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Design of a Self-Shading Mass as a Function of the Latitude for Automatic Seasonal Adjustment

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Abstract. The main objective of this paper is to propose a simple tool for architects to design a self-shading mass, resulting in an automatic seasonal adjustment, i.e., full shading in summer but allowing solar heat gain in winter, within the low latitudes. Commonly, self-shading masses might have inverted pyramidal forms or inward terracing. But in the proposed design, crystal-like forms are generated on the eastern and western façades and an inward sloping form is generated on the equator-facing façade. Those generated forms are not only used from an aesthetical point of view, as might be done in some contemporary buildings, but also ensuring external shading when needed. The different dimensions of the proposed self-shading mass could be obtained by using a design chart that was previously designed and developed by the author. The obtained dimensions are function of the latitude, indicating the building location, the shading height, indicating the building height and the selected cut-off times, indicating the selected hours of shading. A number of smaller crystalline forms, stacked above each other, could have the same effect in blocking the sun rays as a single large one, which might be essential to overcome the elongated depth or protrusion of a self-shading mass.

1. Introduction

Shading design could be considered as one of the most important passive design strategies, needed within the overheated zone, i.e., warm or hot climates. It involves the exclusion of a large amount of the direct solar radiation, emitted from the sun.

Self-shading masses signify those masses that shade themselves and they have been used in both traditional and contemporary buildings. Commonly, self-shading masses might have inverted pyramidal forms or inward terracing, e.g., ST Diamond Building, in Malaysia, whose self-shading inverted pyramid protects itself during the overheated period (Figure 1) [1]. But in the proposed design, crystal-like forms are generated on the eastern and western façades and an inward sloping form is generated on the equator-facing façade.

Those generated forms or elements might have been included in some contemporary buildings for conceptual or aesthetical reasons. Conceptual reasons could be exemplified in the extension to the Royal Ontario Museum (ROM), in Canada, whose intersecting crystal-like forms were inspired by the crystalline forms in the ROM’s mineralogy galleries (Figure 2) [2]. Whereas aesthetical or formalistic reasons could be seen by the growing number of buildings with crystal-like forms within different contexts (Figure 3).

But in the proposed design, the generated forms are not only used from an aesthetical or conceptual point of view, but also ensuring external shading when needed.





Figure 1. Self-shading inverted pyramidal form of the ST Diamond Building, Putrajaya, Malaysia (Source: M. Boubekri, 2014).

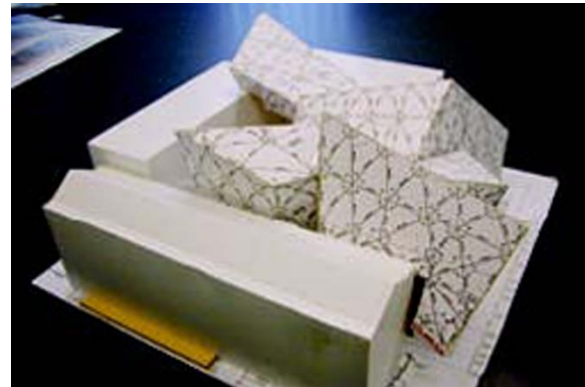


Figure 2. Crystalline forms of the extension to the Royal Ontario Museum, Toronto, Canada (Source: Boake, Terri Meyer, 2012).



Figure 3. Growing number of buildings with crystal-like forms, Cairo, Egypt (Source: the author).

Nomenclature

HSA	horizontal shadow angle [°]
VSA	vertical shadow angle [°]
LAT	latitude [°]
h	shading height [m]
l	self-shading mass length [m]
d	depth of self-shading mass exceeding the original depth [m]
p	protrusion of self-shading mass exceeding the original length [m]
n	number of crystalline forms

2. Main Objectives and Hypothesis

The main objective of this paper is to propose a simple tool for architects to design a self-shading mass, resulting in an automatic seasonal adjustment, i.e., full shading in summer but allowing solar heat gain in winter, within the low latitudes.

