Transformable architecture in relation to the climate of a building.

How can I use the transformability of a building to optimize the indoor climate in a passive way?

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Abstract:

The limitations of a normal building with added sunshades inspired me to start thinking about the possibility of an integrated sunshade with the ability of opening and closing like an added system. Before I was ready to make a transformable building that uses passive energy to influence the indoor climate in a positive way first research was needed. After research to transformable architecture, passive heating and passive cooling I was able to make a toolbox for making a transformable house that uses passive energy. To use that toolbox I made twelve different kind of outdoor weather situations. For every situation I used the toolbox to create the best configuration of the transformable building. Which had led to the basic requirements of my building. After this process I was able to design my first basic building which I will develop in the rest of my graduation year. This research will be a toolbox how to use transformable architecture, passive solar power, wind & thermal mass in your design and in which situation. In the end it is proven that a transformable building can improve the indoor climate of a building. But to develop the final concept to a real building, there are a lot steps to make.

Keywords: Transformable, Adaptable, Passive solar, Wind, Thermal mass
Introduction:

Background
Bioclimatic design is a way of designing which attracts me in a positive way. It is a way of designing buildings and manipulating the environment within buildings by working with natural forces around the building rather than against it. In my opinion this is a good way of thinking to keep in mind during the design of your building.

Using passive solar power, wind and thermal mass are the main points of interest for a good working Bioclimatic design. At the moment these resources are used but not well enough. Sun shading for example, is a good way to regulate the amount of sun entering your building but the systems nowadays are mostly open or closed and in addition, the façade is still heating up with the negative aspects that go with this. Another way of shading is an overhang which can be part of the building, and is more aesthetic than an added sunshade, but these are always ‘on’ or ‘closed.’ Therefore, solar power, wind and thermal mass are used in buildings but almost always with the negative aspects that go with them.

By this observation I was inspired to start thinking about the possibility of an integrated sunshade with the ability of opening and closing like an added system.

Therefore, you do not create a situation where there is one open and closed configuration but the more moving parts the more configurations the more possibilities to create the best situation. And by this idea I came automatically one step further to the idea of movable building parts/spaces.

That means also a whole new subject: transformable architecture. There are several moving systems that are already used in buildings. But which system can be used for which application and which system is the best. In this research will find out the best way to make a building transformable and how to use that transformability to optimize the indoor climate in the most effective way by using passive solar energy, thermal mass and wind.

Research question
How can I use the transformability of a building to optimize the indoor climate in a passive way?

Sub questions:

What kind of different moving-systems are already there?
- How do they work
- What kind of techniques are used
- Are they climate related
- Which parts are useful for my design
- Which systems are there for which movement

What are the influences on the indoor climate to deal with?
- Sun
- Wind (Natural ventilation)
- Thermal Mass

First Findings Applied:
- How can I combine these three methods?
- What are the consequences of row houses en how to deal with?
- How will this system work?
- What are the advantages compared with a standard home?
Relevance
This research will be generic in the sense that it will give you a toolbox how to use transformable architecture, passive solar power, wind & thermal mass in your design and in which situation.
My first design is focussed on row houses. This is a design goal with several restrictions but still a commonly used archetype. Therefore, my first design is still generic.

Method:

Reference Studies In the first part of my research I will find out what has been done so far in transformable architecture by analysing reference projects. After the first reference study I will categorize the different types by technique and reason why they are transformable architecture. This will lead to a small booklet with a survey of all the references.

[Literature Studies] Reading books and papers about my topic will help me to find the right ways to use solar power, thermal mass and natural ventilation to control the indoor climate of a building in a passive way.

Research by Design By making different configurations of a building by myself I will find out the best way to handle the several influences on a building and how to use the transformability of a building to optimize its indoor climate.

Design & Simulation I will test my digital models with sun simulation software to test the given properties. Wind flow is also possible to simulate and test. But very dependent of your design. Therefore it is more useful to simulate the wind in a later stage of your design.

