Interior climate optimization by volumetric adjustment

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Abstract

This research focuses primarily on the functionality of software, specifically Rhinoceros (McNeel & Assoc.) and a few associated PlugIns (Grasshopper, Rhino Assembly), to create and control a model of a building to study the environmental effects of modulation of space. Has technology been completely utilized in addressing comfort maintenance within a dwelling space? For example, animals have a similarities based upon their surface to volume relationship, yet they are able to adjust the ratios based on a reaction to their environmental circumstances. For example, when cold, they are able to “fluff” their fur in order to minimize their surface area in comparison to an increasing “interior” volume. Historically, abilities to influence temperature change within a space have been relegated to passive air exchange systems and more recently completely active air exchange means of control. Technological advances have raised significant questions towards methods and means for this control.

Through use of 3D models and simulations, the topic of climate maintenance in spatial conditions was addressed using environmental controls. Thus modulation of the interior climate as well as the space could simultaneously occur to create a radically different space of habitation. The preparation and writing of this abstract addressed various areas of the SPC requirements, which become apparent during the digestion of the paper.

keywords: Rhinoceros, Grasshopper, Rhino-Assembly, volume, operable architecture, parametric components, climate optimization, dynamic constructs

Introduction

With much of today's life involving highly dynamic and interactive objects, which process much information, one can say that architecture is lacking in its exploration of information processing buildings. A majority of buildings today can be described as static objects. Buildings from the beginning of time have always possessed information, but rarely processed it. Structure, for example, has one job; to maintain its given place in space based on the information it receives from fasteners. An important job albeit, allowing people to dwell in these spaces. These unchanging spaces have become the focus for this research, concentrating primarily on how a space could react to environmental influences, which affect the climate of the interior space resulting in a highly charged dynamic dwelling space.

Research Background

The research began with discussions centered on an animal's surface to volume ratio. It has been shown through studies that an animal's skin surface to body volume ratio, follows a particular curve in relation to the type of climate they inhabit. (Schmidt-Nielsen 1984) Yet these animals all have an ability to change this association somewhat through the adaptation of their skin, namely in shivering, or sweating. Where shivering tends to fluff the fur or cape of the animals it minimizes their surface area in relation to their volume, and helps to bring their interior volume up, in cold temperatures. Warm temperatures invoke the process of sweating which allows the cooling of body temperature through evaporation, although it does not change the surface area of the animal. The winter fur compared to the summer fur is definitely different in terms of thickness. Even natural responses show our adaptation to temperatures, as we grow cold we tend to curl significantly to reduce our surface area, this changes the ratio of our surface to volume area of our bodies. One of the exceptions are elephants, whose body mass is so great compared to their skin surface that heating or cooling via conduction through their skin surface tended to be negligible in altering their internal temperature. (Schmidt-Nielsen 1984)

In relation, a sky scraper is one building type which parallels an elephant's internal temperature mass. A sky scraper is a building type which needs cooling year round even during the cold winters of Minneapolis and Winnipeg. Historical means of dealing with climatic influences have ranged from passive solutions, such as allowing breezes to cool buildings in tropical climates, while in colder climates introduction of heat into the space allowed the space to maintain a degree of comfort. With the advent of air-conditioning, buildings were able to use cooling to maintain comfort levels through the summer months. These concepts evolved to induced heating and cooling year round for buildings.

A building's interior space has a certain amount of BTU present in that space, and it changes based on energy being introduced into that space from humans, machinery, and environmental influences from outside the space. Energy is conducted, from outside, to the interior space via the boundary surfaces, this leads to changes in the space's climactic energy content/BTU. Geometry forms needed to be studied to find out how they influence spatial BTU maintenance. Spheres are the most efficient in terms of surface to volume ratio with a ratio of 3, meaning there is

3 units of surface to every 1 unit of volume.(Wikipedia) While a tetrahedron, or a triangular shaped figure, tends to be the least efficient, a 7.21, in terms of amount of surface compared to interior volume.(Wikipedia)