The main hypothesis for this paper is the possibility of determining the different dimensions of a proposed self-shading mass having one or more crystalline forms, as a function of the latitude (LAT) and shading height (h) at the selected cut-off times.

3. Methodology

In this paper, the different dimensions of the proposed self-shading mass could be obtained by using a design chart that was previously designed and developed by the author [3].

To use this measuring technique, the scope and limitations of the paper, associated with some simplifications and assumptions are shown as follows.

3.1. Scope and Limitations

The paper mainly focuses on shading design within the low latitudes, where shading is needed as an essential passive design strategy. It provides a simple method for architects to generate a proposed self-shading mass having one or more crystalline forms. This method is simple and generic, as it involves the use of a design chart to determine the different dimensions of the proposed self-shading mass as a function of the latitude (LAT) and shading height (h) at the selected cut-off times, resulting in an automatic seasonal adjustment.

The paper does not concern about a number of aspects or parameters, which in turn could be addressed in future researches, such as the cost and the stability of such unique structures or their effect on the quantity or quality of daylighting within the different spaces at the different façades.

3.2. Simplifications and Assumptions

Some simplifications and assumptions were considered while designing the proposed self-shading mass concerning its applicability, orientation of inward sloping form, effect of the shadow angles and specifications of the used base case.

3.2.1. Applicability of the Proposed Self-Shading Mass. The proposed self-shading mass is applicable for forms with rectilinear plans, whose edges are oriented towards the main orientations, located at lower latitudes, with temperate, hot-dry or warm-humid climates where shading is a need [4].

3.2.2. Orientation of Inward Sloping Form. The inward sloping form of the proposed self-shading mass is facing the equator (due south in the northern hemisphere and due north in the southern hemisphere). The used design chart is based on the fact that an equator-facing horizontal shading device, can give an automatic seasonal adjustment: full shading in summer but allowing solar heat gain in winter if the (VSA) = $90^\circ - (\text{LAT})$ [5], e.g., an equinox cut-off for the city of Cairo, Egypt ((LAT) = 30° N), it will be (VSA) = $90^\circ - 30^\circ = 60^\circ$.

3.2.3. Effect of the Shadow Angles. The proposed self-shading mass is handled as a horizontal shading device that is not only characterized by a vertical shadow angle (VSA) that specifies its depth (d) in elevation, but also is affected by the horizontal shadow angle (HSA) that specifies its protrusion (p) resulting in its trapezoidal shape in plan.

3.2.4. Specifications of the Used Base Case. The form, dimensions, selected latitudes, cut-off times and number of crystalline forms are shown as follows.

- Form of the original mass: cube.
- Dimensions of the original mass: external length = 9.00 m, external depth = 9.00 m and external height = 9.00 m.
- Selected Latitudes: LAT 10° , LAT 20° , LAT 30° and LAT 40° .
- Selected cut-off times: 0900-1500 hr., 1000-1400 hr. and 1100-1300 hr.
- Used number of crystalline forms: 1, 2, 3, 4, 5 and 6.

3.3. The Design Chart to Determine the Different Dimensions of the Proposed Self-Shading Mass

The design chart shown in Figure 4 is a combination of two graphs; the first graph on the right and the second graph on the left.

The first graph (on the right) determines the ratio (d/h) between the required depth (d) and the shading height (h), as a function of the latitude (LAT), and it is drawn using the formula:

$$\frac{d}{h} = \tan(\text{LAT})$$

It consists of two axes and a curve; the horizontal axis represents the latitude (LAT), ranging from 0° (Equator) to 40° N and S, while the vertical axis represents the ratio (d/h) between the required depth (d) and the shading height (h). That ratio (d/h) is obtained on the vertical axis after intersecting the curve from the marked latitude (LAT).

