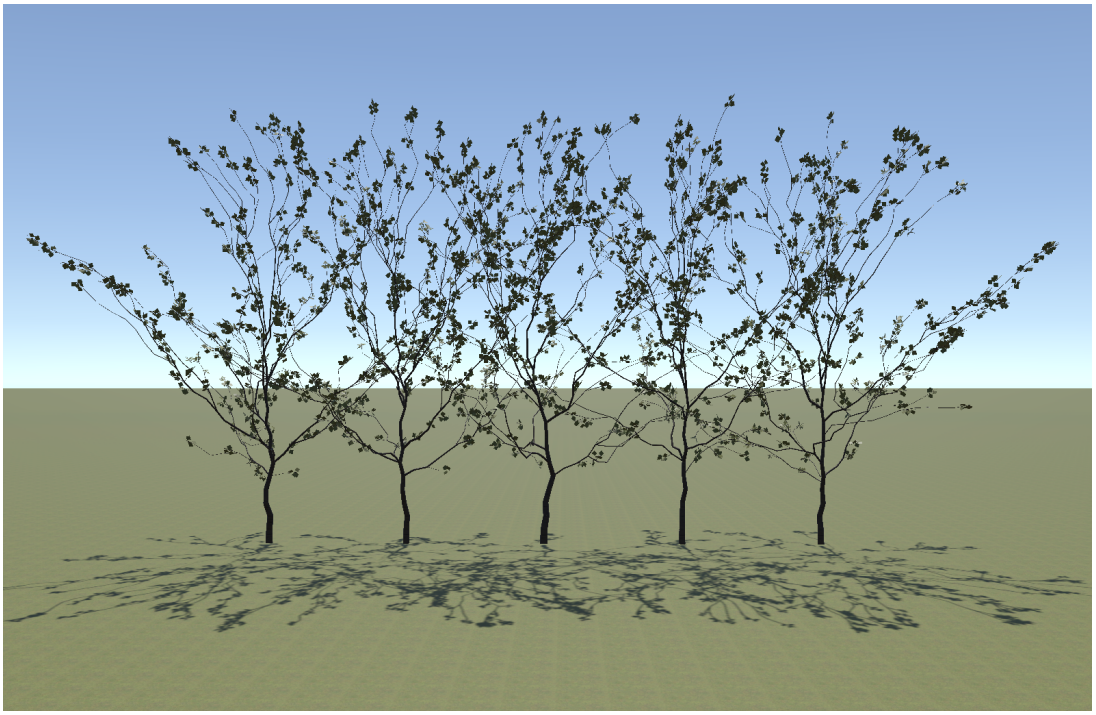
```
ground() =
    let x = 1000
        y = 1000
        z = -0.01
      slab(closed_polygonal_path([xyz(-x,y,z), xyz(x,y,z), xyz(x,-y,z), xyz(-x,-y,z)]), level(-0.05), ground_fam)
    end
```

Trees:

```
 #=
begin
    backend(unity)
    include("SpaceColonization.jl")

    leaf_mat = get_material("Default/Materials/Grass")
    branch_mat = get_material("materials/wood/ExteriorWood9")

    draw_tree(new_tree(x(0)))
end
=#
```

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    map(n -> random_tree(x(n)), 0:2:20)
#     render_view("tress")
end
=#
```

Expected result:



Cylindrical tree:

```
cyl_attractor (generic function with 2 methods)
```

```
cyl_attractor(p=u0()) =
  p + vz(tree_size/1.5) +vcyl(random_range(0, tree_size/5), random_range(0, 2pi), random_range(-
tree_size/2, tree_size/2))
```

Tree parameters:

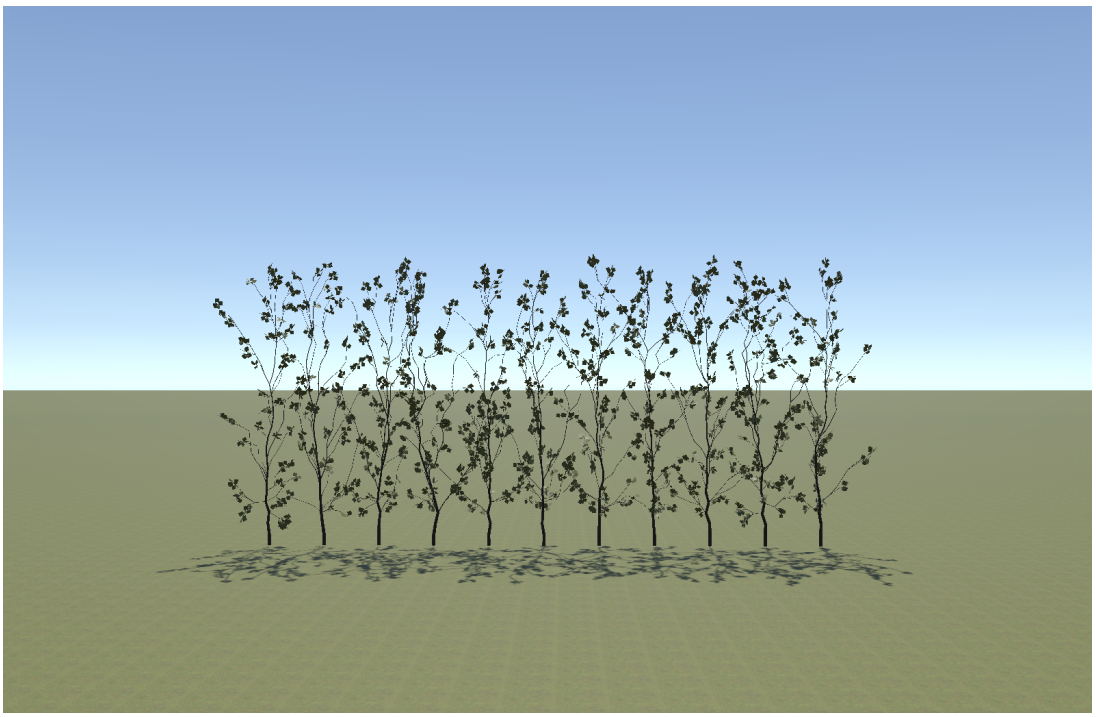
```
0.5
```

```
begin
    tree_size = 13
    segment_length = 0.4
    min_dist = 0.5
end
```

```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    map(n -> draw_tree(new_tree(x(n), cyl_attractor)), 0:2:20)
    render_view("pop_trees_10")
end
=#
```

Expected result:

Expected result:



Complete Building

The `GymPav` function gathers all building elements modeled, plus the random tree line in front of the west façade. Given a point `p`, the function creates the full building structure in accordance with the parameters provided in `Pavilion Dimensions`.

```
GymPav (generic function with 1 method)
```

```
function GymPav(p)
    roof_surf(p, n_panels_x, n_panels_y)
#     roof_truss(p, 30, 70)
    pav_walls(p, n_panels_x, n_panels_y, n_glass_verts)
    floors(p)
    map(n -> draw_tree(new_tree(p+vxy(-5, n), cyl_attractor)), 0:4:pav_length) # tree line in the west façade
end
```

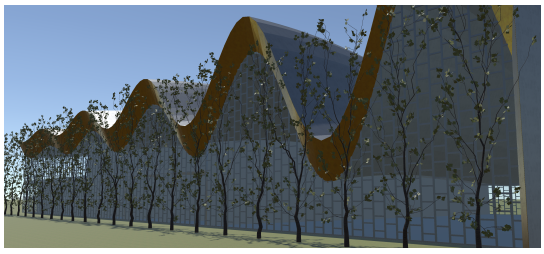
```
#=
begin
    backend(unity)
    delete_all_shapes()
    ground()
    GymPav(u0())
end
=#
```

Saved render views:

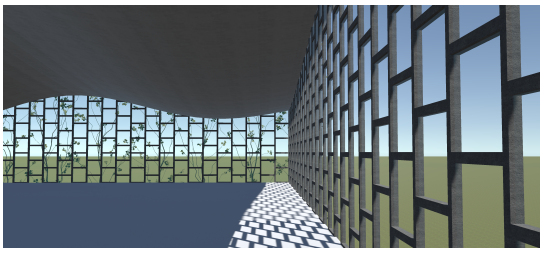
```
begin

#     sun position default

#     set_view(xyz(-27.78546905517578,-12.493826866149902,2.73970365524292),
xyz(-27.147165298461914,-11.735978126525879,2.874735116958618), 35.0)
#     render_view("pav1")


#     sun position x=124 y=53

#     set_view(xyz(37.13166809082031,96.70274353027344,8.049731254577637),
xyz(36.132999420166016,96.71927642822266,8.098581314086914), 35.0)
#     render_view("pav2")

#     set_view(xyz(86.96595001220703,87.33833312988281,7.179433822631836),
xyz(85.97071075439453,87.31035614013672,7.27283239364624), 35.0)
#     render_view("pav3")