Also, recent technological advances such as 3D modeling, simulations, and various components which respond to sensory influences begin to raise questions surrounding typical ways of approaching architectural design. With the understanding of how a shape's relation between surface and volume affects each other, new possibilities revolving around 3D parametric modeling and simulations, the decision was made to refine the design of a project through the use of an appropriate surface to volume ratio, and the new computing technology. (Figure 1)

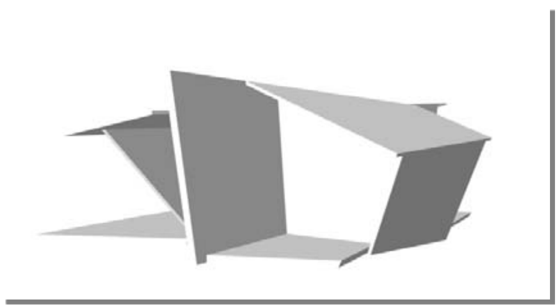


Figure 1: The process model which directed the development of the project design.

Discussion of Procedure

Initially, much discussion revolved around the psychometric chart and the relationships on which it concentrates. (Stein, Reynolds, Grondzik and Kwok 2006) The most interesting relationship within the psychometric chart was the intertwining volume, entropy or BTU and temperature relations. Since those three factors were interrelated, theoretically one could be adjusted affecting the others. This realization began to further direct the development of the project.(Figure 2)

Since architecture is highly centric around the design of space, a procedure involving the use of volume manipulations to alter climate conditions within a space would result in a highly interesting space, a rationally developed project based on environmental influences. The factors which are most crucial in maintaining a spatial climate began to surface as important toward facilitating any such actions involving climate maintenance by volume manipulation.

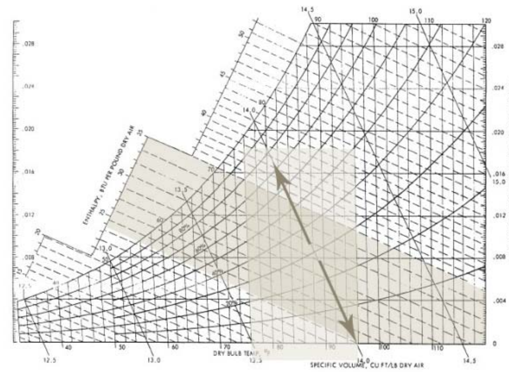


Figure 2: Psychometric chart highlighting the relationship used in the research.

The U-factor, or insulated barrier, volume, and the temperature difference from inside a space to outside the space are the critical factors surrounding controlling a climatic space. It was found that the U factor when plotted next to the volume and temperature difference had the most impact on maintaining a climate at a comfortable level. (Figure 3)

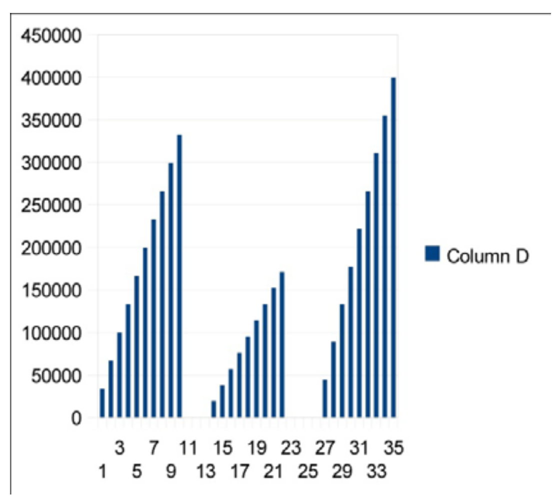


Figure 3: The graph showing importance of U factor of a wall in comparison to the temperature difference and the volume of the space.