The second graph (on the right) determines the ratio (p/h) between the required protrusion (p) and the shading height (h), as a function of the latitude (LAT) and cut-off times, and it is drawn using the formula:

$$\frac{p}{h} = \tan(LAT) \times \tan(HSA)$$

It consists of two axes and three curves; the vertical axis represents ratio (d/h) between the required depth (d) and the shading height (h), while the horizontal axis represents the ratio (p/h) between the required protrusion (p) and the shading height (h). That ratio (p/h) is obtained on the horizontal axis after intersecting one of the three curves according to the selected cut-off times from the marked ratio (d/h), obtained from the first graph.

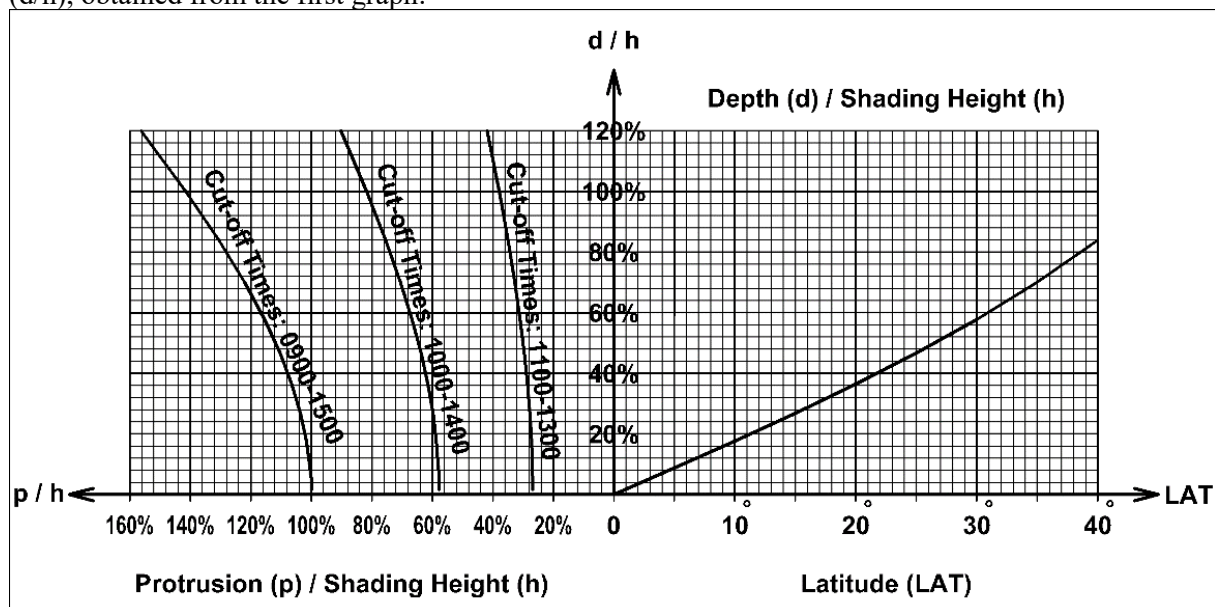


Figure 4. The design chart to determine (d/h) and (p/h) of the proposed self-shading mass (source: Saifelnasr, 2015).

4. The Proposed Self-Shading Mass

4.1. Concept of the Proposed Self-Shading Mass

Shading could be achieved either through shading devices or through building form, i.e., self-shading methods [6]. Accordingly, in this research, the proposed self-shading mass is based on the idea of designing a fixed horizontal shading device, that functions best for equator-facing façades [7], and then integrating it with the original building mass within a single form. That combination would result in the generation of crystal-like forms on the eastern and western façades with dividing ridge lines, and an inward sloping form on the equator-facing façade.

The different dimensions of the proposed self-shading mass could be obtained by using a design chart that was previously designed and developed by the author [3]. The obtained dimensions are function of the latitude (LAT), indicating the building location, the shading height (h), indicating the building height and the selected cut-off times, indicating the selected hours of shading. Thus, they could be determined as ratios with (h); (d/h) and (p/h) for a given latitude at the selected cut-off times (Figure 5).

