constructs of operable
architecture

daniel hillukka
north dakota state university
graduate student fall 2010

deimhillukka@hotmail.com

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, RhinoParametrics), to create and control a model to study the effects of modulation of space. Has technology been completely utilized in addressing comfort maintenance within a dwelling space? Historically abilities to influence temperature change within a space have been relegated to passive systems and more recently completely active 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 were addressed using environmental controls. Thus modulation of the climate as well as the space could simultaneously occur to create a radically different space of habitation.

keywords: Rhinoceros, Grasshopper, Rhino-Assembly, RhinoParametrics, volume, operable, architecture, components, climate optimization

Introduction

With much of today's life involving highly dynamic and interactive objects, which process so 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. 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 sky scrapers are one building type which parallels an elephants internal temperature mass, sky scrapers are 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 materials, this leads to a changes in the space's climactic energy content, and is one of the main reasons we construct buildings, for protection from climatic extremes. This led to the examining of the geometry of forms and the ranges of surface to volume ratios they envelope. 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 shapes relations between surface and volume affects each other, new possibilities revolving around 3D parametricism 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. Are there methods other than simply using passive and active temperature control to maintain comfort levels in constructed spaces? Can altering surfaces, by either by reducing surface area, changing material content, or designing for the appropriate surface to volume ratio, allow a change in energy conduction into the space, thus controlling spatial climates in a new way?

Discussion of Procedure

Initially, much discussion revolved around the psychometric chart and the relationships that it concentrates on.(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.

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. 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. 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 which 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 boundary materials.

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. The program RhinoParametrics was explored and initially was to be used as a basis for the project to be modeled in, but after some exploration and testing of the program it was found to be a software program lacking in its abilities for what was envisioned. At this point the decision was made to switch over to Grasshopper, the visual scripting interface Plugin for Rhinoceros. 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 they 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. An attempt to begin a test rendering, the visualization of a model which changes through time in response to its environment, the realization was that the model controlled by Grasshopper was simply a sketch model, meaning that the parts and meshes were quite simply sketches much the way an architect begins a project by sketching on paper. Grasshopper sketches its surfaces as meshes, they can become surfaces, but the issue is that it is not integrated with physical tolerances to allow parts to become integrated within the design to become a fully operable project. To clarify this more so, a project in Rhinoceros becomes accurate because of the tolerances and surface based modeling approach it uses, Grasshopper on the other hand uses Rhinoceros as a platform to produce meshes, a sketch, which can then be transformed into a model or a set of surfaces, depending on how it is applied. This lead to the search for a Plugin or modeling aid for Rhinoceros which allows a model to function as it could do in realistic constraints and tolerances. 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 design within the program. The tolerances and constraints used in Rhinoceros are simultaneously used by Rhino-Assembly, this allows for the ability to develop a model to a fine tolerance, similar in fashion as one might model a car engine or other interactive moving parts. This is in large part a requirement for demonstrating the ability to construct a piece of architecture which will change and respond based on environmental or desired influences. With the ability to design constructs, or pieces, of architecture while allowing the desired initial conceptual design to be seen through during the process, allowed for simultaneous development of two models to be developed. 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 problems 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 Plugin 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.

Results

Yields from the research centered on spatial interests as well as, climatic control interests.

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 boundary materials. The calculations show how a project might produce a space of varying and seasonal change. As the change in surface area was affecting the conducted temperature change via 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. The development of a model which simulates a building constructed of components, evolving and changing over time becomes conducive towards believability. The importance of 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 by product. 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 individuality 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, as the results have shown in this particular case, yet allow 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. For centuries buildings were constructed as solidly and permanently, just as ink was permanence on paper. With computed tools today, the ability to develop a project as fleeting as the model shown on the pixelated screen is as related and reflects the use of tools by architects through out time. This begins to direct architects toward inclusive design of simulated designs, further enhancing the value and worth of architects.

