Architectural Thermal Forms

Isak Worre Foged
Department of Architecture and Media Technology, Aalborg University
www.create.aau.dk
iwfo@create.aau.dk

Abstract. *The paper presents a developed method and algorithm to create environmental sustainable optimised forms based on the solar energy received in relation to receiving, containing and distributing energy. Different studies are created based upon this approach, to which forms are evaluated against conventional building geometries. The work shows a significant improvement on several aspects of environmental performance. Lastly the work presents an idea of maximum structures, rather than minimum structures as a path in future research work.*
Keywords. *Sustainable environmental architecture; performative generative algorithms; simulation; material distribution.*

INTRODUCTION

The overall form of a building describes not only its architectural language, but also to a large degree its capacity to become environmental sustainable in relation to its local climatic environment. Movement of the sun in relation to the Earth, its surface orientation and its mass constitute the weather condition locally and globally as it regulates air flow, heat accumulation, heat transfer etc. (Oke, 1987). These relations, solar geometry and mass, form the environment for life and its rhythms. The solar environment is thus the singular most important factor in relation to climatic environmental architecture.

The creation of architectural building forms as derivatives of the solar environment has thus the potential of improving the context specific reception and containment of energy towards environmental sustainable architecture. If the position of the sun in relation to Earth surface orientation and its mass properties can determine local environments as briefly described above, then the same could be activated as a strategy for the generation of sustainable environmental architectural forms and their mass properties. The argument that form and distribution of material has the ability to lower the energy used in a building with up to 80% (Petersen, 2012), combined with the urgent need for environmental adapted architecture motivates the research.

Previous work

A recent trend in sustainable buildings in northern climates has largely been designed to minimise surface to volume relations, while increasing energy uptake, as seen in the Lighthouse project from 2009 by Christensen & Co Architects. It uses its circular form as an optimum sustainable geometry [1]. While currently being an advanced example of sustainable architectural form in the built environment, design of architectural forms remains largely based on 'simple' design principles.

Digital techniques in simulation and generation of architectural form have evolved rapidly over the

last decade enabling the handling of complex climatic, geometrical and manufacturing aspects. The ability to construct advanced generative formal organisations have been shown in works by architects Marc Fornes [2] and Roland Snooks (2011) through growth systems and swarm systems. Other complex arrangements of forms are created in the work of Alisa Andrasak (2006) and Jenny Sabin (2008) to just name a few. The methods and techniques from above exhibit individual potentials with different objectives and at various scales. Common, is the descriptions of local and relatively simple rules that govern larger assemblies into elaborate structures. Today, a plethora of projects and a growing group of people develop generative systems that construct a formal output.

The work presented here continuous in the path of generative architectural methods and systems, but develop and connects these efforts explicitly with the generation of form in relation to the climatic environment based on solar-earth-mass relations.

Presented work

This work applies digital computation as an instrument for simulation of environment and material behaviour and generation of architectural form from this information. With an application of generative digital models with an integrated solar analysis that progressively add material in relation to receiving and containing energy, architectural forms are created as a derivative of the solar parameters. This intents to construct both an improved platform for sustainable environmental architecture and a context related architectural expression. The presented research investigates the capacity to create sustainable environmental architectural forms that are a response to a process of encoding a 6-dimensional factor space, constructed from x,y,z coordinates, time, material properties and solar climate. It does so by application of material properties into digital construction elements (points, geometrical entities), thereby linking physical parameters to iterative digital generative studies.

METHODS

The research applies a series of methods. Computation is used to simulate solar energy and thermal storage based on established mathematical models. This is combined with a developed generative method presented here, which distributes matter in space, progressively resulting in potential architectural forms. Lastly the generated forms are evaluated in a comparative analysis to conventional building forms.

Solar simulation

The encoded solar irradiance analysis is based upon geometrical relations described in *Lambert's Law* (Oke, 1987). Through the direct integration of the solar geometry, azimuth and zenith angles, and thus solar energy, the variables of location can be dynamically changed within the generative model described below. The simulated surface of the distributed elements is always facing 'outward' as the model intents to form closed structures.

Constructor: Matter distribution, creating form algorithm

With the intention of improving the holistic performance by solar energy, thermal forms are based upon the combined aspects of receiving, containing and transferring energy. Receiving energy requires an extended surface towards the energy source, following Lambert's Law. Containment in architecture is based upon minimum transfer of energy from the inside to the outside, therefore minimising the surface to volume ratio. Transfer of energy is related to the ability to move the energy received at the surface to the core of the form.