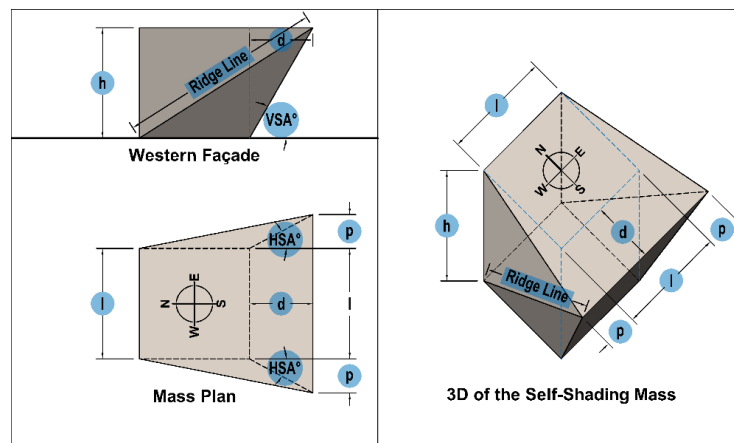


Figure 5. The different dimensions needed to construct the proposed self-shading mass could be obtained from the design chart as ratios with (h) (Source: the author).

4.2. Formation of the Proposed Self-Shading Mass

To construct the proposed self-shading mass, follow the shown steps in Figure 6 as follows. First start with the original rectilinear mass, oriented towards the main orientations; north, south, east and west. Determine the depth (d) from the first graph (on the right) of the design chart and apply it towards the equator-facing orientation. Determine the protrusion (p) from the second graph (on the left) of the design chart and apply it towards the eastern and western orientations. Join the upper equator-facing corners to the upper non-equator-facing corners that would lead to the formation of the trapezoidal shape of the roof. Join the upper equator-facing corners to the lower equator-facing corners that would lead to the formation of the trapezoidal shape of the inward sloping equator-facing façade. Construct the dividing ridge lines by joining the lower non-equator-facing corners with the upper equator-facing corners that would lead to the formation of crystal-like forms on the eastern and western façades. The constructed self-shading mass would result in an automatic seasonal adjustment, i.e., full shading in summer but allowing solar heat gain in winter.