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 first hand 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, even though not all of the components are drawn together. As a more easily understood information for builders might a 3D model be, even more evocative for dwellers would be a space which modulates and adapts for 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 Mahalingaham for his devoted attention to this research, for without him this paper would not have been possible.

References

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Internet: www.wikipedia.com

Internet: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

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)

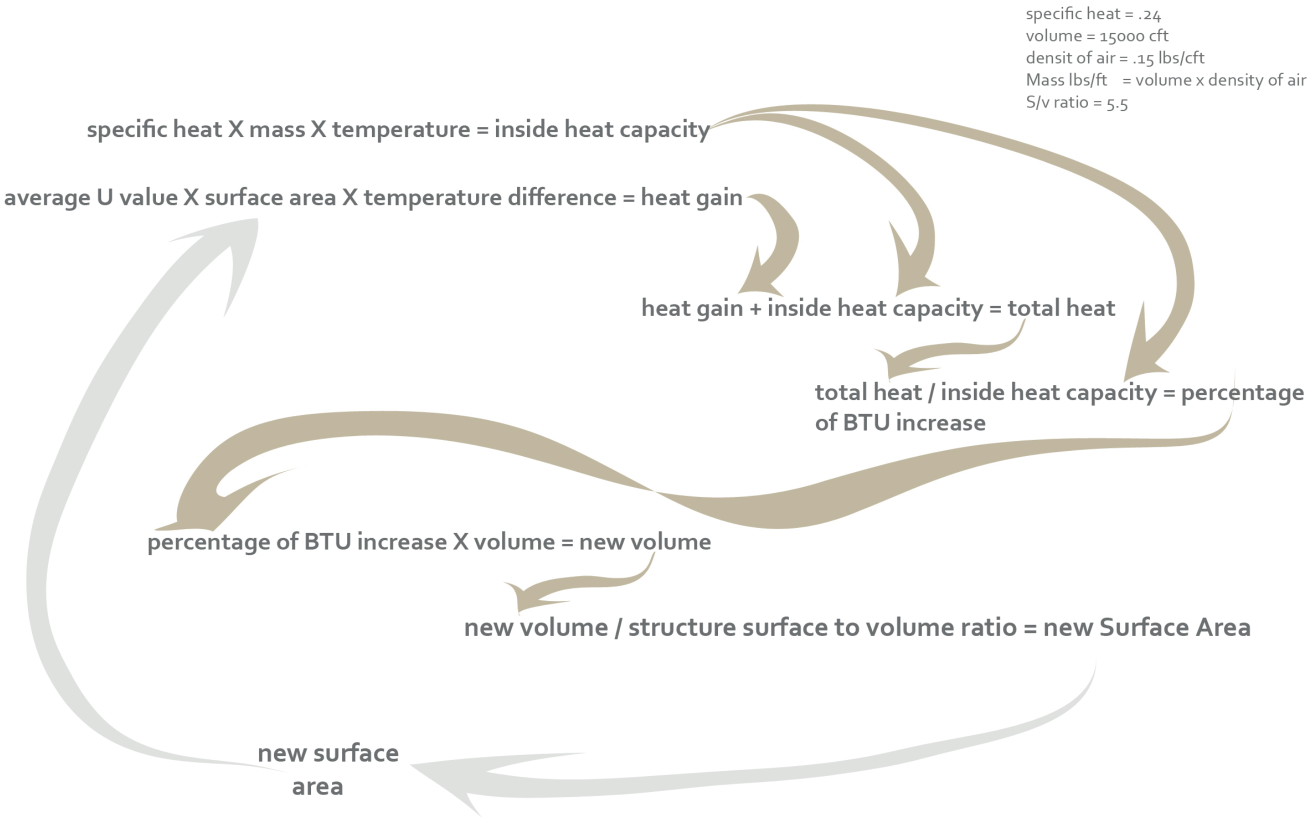


Figure 1. A graphic showing the looping calculation which drives the changing volume of the structure.