Although the U-factor of a typical wall requires much attention in relation to maintenance of climatic conditions of a space, the ability to control a space's BTU level through means of operable boundary planes required attention to how a space might be affected. The experience of differing, or changing spaces could become an unsavory experience if designed incorrectly, the decision to alter primarily two planes from each side of the structure became the focal point. The roofs of each side become operable, with one side able to extend its length, and the other to both change the angle of attachment to the dividing wall as well as changing its covering length as well. The two long exterior walls also were allowed to change their angle of relation to the floor while simultaneously being able to extend their height as well.(Figure 4)

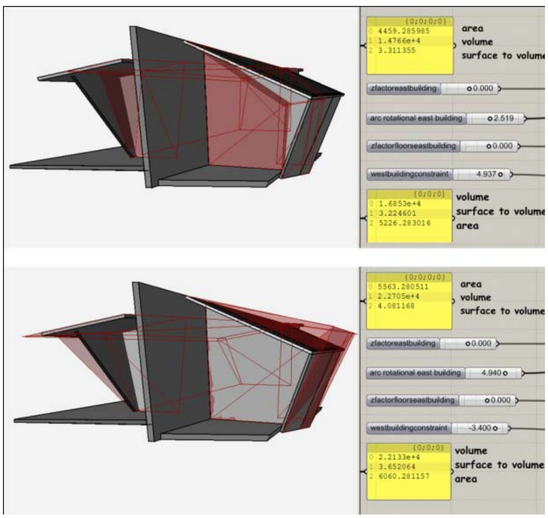


Figure 4: The model showing the relational changes which control interior climate.

This allowed for the expansion and contraction of the enclosure volume to be changed as well as the spatial countenance of the interior spaces to be changed also. The restrictions of the angles and lengths of the boundary planes are based on the volume needed to accompany the extreme environmental conditions of the project, so the maximum low and high temperatures of the climate. An in-depth look at how and whether it could be possible to maintain a comfort level in a space through volume control or modulation, brought physics and thermodynamics into the discussion. The examination of thermodynamic formulas proved that air could be manipulated with pressure and volumetric changes, not simply through induced heating and cooling.(http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html) An example is airplanes, they become pressurized and maintain their volume to a certain size, this aids in the requirement of less heating of the fuselage during high altitude flying. The metal of the skin and structure conducts the cold from outside to the interior of the plane which is why there is a need for induced heat. If planes were able to alter their volumes, an answer for the infiltration of energy through the boundary plane could be to adjust the volume to anticipate for the conducted temperature change, therefore creating a negligible amount of energy to transfer into the space. A set of formulas derived with the aid of a professor began to illustrate how a building might adjust to temperature gains via adjustment of boundary surfaces.(Figure 5)

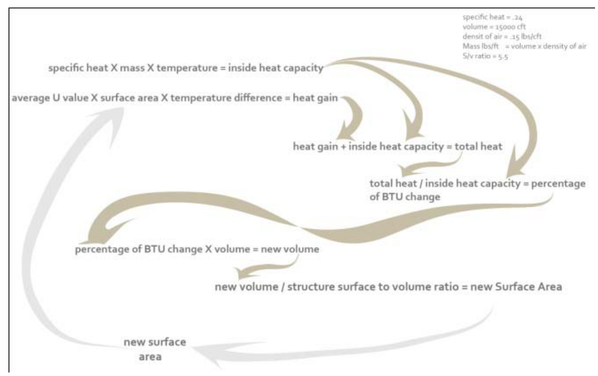


Figure 5: A visualization of the formula used to derive how to control a space's climate.

Early, during the development phase of the project, the goal was to have a completely modeled design which reacts in response to temperature differences and changes from the surrounding environment. A design was developed within Rhinoceros and modeled as a process model. This allowed the designer to select various parts of the process model in the Grasshopper program and adjust them based on what the designer decided it should do. The model was developed to the point at which it was fully functioning and displaying real-time volume, surface area and surface to volume ratios as a slider was manipulated to change the model.(Figure 6)

Yet the realization was made that tolerances did not aid in the production of components for the architectural design, rather the lack of lifelike tolerances led to the lack of development of components.

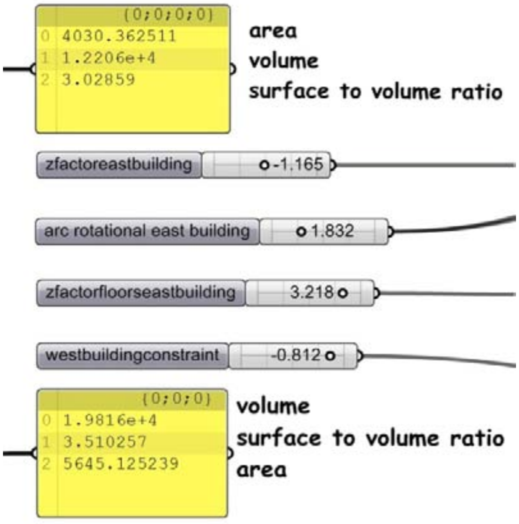


Figure 6: The control panel in Grasshopper showing the changing volume, surface area, and correlating ratio.