Based on these factors, an algorithm can be described which is based on 'the more energy received on a surface of an element, the longer from the core the element can be positioned', Figure 1. The following element created undergoes the same evaluation but rotated around a center point to position it next to the previous element. The longer the elements are positioned away from the centre point (cp) the

Figure 1
Distribution of solid matter from centre point according to energy.
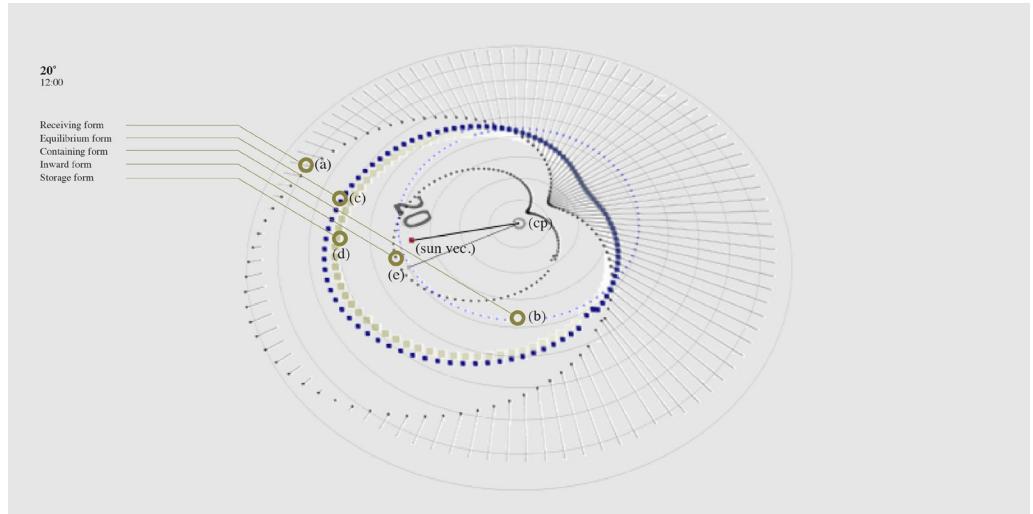
longer distance is between the elements, effectively extending the combined surface oriented towards the energy source. The progressive formation creates elements (a). Following a similar method but with a fixed distance between a centre point and a created element form a circular form with optimum surface volume relation. The progressive formation creates elements (b). The formation located between elements (a) and (b), denoted elements (c) serve as an equilibrated formation. In the studies performed in this paper, (c) is always half the distance between (a) and (b). From (c) solid matter is distributed according to the description below.

Constructor: Matter distribution, creating mass algorithm

Following the creation of form, material properties are applied to the generative model through three different aspects, 1) u-value, the heat transition coefficient, 2) g-value, the solar gain coefficient and 3) thermal mass. These are selected based on their direct reference to established architectural terminology, and from sensitivity analysis of the most influential passive factors for sustainable architecture (Petersen, 2012).

The factors are plotted into a scheme, Figure 2, in relation to solar irradiance from above. The scheme is related to the northern hemisphere, in which southern orientations are effected by higher solar gain. In case of high irradiance materials that allow high solar gain can be low etc. The scheme could be reconfigured for other locations and paired with the above form creation algorithm generating other results than presented below.

Merging the above into one model, we have the following algorithmic procedure:

1. Distribute test elements around center (small inner circle around center point)
2. Calculate element angle vector from center to distributed element
3. Calculate sun vector
4. Calculate angle between element (a) vector and sun vector
5. Calculate radiation energy on each element based on Lambert's Law
6. Distribute elements from center based from quantity of solar energy at each test
7. Distribute element (b) from center with same radii creating circle
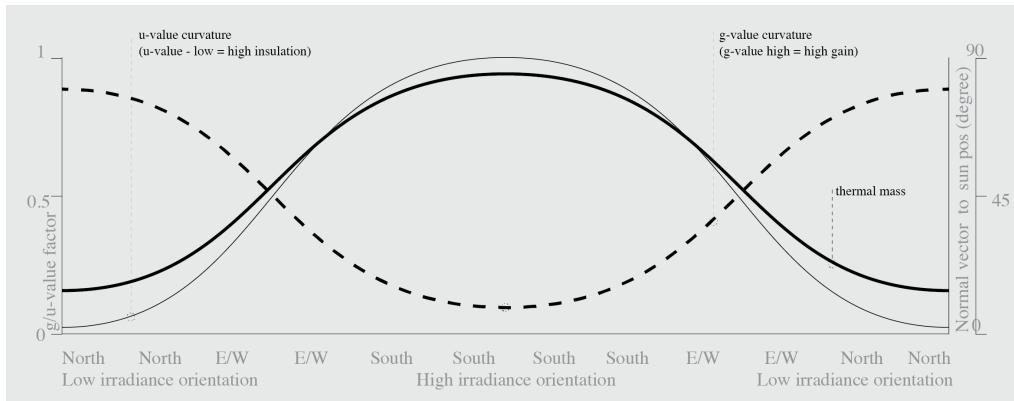8. Calculate distance between elements (a) and

elements (b)

9. Distribute elements (c) between elements (a) and elements (b) as equilibrium
10. Calculate angle between element (c) and sun vector
11. Calculate radiation energy on each element based on Lambert's Law
12. Calculate optimum g- and u- value materials according to g-u-value scheme
13. Distribute elements (d) and scale/colour elements from calculated g- and u-
14. values
15. Calculate stored energy in elements (d) based on material property and
16. received energy
17. Calculate radiant energy emitted from energy stored in elements (d)
18. Distribute elements (e) towards center based radiant energy
19. If, elements(a,b,c,d,e) angle > TWO_PI move elements(a,b,c,d,e) up with
20. distance (z)
21. Return to (1)

Studies

Following studies are done from above developed algorithm.

Study A, mass is distributed based upon calculated optimum u-and g-values indicating what prop-erties a given material should have when located at the given position computed by above method. This has the intention of suggesting a distribution of material and its properties not restricted to accessibility of contemporary materials, Figure 3a.

Study B, thermal properties of bricks (solid mass in geometric entity) is applied in the calculations of thermal storage in the organised form and causes a scaling of the brick. This has effect on the subsequent distribution of thermal material to locally scale reception and further distribution of heated air (fluid matter). This is done with the intention of only applying material where it is needed, Figure 3b.

Study C, evaluates the solar energy on a given surface and suggest from two materials, high and low energy absorption, which material to apply where. This has the intention of making the environment choose a material from a potential (small) catalogue of available materials, Figure 3c.

Comparative analysis

In order to understand the performance of the forms generated, a comparative analysis is done between conventional building forms and the forms derived from the method and algorithm. The comparison is provided on below eight aspects measuring the relations between receiving, using, storing and transferring energy in simple measures.

Figure 3
A,B,C. Distribution of solid matter from elements (c) as thermal storage according to energy.

A / u/g value   B / brick   C / dual
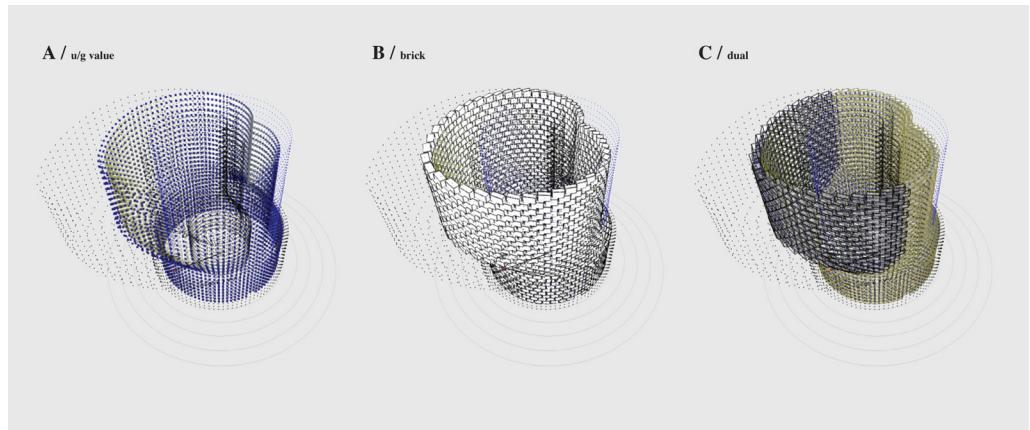
RESULTS

The formations created by the developed method and algorithm illustrates clearly a circular form with a low application of thermal mass when the sun is high on the sky. In climates with a lower sun angle the form equilibrates into advanced forms with extended surface towards the source and decreased surface in the opposing direction. This is particularly evident when observing the formations 'live' or as one can see in figure 3 a,b,c where the sun was set in first 1/3 of the formation high on the sky, 85 degrees. The following 1/3 part of the formation the sun gradually lowered to a resulting angle of 6 degrees creating the transitional form to the last 1/3 of the formation where the sun is kept at 6 degrees.