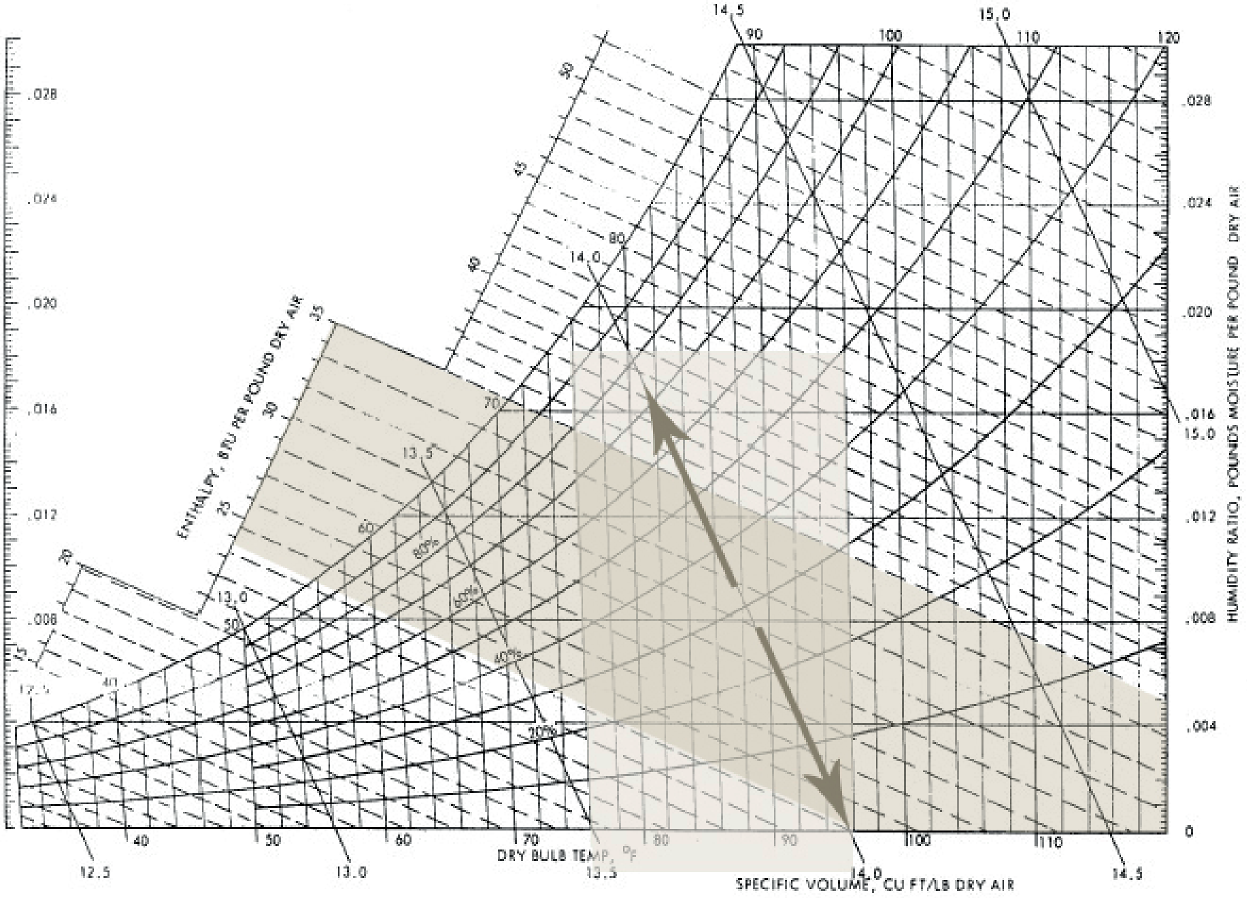


Figure 2. The psychometric chart showing the relationship which this research focused around.