This lead to the search for a Plug-in or modeling aid for Rhinoceros which allows a model to function as it would during lifelike and realistic constraints. Rhino-Assembly was found and with all considerations in mind found to be satisfactory for the purposes required. A model was then developed in a more satisfactory manner being able to model building constructs and details to become a fully operable structure within the program. (Figure 7)

With the ability to design constructs, or pieces of architecture, while allowing the desired initial conceptual design to be seen during the process, allowed for simultaneous development of two models. One a physical model, which simulates how a building may respond and change to information with different, yet compatible parts working together and the second a model which "reads" data and performs analytical calculations revealing the differing changes a building would progress through as the data changes. The next step would be to integrate it with a real time temperature and set the model "free" to visualize how would change over a day, season or year based on the temperature data obtained. This was completed through use of the Rhino Plug-in Grasshopper and a visualization of a simulated building and volume change was viewed through the integration of the model paired with select month's worth of temperature data.

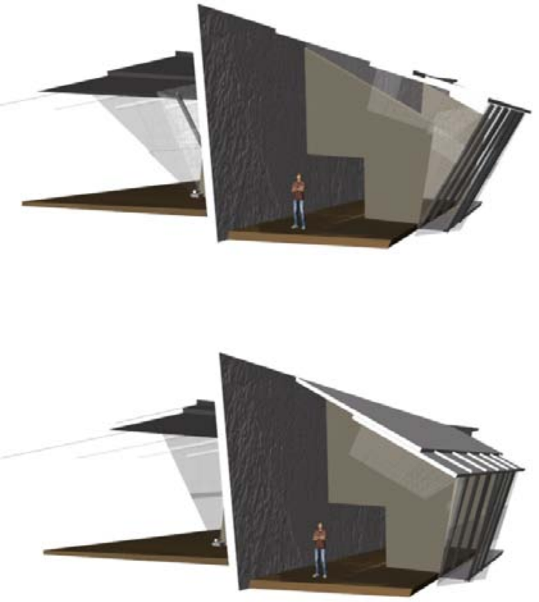
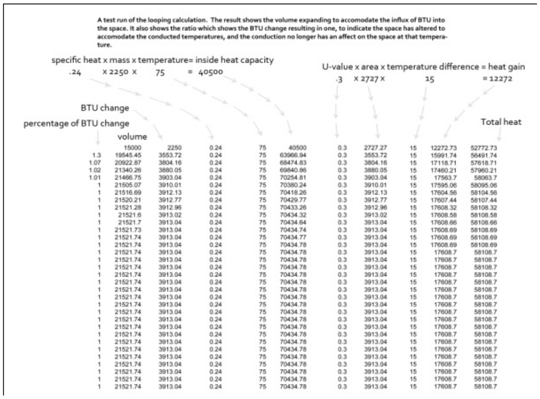


Figure 7: A close up of the model beginning to show the implementation of architectural components designed for the project.

Results



A test run of the looping calculation. The result shows the volume expanding to accomodate the influx of BTU into the space. It also shows the ratio which shows the BTU change resulting in one, to indicate the space has altered to accomodate the conducted temperatures, and the conduction no longer has an affect on the space at that temperature.