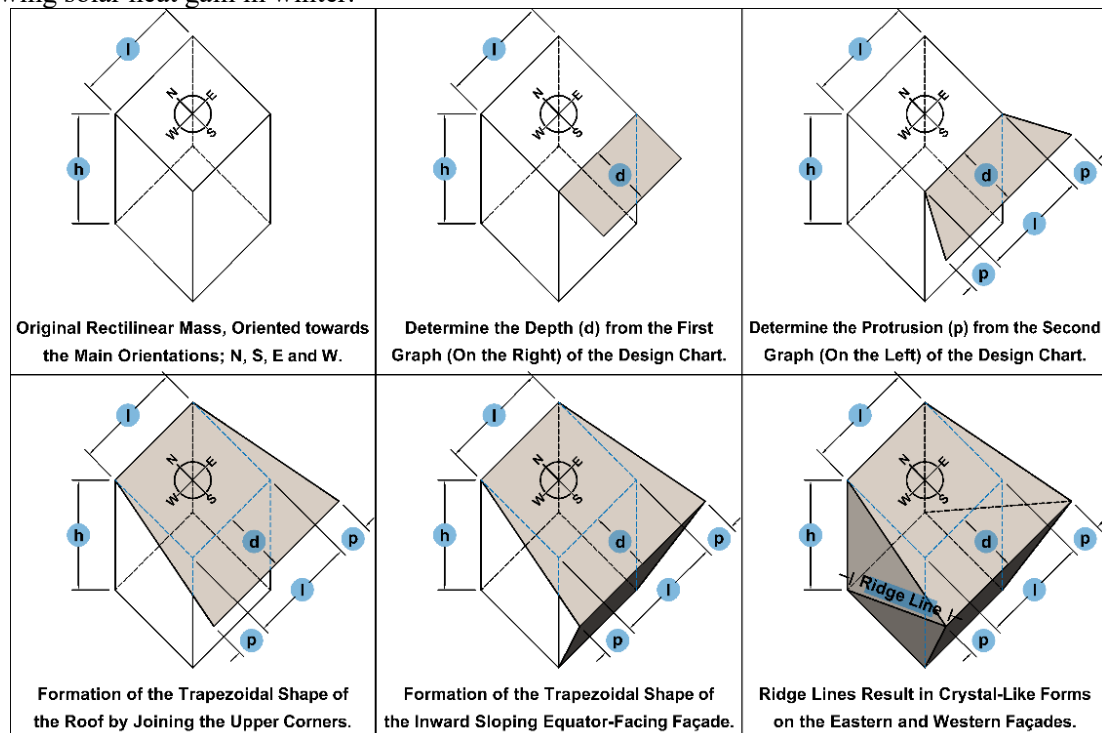


Figure 6. The different steps to construct the proposed self-shading mass (Source: the author).

4.3. Notes on the Proposed Self-Shading Mass and Its Variables

4.3.1. *Effect of the Latitude (LAT).* The change in the latitude is correlated with change in both shadow angles; vertical (VSA) and horizontal (HSA). Consequently, when the latitude (LAT) increases, both of the depth (d) and the protrusion (p) increase. The increase in the depth (d) leads to increasing the slope of the inward sloping form on the equator-facing façade, while the increase in the protrusion (p) leads to elongating the equator facing façade (Figure 7).