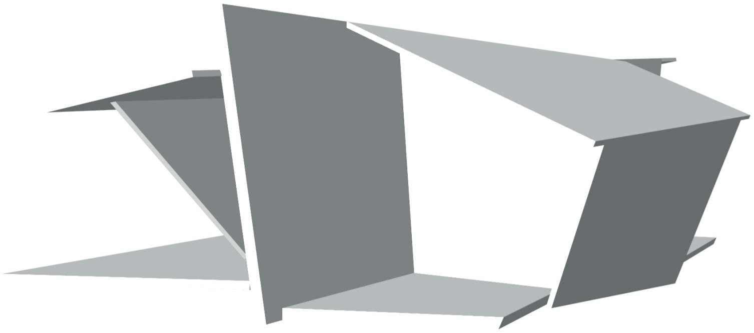
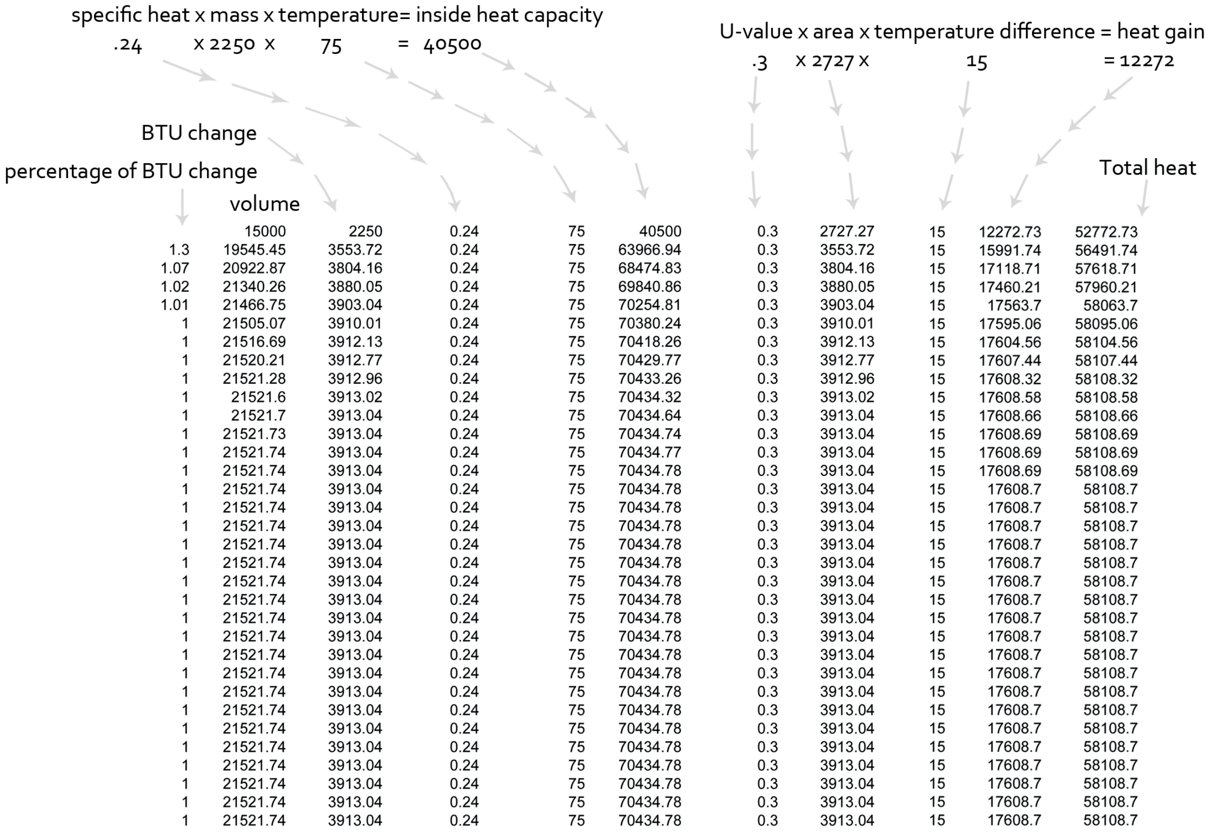


Figure 3. Process model from which the design was developed around.

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.