specific heat x mass x temperature= inside heat capacity
.24 x 2250 x 75 = 40500

U-value x area x temperature difference = heat gain
.3 x 2727 x 15 = 12272

BTU change
percentage of BTU change
volume
Total heat

	15000	2250	0.24	75	40500	0.3	2727.27	15	12272.73	52772.73
1.3	19545.45	3553.72	0.24	75	63966.94	0.3	3553.72	15	15991.74	56491.74
1.07	20922.87	3804.16	0.24	75	68474.83	0.3	3804.16	15	17118.71	57618.71
1.02	21340.26	3880.05	0.24	75	69840.86	0.3	3880.05	15	17460.21	57960.21
1.01	21466.75	3903.04	0.24	75	70254.81	0.3	3903.04	15	17563.7	58063.7
1	21505.07	3910.01	0.24	75	70380.24	0.3	3910.01	15	17595.06	58095.06
1	21516.69	3912.13	0.24	75	70418.26	0.3	3912.13	15	17604.56	58104.56
1	21520.21	3912.77	0.24	75	70429.77	0.3	3912.77	15	17607.44	58107.44
1	21521.28	3912.96	0.24	75	70433.26	0.3	3912.96	15	17608.32	58108.32
1	21521.6	3913.02	0.24	75	70434.32	0.3	3913.02	15	17608.58	58108.58
1	21521.7	3913.04	0.24	75	70434.64	0.3	3913.04	15	17608.66	58108.66
1	21521.73	3913.04	0.24	75	70434.74	0.3	3913.04	15	17608.69	58108.69
1	21521.74	3913.04	0.24	75	70434.77	0.3	3913.04	15	17608.69	58108.69
1	21521.74	3913.04	0.24	75	70434.78	0.3	3913.04	15	17608.69	58108.69
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1	21521.74	3913.04	0.24	75	70434.78	0.3	3913.04	15	17608.7	58108.7

Figure 8: A spreadsheet showing the calculations showing how a particular volume will change in response to the temperature difference with the formulas used.

Through the use of the derived formulas it was found that as the temperature changed, the building would adjust to the temperature being conducted in, via the adjustment of the boundary surfaces. The calculations show how a project might produce a space of varying and seasonal change. (Figure 8) As the change in surface area was affecting the conducted temperature via the adjustment of the boundary materials, this then affected the inside climate and caused the building to adjust once again. Sensory activated components would sense the change in BTU and activate the envelope to adjust to accommodate this environmental influence. Thus a building becomes a processor of information, which addresses two types of information; climatic information, as well as spatial volume information. Other results included the formation of a physical tolerance restraint model which illustrates the difficulties in developing a fully functioning model. (Figure 9)

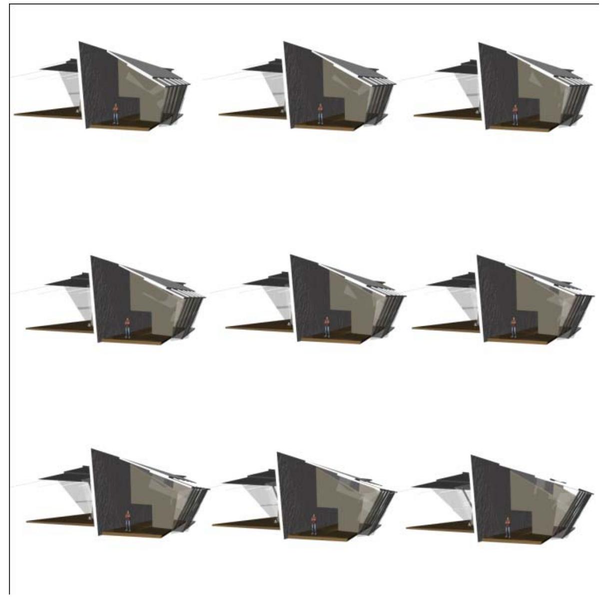

Figure 9: View showing the physical model showing the structure moving in response to temperature changes.

The development of a model which simulates a building constructed of components, evolving and changing over time becomes conducive towards believability. The importance of the implications in developing a functioning model is important regarding many aspects. During the development of the functional model many physical, lifelike conditions caused the conditions of the components to change due to restrictions imposed by the developing design, and the desire by the designer to stay true to the design intent. This resulted in the creation of new dynamic architectural components, which would not have been realized without this project.

Conclusion

The calculation loop results show the reaction of a building which responds to energy conducted into the interior climate. The result shows the building volume stabilizing at a volume in which the incoming energy is offset by the sheer amount of BTU available within the space already. In essence the calculations show a building which finds a stabilization point, or creating the same scenario that an elephant's surface to volume ratio has created for their body temperature control, interior BTU being so great that conduction of energy via their skin does little to offset and change their body temperature.