In lower solar angles the most non-circular results are seen and therefore creates the largest differences to conventional building forms. Within the comparative analysis it is clear to see the performance in relation to the combined factors of receiving, containing and transferring energy, with significant improvements achieved based on the presented method.

Based upon the thermal matter volume distributed on the generated surface a heterogeneous surface structure density was created resulting in an organisation of solid matter only where needed. In figure 4, this has a large effect when compared to conventional methods of applying material homogeneously on all outward facing surfaces.

CONCLUSION

Based upon the presented studies we can suggest that energy optimum forms cannot be generalised to e.g. circular forms, but are much more a result of localised factors constructing the environment. If an urban environment were included this environment would perform different due to the change of casted shadows from neighbouring buildings.

If considering a tall and dense urban environment, where little to no direct radiation would occur, the hierarchy of factors could change, meaning the equilibrated form (elements c) could have a stronger 'weight' towards the energy containing form (elements b), rather than energy receiving form (elements a), as the energy for reception is not accessible. This, as a consequence, would create forms in dense urban areas that are more uniform circular than curvilinear oval forms as shown above. As the form rise above neighbouring buildings the 'weights' could alter again towards a hierarchy where reception of energy was favoured, resulting in very modified geometry compared to the perfect circle. This is what we see in figure 3abc.

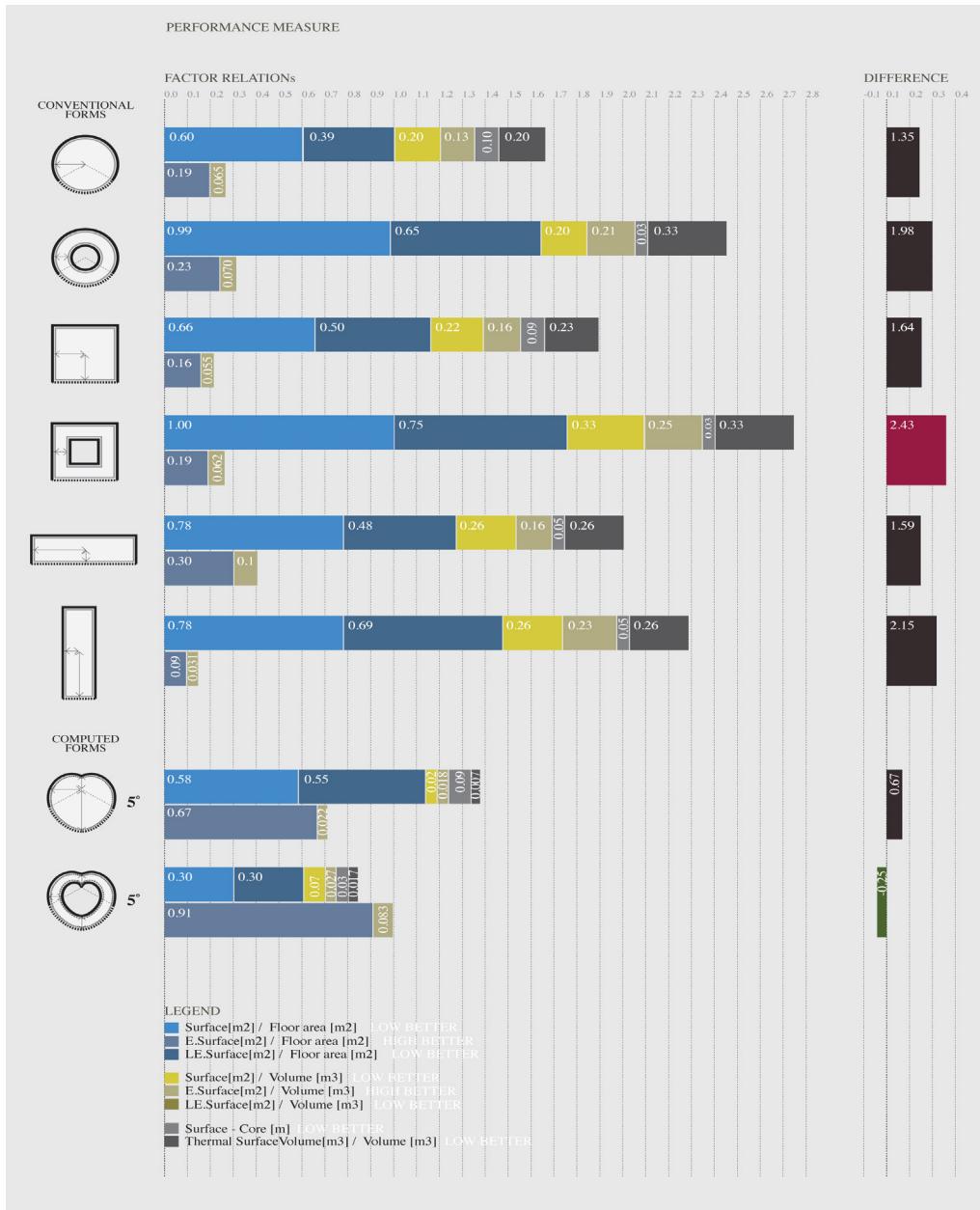The model, beyond the overall form, also introduces the calculation of a floor plan depth by how