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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
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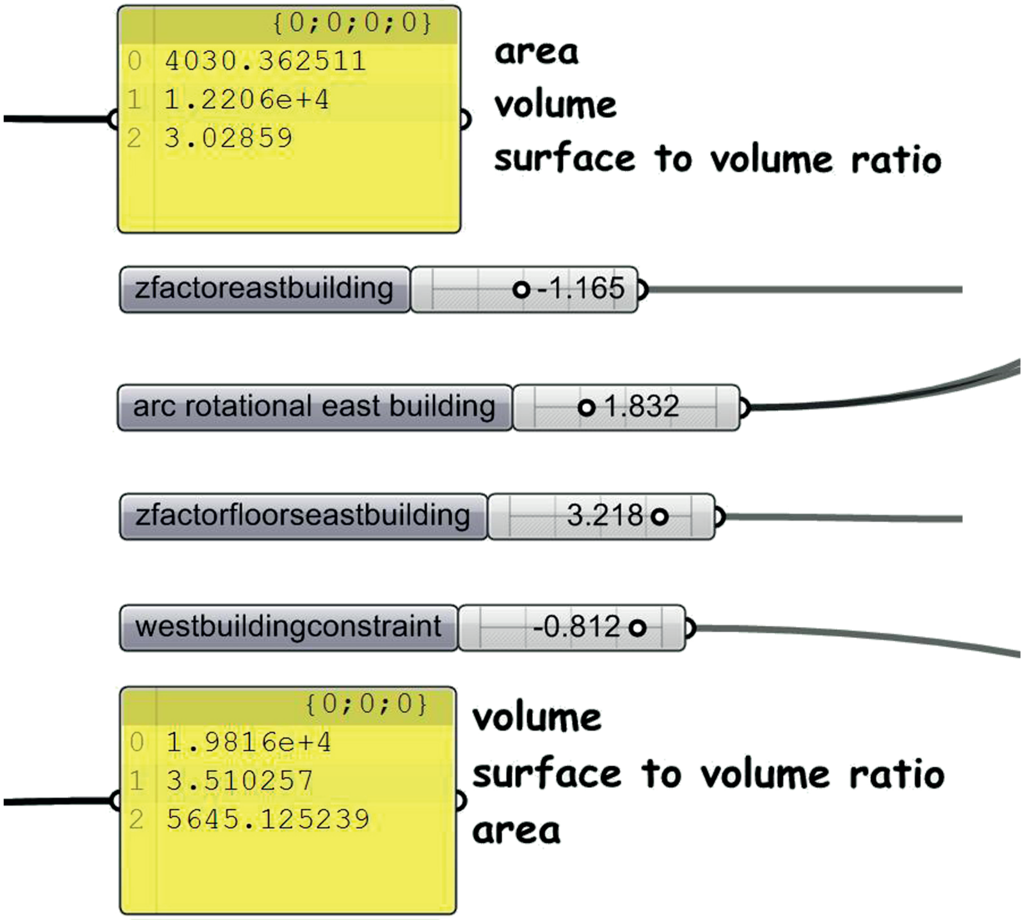
1	21521.74	3913.04	0.24	75	70434.78	0.3	3913.04	15	17608.7	58108.7

Figure 4. Spreadsheet chart which shows the numbers driving the volume of the structure. Causing a structure to expand and contract.



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1 1.2206e+4
2 3.02859
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arc rotational east building 1.832