Limitations:

Building type: Row house
User: Family 4 - 5 persons
Scale: 3 - .... Houses next to each other
What is movable: Everything bigger than an add-on solution
Energy use: As much passive energy as possible
Spatial quality: Bigger than in a standard home
Living quality: Same functions as a standard row house
**Results:**

**Reference study:**
There are multiple examples of transformable architecture. Varied from movable indoor walls till complete movable buildings. Almost every building size and scale is possible to make transformable. Also the reason behind the transformable function varies. Extension of the current space, adaptable to other functions, daylight but also the indoor climate. What stands out is the fact that almost every form of transformability in the references is related to one part of the building in one direction with one function. Multiple parts, in different directions with different functions is an exception. (Kronenburg, 1995, 2007) (Mostaedi, 2006)

**Passive Heating & Cooling:**
Passive heating and cooling is all about heat gain and heat protection. Heat gain is the radiation of the sun which enters your building and heat protection is preventing your building from sun radiation or loosing heat during wintertime. Furthermore you should take in account that your inside temperature must be stable and the outside conditions are changing constantly. (Wright, 1984)

**Basis: Orientation & Insulation**
The optimal orientation to the sun for heat gain, is perpendicular to the sun for the collecting surfaces. You will get the best result when the collecting surface is a little bit angled to the sun but a south oriented vertical surface much more practical. Exact south orientation is not required. A Difference of 15 degrees will lead to a 98% effectiveness.

![Figure 1: Effectiveness of the sun under different angles. (Own ill.)](image)

Orientation differences for specific rooms are also important. Because each room has its own type of use and heating requirements. Morning sun is best for bedrooms, sun at midday for greenrooms and sun at afternoon for living areas. Living rooms need heat during the evenings. Kitchens generate heat all year and can be self-heated in winter. Technical Spaces and bathrooms have low activity and can be best situated at north. (Achard, 1986)

Good insulation and air tightness are needed to keep the heat inside during wintertime and the heat outside during summertime. The bigger the insulation value the lower the heating demand and vice-versa. A good air tightness of the building will prevent it of heat loss and will also provide lower heating demands. (Wright, 1984)
Passive Heating:
Heating your building during wintertime with passive solar power can be done by three different types of solar use: Direct Gain, Thermal storage wall & Sunspace.

Direct gain can be applied to every south oriented surface, every other direction loses more energy than it gains during winter time. The principle is based on glass which makes direct entering of the sun possible in combination with thermal mass to prevent the building of overheating in the afternoon and overcooling during the night. You need the right mix of south faced glazing and thermal mass.

<table>
<thead>
<tr>
<th>Thermal Mass</th>
<th>Thickness</th>
<th>Surface Area per m² of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry or concrete exposed to direct solar radiation</td>
<td>10 - 15 cm</td>
<td>0.28 m²</td>
</tr>
<tr>
<td>Masonry or concrete exposed to reflected solar radiation</td>
<td>5 - 10 cm</td>
<td>0.56 m²</td>
</tr>
<tr>
<td>Water</td>
<td>About 15 cm</td>
<td>About 0.05 m²</td>
</tr>
</tbody>
</table>

Thermal mass in direct gain systems (Lechner, 1991)

A thermal storage wall is a system which works with a delay. It is based on a thick wall placed behind a south oriented glass panel. The system collects heat during the day to function as a radiator during the colder night. This system can be optimised with insulated shutters to keep the heat in during winter and out during the summer.