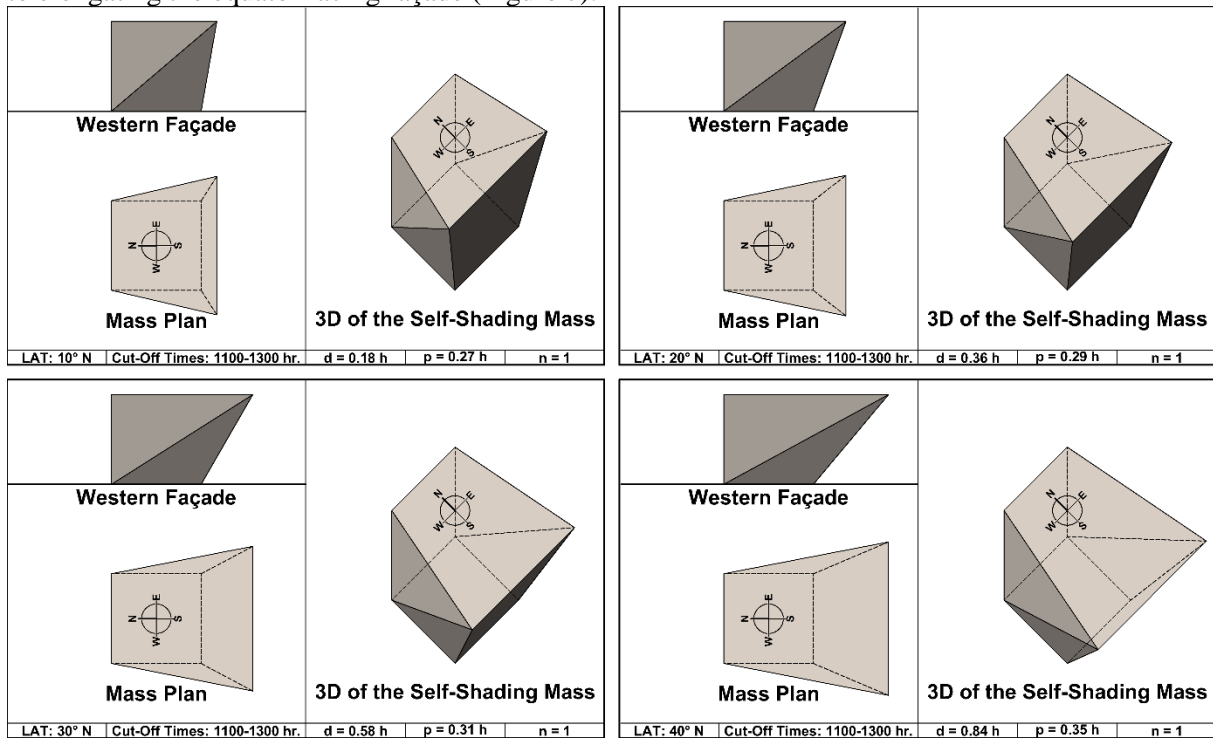


Figure 7. Different self-shading masses constructed for different latitudes; 10° N, 20° N, 30° N and 40° N, at the selected cut-off times: 1100-1300 hr. (Source: the author).

4.3.2. *Effect of the Selected Cut-Off Times.* When the self-shading mass is designed over a larger period of cut-off times, the protrusion (p) increases, leading to elongated equator facing façade (Figure 8).

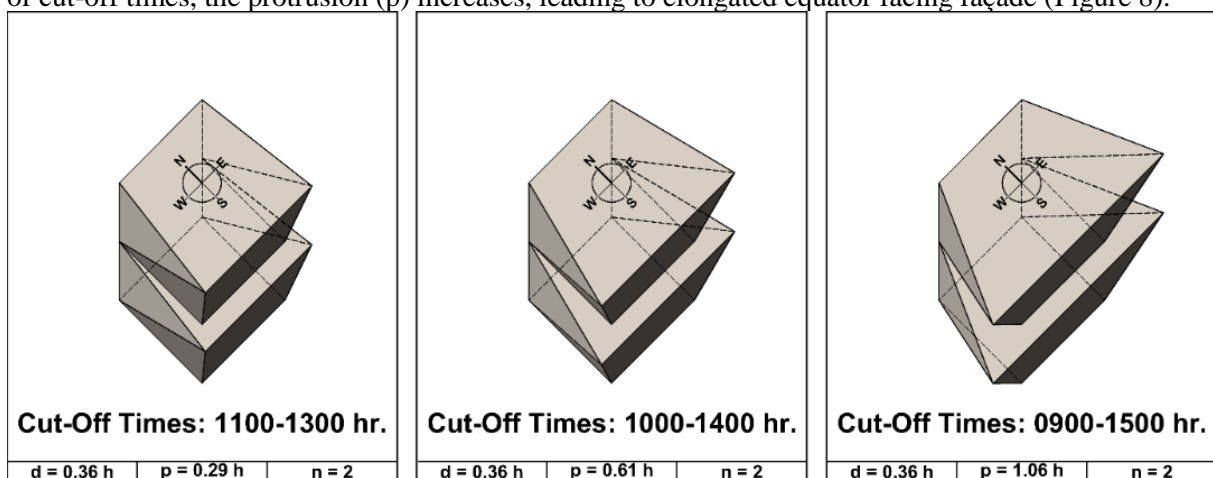


Figure 8. Different self-shading masses constructed for latitude 20° N, at different selected cut-off times (Source: the author).