zfactorfloorseastbuilding 3.218

westbuildingconstraint -0.812

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2 5645.125239
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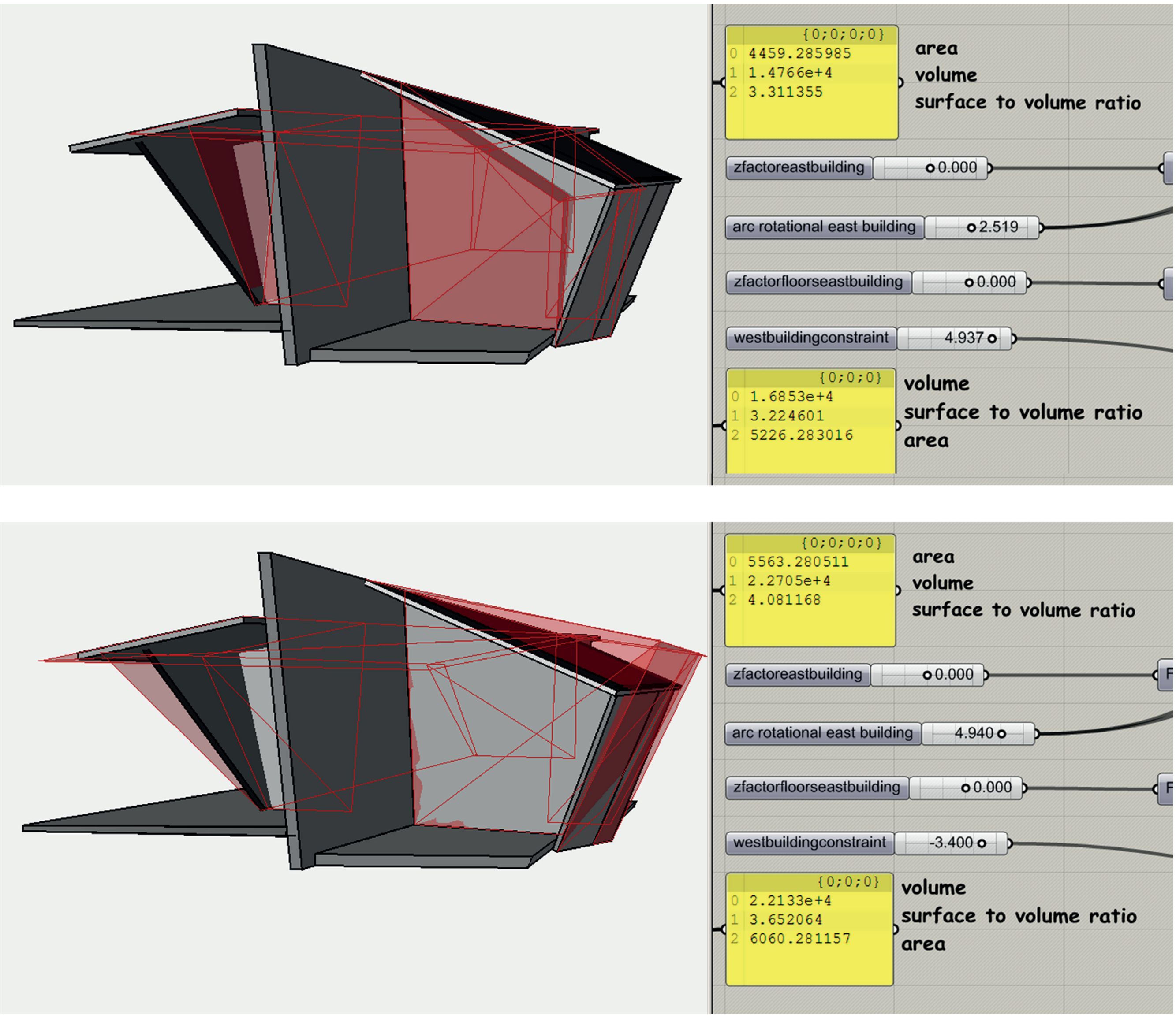
Figure 5. A graphic of the control panel in Grasshopper3D which allows the control of a analytical model.



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area
volume
surface to volume ratio

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arc rotational east building 2.519
zfactorfloorseastbuilding 0.000
westbuildingconstraint 4.937

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volume
surface to volume ratio
area

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```

area
volume
surface to volume ratio

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westbuildingconstraint -3.400