<table>
<thead>
<tr>
<th>Thermal Mass</th>
<th>Thickness</th>
<th>Surface Area per m² of Glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adobe (dry earth)</td>
<td>15 - 25 cm</td>
<td>1</td>
</tr>
<tr>
<td>Concrete or brick</td>
<td>25 - 40 cm</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>20 or more</td>
<td>1</td>
</tr>
</tbody>
</table>

Estimating the required thickness of a thermal storage wall (Lechner, 1991)

Sunspaces are designed to collect heat for itself but also for the rest of the building. It functions also as secondary living area. Its semi-outdoor character is very attractive by people. (Lechner, 1991)

<table>
<thead>
<tr>
<th>Thermal Mass</th>
<th>Thickness</th>
<th>Surface Area per m² of Glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry common wall non insulated</td>
<td>20 - 30 cm</td>
<td>1</td>
</tr>
<tr>
<td>Masonry common wall insulated</td>
<td>10 - 15 cm</td>
<td>2</td>
</tr>
<tr>
<td>Water</td>
<td>About 30 cm</td>
<td>About 0.5</td>
</tr>
</tbody>
</table>

Thermal mass in sunspaces (Lechner, 1991)
Each system has its own advantages and disadvantages:

<table>
<thead>
<tr>
<th>System</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Gain</td>
<td>+ Use of big windows</td>
<td>- Too much light can cause glare</td>
</tr>
<tr>
<td></td>
<td>+ Least expensive</td>
<td>- Thermal storage floors must not be covered</td>
</tr>
<tr>
<td></td>
<td>+ Most efficient</td>
<td>- Overheating can occur if precautions are not taken</td>
</tr>
<tr>
<td></td>
<td>+ Daylighting and heating can be combined</td>
<td>- Fairly large temperature swings must be tolerated (about 5 degrees C)</td>
</tr>
<tr>
<td></td>
<td>+ Very flexible and best when total glazing area is small</td>
<td></td>
</tr>
<tr>
<td>Thermal storage wall</td>
<td>+ Gives high level of thermal comfort</td>
<td>- More expensive than direct Gain</td>
</tr>
<tr>
<td></td>
<td>+ Good in conjunction with direct gain to limit light intensity</td>
<td>- Less of glazing will be available for views and daylighting</td>
</tr>
<tr>
<td></td>
<td>+ Easy to retrofit on existing walls</td>
<td>- Not good for very cloudy climates</td>
</tr>
<tr>
<td></td>
<td>+ Medium cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ Good for large heating loads</td>
<td></td>
</tr>
<tr>
<td>Sunspaces</td>
<td>+ Very attractive</td>
<td>- Most expensive system</td>
</tr>
<tr>
<td></td>
<td>+ Extra living space</td>
<td>- Least efficient</td>
</tr>
<tr>
<td></td>
<td>+ Can function as greenhouse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ Most appropriate for residential units</td>
<td></td>
</tr>
</tbody>
</table>

**Advantages & Disadvantages of solar systems (Lechner, 1991)**

**Passive Cooling:**
You need a cooling system to protect your building from overheating during summertime. The best passive way is protection against sun radiation by shading. It is very important to block the radiation before it enters the glass. If you don’t, the radiation will enter your building and that will lead to extra, unnecessary ventilation to remove this heat. (Wright, 1984) In summertime your windows need shadow but in wintertime they don’t because they need to be open to collect heat. This can be done by a movable sunshades or by an overhang. Trees which lose their leaves in wintertime are also an option. Cooling the inside of a building in a passive way can be done by thermal mass. Thermal mass is able to absorb the surplus of heat to prevent the building from overheating. The surplus of heat can escape by natural ventilation during night-time. (Dobbelsteen et all, 2012)

**Natural Ventilation:**
Ventilation is not only important to improve the air quality but it can also be used to influence the indoor temperature. Research has proven that rooms with natural ventilation have a much wider comfort zone than rooms with HVAC systems. People like the possibility to be able to open a window in the room where they are. Natural Ventilation is an easy way to ventilate your building. You can divide natural ventilation in three basic principles.

![Figure 3: Pressure differences, thermal differences, solar chimney. (Own ill.)](image-url)
The first principle is based on pressure differences. Like water, air flows from a zone with a high air pressure to a zone with a lower pressure. In a building situation this is normally the wind on a façade which create a higher air pressure.