To incorporate a changing and more accurate U factor in reflection of the changing boundary planes of the model would result in more accurate and conclusive results. Yet the simulations done through the research and the path to achieve the results, show promise in the results displayed. Influences on the spatial climate not accounted for, range from human body heat, appliances such as refrigerators, computers, and other such machines with heat as a byproduct. It is this type of inclusion in future advancements, paired with a cost analysis of a proposed design in operation to compare energy costs over use of an adaptable space to a conventionally controlled climatic space.

Although this project is shown being applied to a residential type project, this process of rationalization is not limited to a certain typology, climate zone or building system. In reality the computations formulated show the generality of application. The design was developed independent of the computations, but with the holistic understanding of developing the project towards an adaptable structure. As the project concluded the realization was made that application of modulated components tend to filter in naturally towards the end of the design process. This led to the understanding of integration of rationalization within the realm of design. Design becomes the restraint and intent of the project, while the rationalization of components into the design began to reveal the symbiotic birth of new constructs of architecture which were not thought of during the initial design stages of the project. Developing new constructs or components designed specifically for this project allows the visualization of a process incorporating far more than simply design, but the incorporation of the practical side of the discipline as well.

Implications for Practice and Advancement of Research

The research has left many avenues of pursuit open in regards to rationalization of a space in response to environmental influences. Climate is one of many such areas of investigation which look to be very promising. The control of natural light into a space, or correspondingly reducing artificial light, and creating a lighting condition based on the programmatic requirements of the space is another direction available. Light and energy, are just a few areas where the rationalization of space could be investigated and researched more.

The sense that a design has been rationalized, due to the environmental conditions imposed on it, yet allows a designer the freedom to develop a design is important. The thought of using rationalization to structure or hinder design implies unimaginative design. Rather the implications of this particular research are thought to expand the vocabulary of both architects and the field of design. A spatial composition varying in its size and enclosure is the threshold of a new era of performance buildings. The use of computers to simulate a combination of constructs to create a spatial boundary, one which evolves over time, shows the importance of tooling in the field of architecture.

The ability for architects to model designs in whole, or completeness would address many issues in the practical side of the discipline. A most important ideal would be one which would address the implications of using a 3D model as a “construction document” instead of a using plans, sections and elevations as architects primarily use today. The ability to produce complete information with by use of sections and plans creates more issues than simply submission of a 3D model which has vastly far more information at hand. The simple layering of different components of the building can allow builders to see firsthand how exactly a certain detail will work in all phases not simply in section and plan. A 3D model for builders would be much more informative than pages of drawings that reference each other over and over, and require much insight and the ability to foresee how one aspect might affect and connect with another. As more easily understood information for builders would a 3D model be, even more evocative for dwellers would be a space which modulates and reacts to the environment. This creates a dynamic space which is constantly changing, creating new views, new views of the form, and highlighting the sensory input for the users. A building which processes information, highly reflective of our culture, yet responds to the simple influx of information of its environment.

Acknowledgements

I would like to thank North Dakota State University professor Dr. Ganapathy Mahalingam for his devoted attention to this research, for without him this paper would not have been possible.

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Figure 1: Calculation Loop Derived By: Ganapathy Mahalingaham, Created by: Daniel Hillukka

Figure 2: Source: http://www.geocities.ws/jitrayut/rhumidity.html, Changes: Daniel Hillukka

Figure 3: Process Model Created by: Daniel Hillukka (Rhinoceros)

Figure 4: Spreadsheet of Calculations Created by: Daniel Hillukka (OpenOffice Calc)

Figure 5: Model Control Panel, Created by: Daniel Hillukka (Grasshopper3D, Rhinoceros)

Figure 6: Grasshopper Mesh Overlay of Rhino Process Model, Created By: Daniel Hillukka (Rhinoceros, Grasshopper3D)

Figure 7: Evolving Model, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)

Figure 8: Model Close Up, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)

Figure 9: Evolving Model Second View, Created By: Daniel Hillukka (Rhinoceros, Rhino-Assembly)