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1 3.652064
2 6060.281157
```

volume
surface to volume ratio
area

Figure 6. A view showing the range of motion which a model goes through and the corresponding numbers of the sliders changing. Also showing the changing volume, area, and surface to volume ratio.

Figure 7. A view of the model controlled by Rhino-Assembly, driving a model through the ranges of the buildings movements.

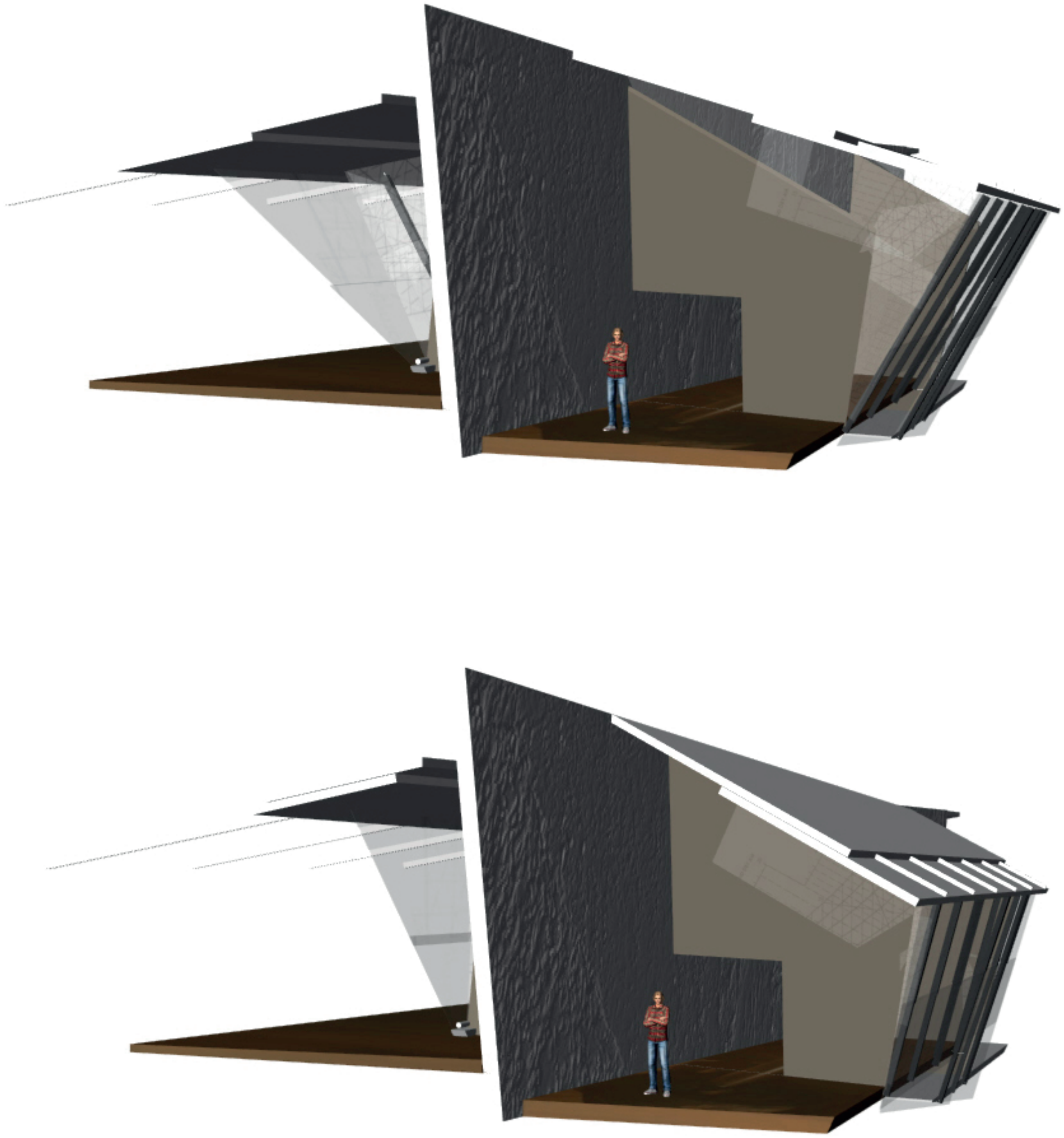

Figure 8. A close up of the model driven by Rhino-Assembly.

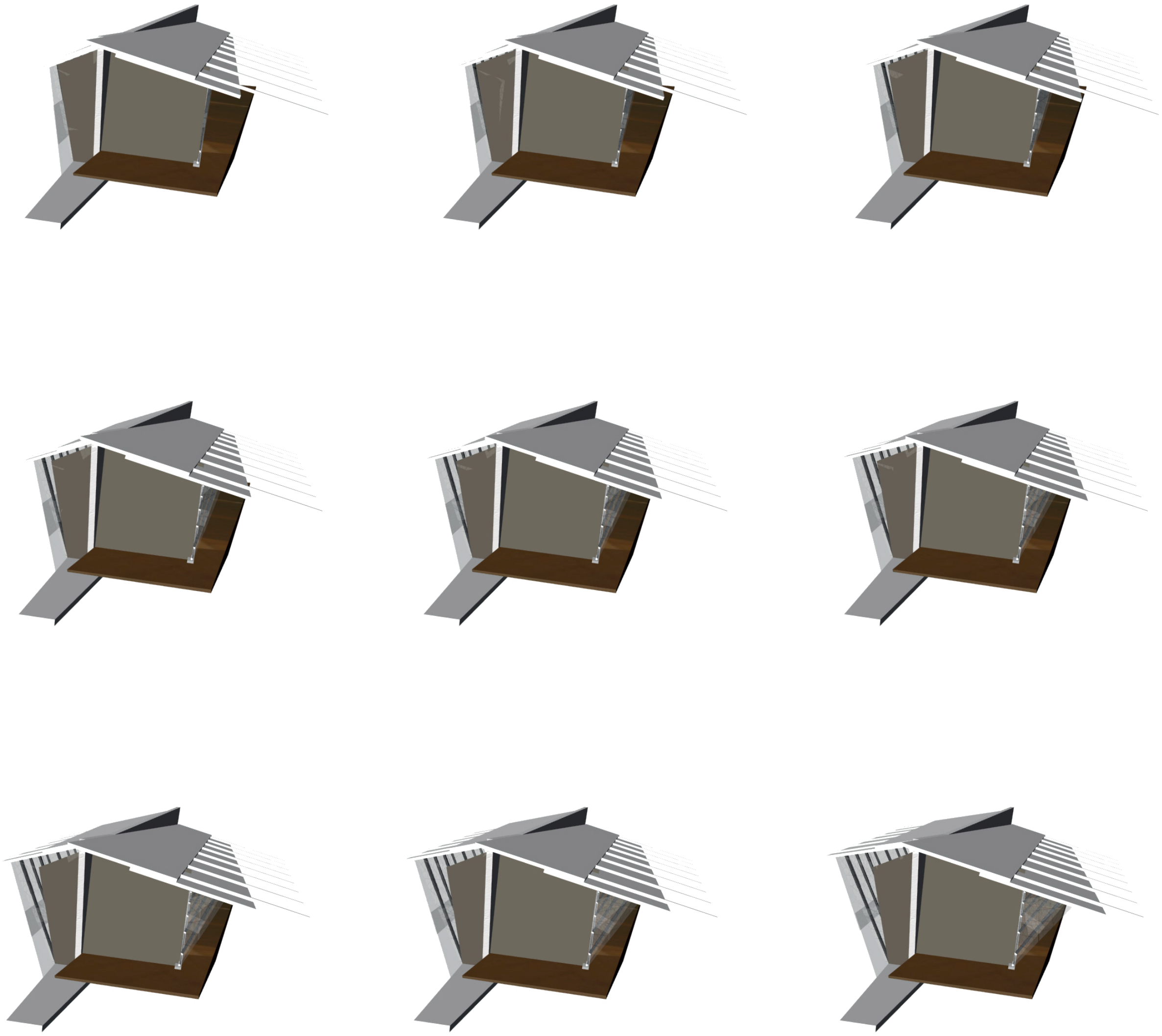

Figure 9. Another view of the Rhino-Assembly model, with movements.