The second principle is based on thermal differences. Hot air will rise and cold air will sink. This can be used in situations when the indoor temperature is different with the outdoor temperature to create a natural air flow.

The third principle uses solar power to heat a surface behind glass or a solar chimney. The heated surface heats also the air around it and that causes an airflow.

These three principles can be used separately but also together for a more constant air flow. (ter Haar, Sholten, 2014)

**Thermal Mass:**
In the figure below you can see that thermal mass able to temper the fluctuation of the temperature inside a building. By the thermal mass the temperature keeps almost every moment in the climate zone.

![Figure 4: Indoor temperature without (left) and with (right) thermal mass. (Own ill.)](image)

The thermal mass stores the heat during the day and loses this during the night. This effect can be optimised by night ventilation but also with movable insulation. By the insulation you can regulate the heat loss and gain and make a difference between the energy flow during the day and night. (Lechner, 1991)

**Conclusion literature studies:**
After this literature study I can conclude there are two systems to keep in mind during my design: Direct impact and delayed impact.

Delayed impact is the basic system that will prevent you from peaks in your indoor temperature. This is the thermal mass you will bring in your building. You can optimize this thermal mass by movable insulation or by making the thermal mass movable itself.

The Direct impact is the influence you will have on the basic system. Regulating the amount of direct gain and heat loss. This can be done by a shadow system or rather a system to place your building in the sun. Extra cooling can also be done by natural ventilation.

<table>
<thead>
<tr>
<th></th>
<th>Heating</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct Impact</strong></td>
<td>Direct Gain</td>
<td>Shading/Wind</td>
</tr>
<tr>
<td><strong>Delayed impact</strong></td>
<td>Thermal storage</td>
<td>Thermal storage</td>
</tr>
<tr>
<td></td>
<td>Day -&gt; Night</td>
<td>Night -&gt; Day</td>
</tr>
</tbody>
</table>

Direct impact & Delayed impact (Own ill.)

Actually you need a combination of the three basic passive solar adjustments: direct gain, thermal storage wall and a sunspace. A good solution to integrate all that types of passive solar adjustments is a double façade with adaptable skins. In this way you can vary the ‘openness’ of the façade and regulate the amount of sun, shadow and layers. In fact you create an adaptable buffer zone as façade of your building.
Translation to Design:

Every weather situation has its own demand for façade and building configuration. From complete shadowed to complete faced to the sun for direct gain and from complete open to complete closed or ‘double closed’ to create a buffer zone during winter time for the best comfort.

The demand for different configurations seems to be a demand for a transformable building. But first I need to figure out what kind of demand there is for every kind of situation. Therefore I made a matrix with three weather types: Sunny, Cloudy/Sunny and Cloudy. And four temperature categories: 0 °C and lower, 10 °C, 20 °C and 20 °C and higher.

For every category I describe how many sun, shadow and natural ventilation is needed. Beside that I will describe a configuration for the double façade which is made of glass. This façade can vary from both layers closed to both layers open.

<table>
<thead>
<tr>
<th></th>
<th>&lt; 0 °C</th>
<th>10 °C</th>
<th>20 °C</th>
<th>&gt;20 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>0%</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Both Closed</td>
<td>Outer Closed</td>
<td>Both Open</td>
<td>Both Open</td>
</tr>
<tr>
<td>Cloudy/Sunny</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Both Closed</td>
<td>Both Closed</td>
<td>Both Open</td>
<td>Both Open</td>
</tr>
<tr>
<td>Cloudy</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Both Closed</td>
<td>Both Closed</td>
<td>Both Open</td>
<td>Both Open</td>
</tr>
</tbody>
</table>

Matrix with different weather and temperature situations. (Own table)

This matrix is the starting point for my design. If I keep this configurations in mind during my design I will be able to transform to every type of weather.