#     set_view(xyz(-22.71254539489746,144.94818115234375,7.690451622009277),
xyz(-22.17136001586914,144.1073455810547,7.7015814781188965), 35.0)
#     render_view("pav4")

#     set_view(xyz(-12.342000961303711,103.7385025024414,3.020662307739258),
xyz(-11.917301177978516,102.83597564697266,3.0918772220611572), 35.0)
#     render_view("pav5")

#     set_view(xyz(-2.6654765605926514,130.2740020751953,1.4012055397033691),
xyz(-2.5774435997009277,129.29388427734375,1.5790280103683472), 35.0)
#     render_view("pav6")

#     set_view(xyz(126.3520736694336,-49.96141815185547,27.672582626342773),
xyz(125.61244201660156,-49.31004333496094,27.503311157226562), 35.0)
#     render_view("pav7")

end
```

Unity renders

Pav 1

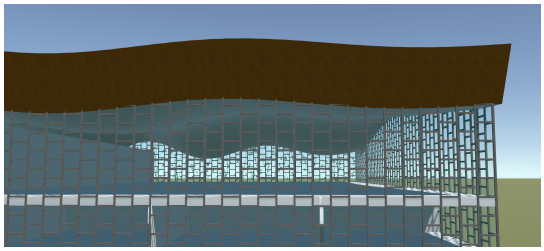


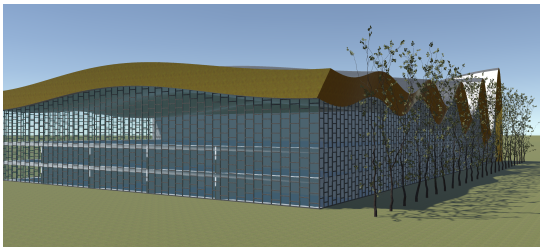
Pav 2



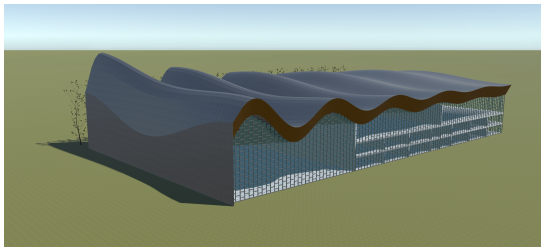
Pav 3

Pav 4

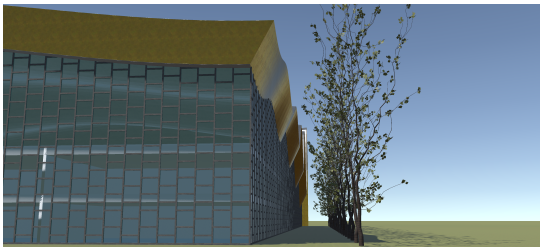




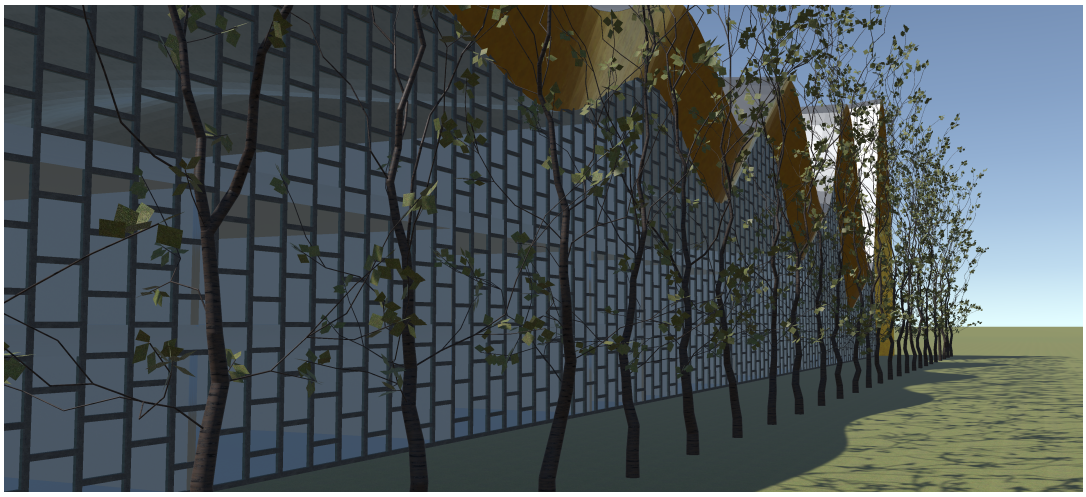
Pav 7



Pav 6



Pav 5



The end