Figure 4
Comparative analysis be-
tween conventional building
forms and the computed
forms.

long the energy potentially could be transferred into the building after reception at the envelope. If further developed, this approach could suggest internal spatial organisation and divisions according to light levels needed, operating temperature, and spatial programme when considering the occupier as an environmental source.

Introducing more sources of energy, such as air flow cooling the surface or internal loads of occupancy and equipment could in a reciprocal relation further alter the articulation of the generated architectural form as energy is created both on the inside and outside of the envelope.

DISCUSSION

The work follows the biological notion by Darcy W. Thompson (1992) that a *'form of an object is a diagramme of forces'*. Additionally, we might add that the local forces are derivatives of the local form it interacts with.

Architecture has, for good reasons of structural optimisation, had a singular focus of 'minimum structures' by a tremendously rich legacy from Frei Otto, Erik Reitzel and others. However, this work also suggest to embark on an approach that can be referred to as *'maximum structures'*, which not only focuses on minimisation of used material, but equally how it maximise its performative organisation in relation to environmental sustainable architectures.

Such an approach could be initiated by the presented method of distributing material properties, such as thermal mass, transparency, even tactility, to expand the performative and aesthetical instrumentality of the generative models. This again, would expand the factors involved, and suggest an added hierarchy of factors to the one used within this work by the mentioned sensitivity analysis for sustainable architectures.

The work is presented as environmental performative forms, but as the built environment changes through urban reconstruction over time, the local climatic environments alter with it in a reciprocal manner. This suggests that the approach could be expanded into a more responsive structure, which by above method could suggest new forms, but with an underlying structural organisation that would allow for a dynamic adaptation resulting in changing the overall form of the building.

A less drastic approach in relation to moving structure adaptation could be performed locally at the material scale, directly utilising the presented method of material property distribution. This would require that the time-based adaptive properties, such as phase-change-materials where implemented in the initial generative process of distributing mass.

REFERENCES

Andrasek, A., 2006, *Continuum – A Self-Engineering Creature-Culture*, AD Wiley.

Oke, T.R., 1987, *Boundary Layer Climates*, 2nd Edition, Routledge.

Oxman, N., 2010, 'Material Based Design Computation', PhD Thesis, MIT, Boston

Petersen, D.M., 2011, 'Informing the Design Process: A Study of Architect's Approach to Environmental Architecture', PhD Thesis, Aalborg University

Sabin, J. and Jones, P.L., 2008, Nonlinear Systems Biology and Design – Surface Design, *International Conference ACADIA Proceedings*.

Snooks, R., 2011, 'Digital Crafting Symposium. Generative Logics', Lecture, 18. January, Aarhus School of Architecture

Thompson, D.W., 1992, *On Growth and Form, Dover Publications*, New York.

[1] http://www.christensenco.dk/projekter&p=22 (Retrieved: 29 November 2012)

[2] http://theverymany.com/ (Retrieved: 25 January 2012)