If the building is adaptable to every situation does not mean it must be configured like the given situations. Besides the value of the adaptability itself there is an extra value for the user to adjust the building like he wants.
First Design:

My first design will be a house for a 4 people family. Thinking about the transformability of the family house there were two options: The houses work together or on itself for the climate. Maybe a better result is possible with the houses working together but then you lose the extra value of the influence of the owner on his own house. Therefore I have chosen the house is transformable on itself.

To make the design more generic I have chosen for a row house design. This choice limits the direction of the movement but it is not only the direction of the movement which matters but also how you move.

After this first limitations there were three designs left:

- Sliding volumes: six volumes that can slide over a rails to vary the amount of sun, shadow, the buffer zone and create a courtyard.

- Turning hood: A big hood can turn over the building to block the sun or to let the sun enter the building. With this one you can choose to create extra space in front or at the back of the building. This one is limited in the variation options.

- Stacked Blocks: The stacked blocks can slide over each other to create shadow for the block beneath it or to create some direct gain of the sun. This one is also hard to vary with.

Sliding volumes has the best opportunities for different configurations. The basis consists of 2 living volumes with 4 movable roofs. The outer ones contains a closable glass façade and the inner ones a closable glass roof. With this six volumes I can create the twelve different situations of the matrix:

This volumes have together the same area in square meters as a normal row house. About 100 m² living space in two stories. Also the garden will be the same size as a the garden of a normal house: 50 m².
This is the result of the first research to the possibilities of the basic building I described.

For every type of weather and temperature I have tried to configure the best situations using the 6 volumes.

The options differ from totally closed with a double closed façade to create a buffer zone during winter time with low temperatures to a summer situation where as much as possible shadow is needed and the building is totally open because the outdoor temperature is the same as the required indoor temperature. If the temperature goes even higher there is a possibility to close the building again and let the hood work like a tropical roof with ventilation underneath the shadow panels.

In the picture below you see how the building will work by different temperatures on a sunny day. Also the direction of the sun is taken into account.

-5°C  21 jan

10°C  21 may

20°C  21 jun

25°C  21 Jun

In the picture you see the buffer zone, one climate zone, total ventilation and the tropical roof function again which can be created with one building. The differences between the entry of the sun is also visible.
**Conclusion:**
Almost every building size and scale is possible to make transformable. What stands out is the fact that almost every form of transformability in the references is related to one part of the building in one direction with one function. Multiple parts, in different directions with different functions is an exception.
With good methods it is possible to control your indoor climate with Passive solar power, natural ventilation and thermal mass. At least you can influence your indoor climate in a positive way. Actually you need a combination of the three basic passive solar adjustments: direct gain, thermal storage wall and a sunspace.
A good solution to integrate all that types of passive solar adjustments is a double façade with adaptable skins. In this way you can vary the ‘openness’ of the façade and regulate the amount of sun, shadow and layers. In addition to the double facade you need to keep in mind some opportunities to ventilate the building and a well-designed thermal mass as basis for your design. In fact you create an adaptable buffer zone as façade of your building.
It is possible to influence the indoor climate in a positive way with different transformable components that can slide in one direction. They will use the same area as a normal row house but the indoor climate will be better than the climate of a standard house. Besides the climate opportunities the building becomes also more interesting in a special and architectonical way.

**Discussion:**
It is clear that the described building will contribute to a better indoor climate but the real efficiency is difficult to determine. Because it is dependant of many factors that can influence your building: insulation values, window area, the climate, the rest of the heating and cooling installation etc. But in the state the building is now it is impossible to do more calculations on it.
Furthermore there is the fact of translating this concept to a real building. How will it really work and what materials do I need to build this. Is it possible to make this concept watertight and how do I construct this building are all questions I will answer after my P2.
Finally, there is the comparison with a ‘normal’ row house. Spatial, architectural and the climate of this building will be better. But is it a realistic thought to place this building in the same category as a row house, or becomes this more a luxury villa. This is also an important question to answer.
References