4.3.3. Number of Crystalline Forms. A number of smaller crystalline forms (n), stacked above each other, could have the same effect in blocking the sun rays as a single large one, which might be essential to overcome the elongated depth or protrusion of a self-shading mass. In that case, the shading height for each crystalline form is equal to the original mass height divided by the number of crystalline forms (n) (Figure 9).

$$\text{shading height for each crystalline form} = (\text{original mass height})/n$$

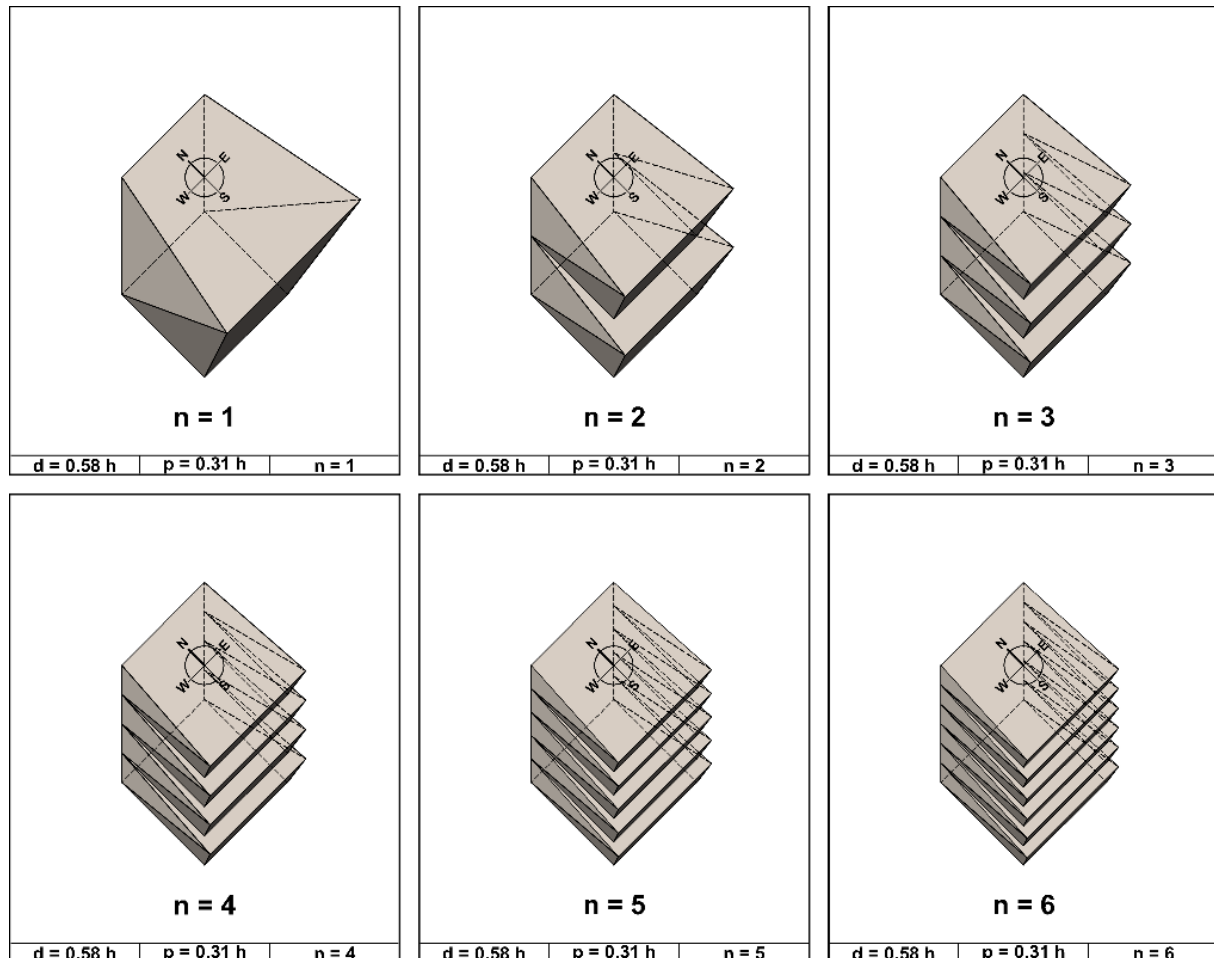


Figure 9. Proposed self-shading masses with different number of crystalline forms constructed for latitude 30° N, at the selected cut-off times: 1100-1300 hr. (Source: the author).

4.3.4. Proposed Materials for the Different Surfaces of the Self-Shading Mass. For crystal-like forms on the eastern and western façades, it is better to use opaque cladding with minimum glazing. Oppositely, it is acceptable to use maximum glazing in the inward sloping form on the equator-facing façade as well as non-equator-facing façade. Based on the idea that the proposed self-shading mass would result in seasonal adjustment, that glazing could be the source of daylighting during summer and passive solar heating during winter [8]. As for the flat surfaces, represented in the roof or those resulting from using more than one crystalline form, they acquire maximum solar radiation. For that reason, they could be either being applied as green roofs for insulation or applying photovoltaics on them with suitable slopes for generating energy (Figure 10).

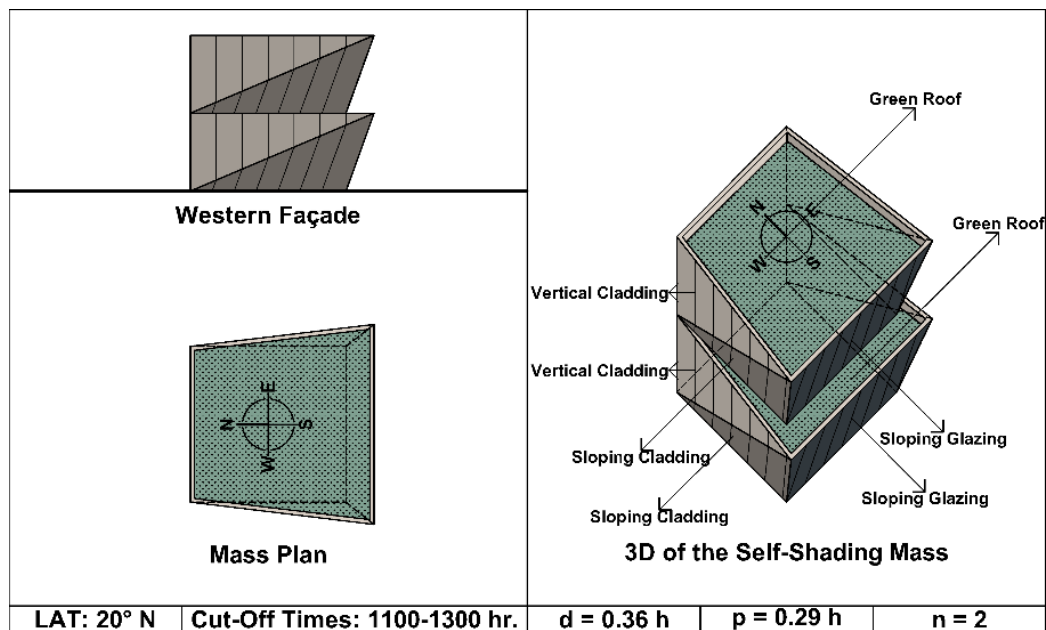


Figure 10. Schematic drawing showing some proposed materials for the different surfaces of the proposed self-shading mass (Source: the author).

5. Discussion and Conclusions

It is possible to determine the different dimensions of the proposed self-shading mass having one or more crystalline forms, as a function of the latitude (LAT) and shading height (h) at the selected cut-off times. Those generated forms are not only used from an aesthetical point of view, but also resulting in an automatic seasonal adjustment, within the low latitudes.

In future researches, the proposed self-shading mass could be upgraded to be suitable for masses other than rectilinear ones, e.g., masses with curves, or masses whose edges are not oriented towards the main orientations. It could be upgraded to find specific dimensions or details that might be suitable for a particular task, e.g., when applying photovoltaics to the surfaces with maximum solar radiation, i.e., the roof. The same methodology could be used for finding the dimensions of other volumes such as, climatic envelopes, etc. Other researches might involve studying the cost effectiveness or energy savings that might result from the use of such self-shading masses.

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